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Optimal Generation Scheduling and Dispatch of Multi-Source Power System Using hybrid GWO Algorithm

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Abstract: The paper presents a hybrid version of Grey Wolf Optimizer (GWO) algorithm for solving the generation scheduling and dispatch problem of Multi-Source power system. The advantages of using multiple fuels (i.e. coal, gas, oil etc.) is to minimize gaseous emission, as different fuels have different emission levels. In the proposed research, the GWO algorithm is combined with random exploratory search algorithm and presented for the solution of combinatorial scheduling and dispatch problem of electric power system. To verify the feasibility of proposed algorithm on generation scheduling and dispatch problem, ten generating unit test system has been taken into consideration, which consist of 4 units based on coal, 2 units based on gas and 4 units based on oil. Also, the impact of renewable sources (i.e. solar and wind) has been taken into consideration for different spinning reserve requirements and it has been experimentally found that the proposed algorithm has significant impact on annual cost saving.

Keywords: Generation Scheduling and Dispatch, Grey Wolf Optimizer, Unit Commitment Problem.

I. Introduction

Multidisciplinary design optimization and multidisciplinary system design optimization are emerging area for the solution of design and optimization problems incorporating a number of disciplines. Scientific revolution has affected every aspect of contemporary life. In recent years, with the advancement in technology a new era of problem solving methods are emerging making use of computers. They are becoming common approach for solving complex problems. The engineering problems to be tackled consist of various difficulties such as constraints, uncertainties, local solution, multiple objective, etc. Optimization technique should be able to discourse these issues. In the recent years, various meta-heuristics search algorithms has been implemented such as Biogeography based Optimizer [1], Grey Wolf Optimizer [2], Ant Lion Optimizer [3], Moth Flame Optimizer [4], Multi Verse Optimizer [5], Dragon Fly Algorithm [6], Sine Cosine Algorithm [7], Lightning Search Algorithm [8], Seeker Optimization Algorithm [9],Virus Colony Search Algorithm [10], Whale Optimization Algorithm [11]. But it is logically proven by No-Free-Lunch theorem 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. In the proposed research, Gery wolf optimizer is hybrid with random exploratory search method to solve the multi-source generation and dispatch problem taking coal, oil and gas plants into consideration for the optimal dispatch of load with reduced emission of pollutants. The new scenario of power production focused on the green power production therefore the impact of solar and wind power is also considered to evaluate the change in the overall generation cost of multi-source power system by considering effect of wind and solar power and without considering wind and solar power and a combined effect is also calculated by combining wind and solar to multi-source power system (MSPS).

II. Unit Commitment Problem Formulation

Unit Commitment of power system units is a multidimensional optimization task for preparation and maneuver of participated units. Contemporary power system networks, has diverse generating resources which can be broadly grouped together in to two categories, conventional generation sources and non-conventional sources. Unfortunately, load demand is never steady it has the tendency to change at every instant of time As load demand is a random variable , a great difficulty arise for the generation that tend to cope with this variable load. Thus, it is required to make a judgment which unit to be turned on and which unit to turnoff and at what time duration it is desirable in the power system network. This complex process of obtaining on off pattern of unit which should satisfy the load demand and spinning reserve parameter is better known as unit commitment process [1]. In recent years, due to tremendous increase in load demand, large interconnections of hybrid electric networks are taken into consideration, which basically consist of an integration of multi-source unit consisting of coal, oil and gas unit with renewable energy source as solar and wind systems, acknowledged as hybrid renewable energy system (HRES)[12][13][14]. Hence, the hybrid variant of grey wolf optimizer combined with random exploratory search algorithm has been proposed to evaluate the generation scheduling and dispatch of multi-source power system combined with renewable energy system. The objective function for multi-source power system with consideration of wind and solar power can be mathematically described as per eqn.(1), as wind turbine and solar panel do not consume fossil fuel and does not include any fuel cost.

$$FC_T = \sum_{h=1}^{H}\sum_{n=1}^{NOU} FC_n(P_n^h)\,U_n^h + U_n^h(1-U_n^{h-1})SUC_{n,h} + U_n^{h-1}(1-U_n^h)SDC_n \tag{1}$$

where, $FC_n(P_n^h)$ describe the fuel cost of n-th generating units at h-th hours and $SUC_{n,h}$ represents the startup cost of n-th generating units for h-th hours and these cost may be mathematically described as:

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

$$SUC_{n,h} = \begin{cases} HSC_n & if \quad T_{n,down} \le T_{n,off}^h \le T_{n,down} + T_{n,cold} \\ CSC_n & if \quad T_{n,off}^h \ge T_{n,down} + T_{n,cold} \end{cases} \tag{3}$$

Where, HSC_n hot start is cost, and CSC_n is cold start cost, $T_{n,down}$ is minimum down time of n-th unit, $T_{n,off}^h$ is consecutive off time of n-th unit and term $T_{n,cold}$ represents the cold start hour of the n-th units.

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

a) Power Operational constraints:

$$\sum_{i=1}^{N} P_{i,t} + P_{W,t} - P_{D,t} = 0 \tag{4}$$

b) Spinning Reserve Constraint

$$SR_{j,u}^h = \min(P_{j,\max} - P_{j,h}, \quad U_{R,h}\,T_l) \tag{5}$$

$$\sum_{n=1}^{NOU} u_{n,h} SR_{n,h}^h \ge R_D^h + W_u . P_{w,h} \tag{6}$$

(c) Minimum up and down time constraints

$$\left(P_{n,h-1}^{on} - P_{n,\min}^{on}\right)\left(U_{n,h-1} - U_{n,h}\right) \ge 0 \tag{7}$$

$$\left(T_{j,t-1}^{off} - T_{j,\min}^{off}\right)\left(U_{j,t-1} - U_{i,t}\right) \ge 0 \tag{8}$$

(d) Maximum and Minimum Power Limit

$$P_n^{\min} \le P_{n,h} \le P_n^{\max} \tag{9}$$

The function for the calculation of wind and solar power can be mathematically represented[15].

Power output function of wind speed is given by:

$$P_{W,t} = \begin{cases} 0 & (v_{w,t} \le v_1 \quad or \quad v_{w,t} \ge v_3) \\ \varphi(v_{w,t}) & (v_1 \le v_{w,t} \le v_2) \\ P_{wn} & (v_2 \le v_{w,t} \le v_3) \end{cases} \qquad t=1, 2\dots T \tag{10}$$

Where $v_{w,t}$ = wind velocity forecasted for hour t;

v_1 = minimum wind speed;
v_2 = rated velocity of wind turbine;
v_3 = maximum wind speed;

$\varphi(v_{w,t})$ = wind to energy conversion function;
P_{wn} = rated power generated from wind unit.

Power calculation of solar energy system

$$P_{pv}(G_t) - P_{b,t} - P_{s,t} = 0 \qquad t=1, 2……..T \tag{11}$$

$$\left|P_{b,t}\right| \le P_b^{\max} \qquad t=1, 2……..T \tag{12}$$

$$\left|P_{s,t}\right| \le P_s^{\max} \qquad t=1, 2……..T \tag{13}$$

Where P_{pv} (.) = solar radiation to energy conversion function :

$$P_{pv}(G_t) = \begin{cases} P_{sn}\frac{(G_t)^2}{G_{std}R_c}, 0<G_t<R_c \\ P_{sn}\frac{G_t}{G_{std}}, G_t>R_c \end{cases} \qquad t=1, 2 ..….T \tag{14}$$

Where G_t = amount of solar radiation analyzed at hour t;
G_{std} = radiation in average atmosphere set as 1000W/m^2;
R_c =a assured radiation level set as 150 W/m^2;
P_{sn} = rated power generated by PV generator;
$P_{b,t}$ = power charge/ discharge/ from battery at hour t ;

III. Hybrid Grey Wolf Optimizer

Primarily developed Grey Wolf Optimizer, is a transformative calculation algorithm, based on grey wolves, which recreate the social stratum and chasing component of grey wolves in view of three principle ventures of chasing: scanning for prey, encompassing prey and assaulting prey and its mathematically model was designed in view point of hierarchy level of different wolves. The best solution was designated as alpha (α). Accordingly, the second best solution is named beta (β) and third best as delta (δ) individually. Whatever is left of the hopeful solution are thought to be omega (ω), kappa (κ) and lambda (λ). For the fitness value calculation, the advancement (i.e. chasing) is guided by α, β and δ. The ω, κ and λ wolves trail these three wolves. In GWO, Encircling or Trapping of Prey was achieved by calculating $\vec{D}$ and $\vec{X}_{GWolf}$ vectors described by equations (15.1) and (15.2).

$$\vec{D} = \left|\vec{C}.\vec{X}_{Prey}(iter) - \vec{X}_{GWolf}(iter)\right| \tag{15.1}$$

$$\vec{X}_{GWolf}(iter+1) = \vec{X}_{Prey}(iter) - \vec{A}.\vec{D} \tag{15.2}$$

Where, *iter* demonstrates the present iteration, $\vec{A}$ and $\vec{C}$ are coefficient vectors, $\vec{X}_{Prey}$ is the location vector of the prey and $\vec{X}_{GWolf}$ shows the location vector of a grey wolf and the vectors $\vec{A}$ and $\vec{C}$ are calculated as follows:

$$\vec{A} = 2\vec{a}.\vec{\mu}_1 - \vec{a} \tag{15.3}$$

$$\vec{C} = 2.\vec{\mu}_2 \tag{15.4}$$

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

The hunting of prey are achieved by calculating the corresponding fitness score and positions of alpha, beta and delta wolves using equations (16), (17) and (18) respectively and final position for attacking towards the prey was calculated by equation (19).

$$\vec{D}_{Alpha} = abs(\vec{C}_1.\vec{X}_{Alpha} - \vec{X}) \tag{16a}$$

$$\vec{X}_1 = \vec{X}_{Alpha} - \vec{A}_1.\vec{D}_{Alpha} \tag{16b}$$

$$\vec{D}_{Beta} = abs(\vec{C}_2.\vec{X}_{Beta} - \vec{X}) \tag{17a}$$

$$\vec{X}_2 = \vec{X}_{Beta} - \vec{A}_2.\vec{D}_{Beta} \tag{17b}$$

$$\vec{D}_{Delta} = abs(\vec{C}_3.\vec{X}_{Delta} - \vec{X}) \tag{18a}$$

$$\vec{X}_3 = \vec{X}_{Delta} - \vec{A}_3.\vec{D}_{Delta} \quad (18b)$$

$$\vec{X}(iter+1) = \frac{(\vec{X}_1 + \vec{X}_2 + \vec{X}_3)}{3} \quad (19)$$

In the proposed hybrid Grey-Wolf Optimizer-Random Exploratory search (hGWO-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 using equation (20).

$$f_{final} \leftarrow \min(f^+, f^-, f) \quad (20)$$

The exploration phase in hGWO-RES is similar to GWO. , In order to explore the search space globally, vector $\vec{A}$ and $\vec{C}$ are used, which mathematically model divergence.

IV. Solution Strategy for Unit Commitment Problem

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 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 unit commitment problem by using hGWO-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*T} following steps clarify modus operandi of unit commitment problem.

Step-1: To solve single area unit commitment problem, every individual is showed as 1/0 showing ON/OFF status correspondingly. The on/off schedule of the units is stored as an integer-matrix U, which is mathematically defined as:

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

Where, u_n^h is unit on/off 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 minimum up/ down time violations

Step-5: Units of some search agents are de-committed in the population to decrease unnecessary spinning reserve owing by minimum up/down time repairing

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 hGWO-RES algorithm and determine overall best generation cost and commitment schedule.

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

Step-13: Otherwise, increment the iteration and go back to step 3.

Step-14: Stop and find the ideal result of single area unit commitment problem from the distinct position in the population that produced the minimum total generation cost.

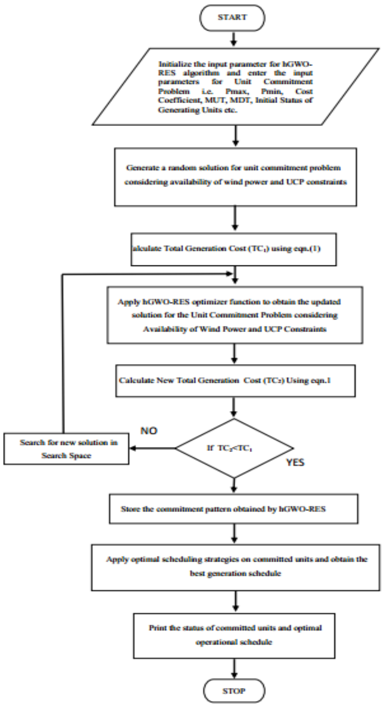


Fig.1: Flow chart for Solution of UCP using hGWO-RES

V. Constraints handling strategy/ Repair Mechanism of constraints

The achieved major unit scheduling by hGWO-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.

5.1. Minimum up and Minimum down time handling strategy :

Minimum up and down time of specific unit is defined as connective hours that 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

$$T_{n.on}^{h} = \begin{cases} T_{n,on}^{h-1} + 1 & if\ u_n^h = 1 \\ 0 & if\ u_n^h = 0 \end{cases} \qquad (21)$$

$$T_{n,off}^{h} = \begin{cases} T_{n,off}^{h-1} + 1 & if\ u_n^h = 0 \\ 0 & if\ u_n^h = 1 \end{cases} \qquad (22)$$

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

When crowning load duration appreciably inferior to the minimum down time of particular unit. Minimum up time is violated. And constraint associated with minimum down time is disturbed at low load level where low 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: Calculation of duration of all units on and off times for whole 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 $T_{n,on}^{h-1}\le MUT$ then set $u_n^h=1$

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

VI. Results and Discussion

In order to verify the performance of proposed hGWO-RES algorithm for generation scheduling and dispatch problem, the conventional UCP for multi-source power system considering coal, gas and oil plants and UCP considering solar and wind power as renewable energy sources are solved the results are calculated for 50 iterations with 40 search agents and their corresponding solutions are represented in Table-1 through Table-5 the convergence curve for MSPS with and without considering the effect of wind and solar power is shown in fig.2 and fig.3 shows the Impact of solar and wind power.

Table-1: Multi-Source generation scheduling and commitment for 10-unit system with 5% spinning reserve using hGWO-RES

Hour	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
1	1	1	0	0	1	1	1	0	0	0	223	150	0	0	162	80	85	0	0	0
2	1	1	0	1	1	1	1	0	0	0	253	150	0	20.000001	162	80	85	0	0	0
3	1	1	0	1	1	1	1	0	0	0	353	150	0	20	162	80	85	0	0	0
4	1	1	0	1	1	0	0	0	0	0	455	203	0	130	162	0	0	0	0	0
5	1	1	0	1	1	0	0	0	0	0	455	253	0	130	162	0	0	0	0	0
6	1	1	0	1	1	0	0	0	0	0	455	353	0	130	162	0	0	0	0	0
7	1	1	0	1	1	1	1	1	1	1	454.99998	150	0	53.000017	162	80	85	55	55	55
8	1	1	0	1	1	1	1	0	0	1	455	233	0	130	162	80	85	0	0	55
9	1	1	1	1	1	1	1	0	0	0	455	258	130	130	162	80	85	0	0	0
10	1	1	1	1	1	1	1	0	0	0	455	358	130	130	162	80	85	0	0	0
11	1	1	1	1	1	1	1	1	0	0	455	353	130	130	162	80	85	55	0	0
12	1	1	1	1	1	1	1	1	1	0	455	348	130	130	162	80	85	55	55	0
13	1	1	1	1	1	1	1	0	0	0	455	358	130	130	162	80	85	0	0	0
14	1	1	1	1	1	1	0	1	0	1	455	233	130	130	162	80	0	55	0	55
15	1	1	1	1	1	0	0	0	0	0	455	323	130	130	162	0	0	0	0	0
16	1	1	1	1	1	0	0	0	0	0	455	173.00001	130	129.99999	162	0	0	0	0	0
17	1	1	1	1	1	0	1	0	0	0	455	150	63.72851	84.27149	162	0	85	0	0	0
18	1	1	1	1	1	1	1	0	0	0	455	150	73.995934	94.004066	162	80	85	0	0	0

19	1	1	1	1	1	1	1	0	1	0	455	150	97.097639	115.90236	162	80	85	0	55	0
20	1	1	1	0	1	1	1	1	1	0	455	378	130	0	162	80	85	55	55	0
21	1	1	1	0	1	1	0	0	1	1	455	363	130	0	162	80	0	0	55	55
22	1	1	1	0	1	0	0	0	0	0	455	353	130	0	162	0	0	0	0	0
23	1	1	0	0	1	0	0	0	0	0	455	283	0	0	162	0	0	0	0	0
24	1	1	0	0	0	0	0	0	0	0	455	345	0	0	0	0	0	0	0	0
Total cost=20532$																				

Table-2: Multi-Source generation scheduling and commitment for 10-unit system with 10% spinning eserve using hGWO-RES

Hour	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
1	1	1	0	0	1	1	0	0	1	1	198	150	0	0	162	80	0	0	55	55
2	1	1	0	0	1	1	0	0	0	0	358	150	0	0	162	80	0	0	0	0
3	1	1	0	0	1	1	0	0	0	0	455	153	0	0	162	80	0	0	0	0
4	1	1	0	0	1	0	0	0	0	0	455	333	0	0	162	0	0	0	0	0
5	1	1	1	0	1	0	0	0	0	0	455	253	130	0	162	0	0	0	0	0
6	1	1	1	0	1	0	0	0	1	0	455	298	130	0	162	0	0	0	55	0
7	1	1	1	0	1	1	1	1	1	0	455	150	108	0	162	80	85	55	55	0
8	1	1	1	1	1	1	1	0	0	0	455	158	130	130	162	80	85	0	0	0
9	1	1	1	1	1	1	1	0	0	0	455	258	130	130	162	80	85	0	0	0
10	1	1	1	1	1	1	1	0	1	0	455	303	130	130	162	80	85	0	55	0
11	1	1	1	1	1	1	1	0	1	1	455	298	130	130	162	80	85	0	55	55
12	1	1	1	1	1	1	1	1	1	1	455	293	130	130	162	80	85	55	55	55
13	1	1	1	1	1	1	1	0	0	1	455	303	130	130	162	80	85	0	0	55
14	1	1	1	1	1	0	1	0	0	1	455	283.00001	129.99999	130	162	0	85	0	0	55
15	1	1	1	0	1	0	1	1	1	1	455	203	130	0	162	0	85	55	55	55
16	1	1	1	0	1	0	1	1	1	1	455	150	33	0	162	0	85	55	55	55
17	1	1	1	0	1	0	0	0	0	1	455	198	130	0	162	0	0	0	0	55
18	1	1	1	0	1	0	0	1	0	0	455	298	130	0	162	0	0	55	0	0
19	1	1	1	0	1	1	0	1	0	0	455	318.00001	129.99999	0	162	80	0	55	0	0
20	1	1	1	1	1	1	1	0	1	0	455	303	130	130	162	80	85	0	55	0
21	1	1	0	1	1	1	1	1	1	0	455	278	0	130	162	80	85	55	55	0
22	1	1	0	1	1	0	1	0	0	0	455	268	0	130	162	0	85	0	0	0
23	1	1	0	1	0	0	0	0	0	0	455	315	0	130	0	0	0	0	0	0
24	1	1	0	1	0	0	0	0	0	0	455	215	0	130	0	0	0	0	0	0
Total cost=20431$																				

Table-3: Wind-Multi-source scheduling and dispatch for 10-unit system with 10% spinning reserve using hGWO-RES

Hour	Commitment Status of Generating Units										Generation Scheduling for Committed Units									
	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
1	1	1	0	0	1	0	1	0	0	0	221	150	0	0	162	0	85	0	0	0
2	1	1	1	0	1	0	1	0	0	0	223	150	20	0	162	0	85	0	0	0
3	1	1	1	0	1	0	1	1	0	0	296.6	150	20	0	162	0	85	55	0	0
4	1	1	1	0	1	1	1	1	0	0	289.2	150	20	0	162	80	85	55	0	0
5	1	1	1	0	1	1	0	0	0	0	449.9	150	20	0	162	80	0	0	0	0
6	1	1	1	0	1	1	0	0	0	0	455	179.3	130	0	162	80	0	0	0	0
7	1	1	1	0	1	1	0	1	0	0	455	164.5	130	0	162	80	0	55	0	0
8	1	1	1	1	1	1	0	0	0	0	455	151.8	130	130	162	80	0	0	0	0
9	1	1	1	1	1	1	0	1	0	0	455	216.7	130	130	162	80	0	55	0	0
10	1	1	1	1	1	1	1	0	0	0	455	293.1	130	130	162	80	85	0	0	0
11	1	1	1	1	1	1	1	0	0	1	455	264.9	130	130	162	80	85	0	0	55
12	1	1	1	1	1	1	1	1	1	0	455	282	130	130	162	80	85	55	55	0
13	1	1	1	1	1	1	1	0	0	0	455	301.5	130	130	162	80	85	0	0	0
14	1	1	0	1	1	1	1	0	0	0	455	253.9	0	130	162	80	85	0	0	0
15	1	1	0	0	1	1	1	0	0	0	455	329.3	0	0	162	80	85	0	0	0
16	1	1	0	0	1	0	0	0	0	0	455	349.6	0	0	162	0	0	0	0	0
17	1	1	0	0	1	0	0	0	0	0	455	266.9	0	0	162	0	0	0	0	0
18	1	1	0	0	1	0	0	0	1	0	455	293.3	0	0	162	0	0	0	55	0
19	1	1	0	0	1	1	1	0	0	0	455	287.5	0	0	162	80	85	0	0	0
20	1	1	1	0	1	1	1	0	0	1	455	314.7	130	0	162	80	85	0	0	55
21	1	1	1	0	1	1	1	0	0	0	455	287.9	130	0	162	80	85	0	0	0
22	1	0	1	1	1	1	1	0	1	1	455	0	43.14233	64.75767	162	80	85	0	55	55
23	1	0	1	1	1	0	0	0	0	1	455	0	61.16165	81.83835	162	0	0	0	0	55
24	1	0	1	1	1	0	0	0	0	0	455	0	56.90067	77.79933	162	0	0	0	0	0
Total cost = 18488$																				

Table-4: Solar-Multi-Source scheduling and dispatch for 10-unit system with 10% spinning reserve using hGWO-RES

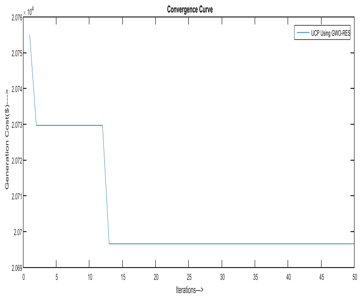
Hour	Commitment Status of Generating Units										Generation Scheduling for Committed Units									
	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
1	1	1	0	0	1	1	0	1	0	1	198	150	0	0	162	80	0	55	0	55
2	1	1	0	0	1	1	0	0	0	0	358	150	0	0	162	80	0	0	0	0
3	1	1	0	0	1	1	0	0	0	0	455	153	0	0	162	80	0	0	0	0
4	1	1	0	0	1	0	0	0	0	0	455	333	0	0	162	0	0	0	0	0
5	1	1	0	1	1	0	0	0	0	0	455	253	0	130	162	0	0	0	0	0
6	1	1	0	1	1	0	0	0	1	0	455	298	0	130	162	0	0	0	55	0
7	1	1	0	1	1	1	1	1	0	1	455	150	0	108	162	80	85	55	0	55

8	1	1	0	1	1	1	1	0	1	1	455	171.92	0	130	162	80	85	0	55	55
9	1	1	0	1	1	1	1	1	0	0	455	299.56	0	130	162	80	85	55	0	0
10	1	1	1	1	1	1	1	0	0	0	455	305.92	130	130	162	80	85	0	0	0
11	1	1	1	1	1	1	1	1	1	1	455	177.16	130	130	162	80	85	55	55	55
12	1	1	1	1	1	1	1	1	0	1	455	271.84	130	130	162	80	85	55	0	55
13	1	1	1	1	1	1	0	1	0	0	455	308.396	130	130	162	80	0	55	0	0
14	1	1	1	1	1	0	0	0	1	0	455	293.84	130	130	162	0	0	0	55	0
15	1	1	1	1	1	0	0	0	0	0	455	260.36	130	130	162	0	0	0	0	0
16	1	1	1	1	1	0	1	0	0	0	455	150	56.45661	77.37839	162	0	85	0	0	0
17	1	1	1	1	1	0	1	0	0	0	455	150	50.91477	72.12523	162	0	85	0	0	0
18	1	1	1	1	1	0	1	1	0	0	455	150	86.1731	105.5469	162	0	85	55	0	0
19	1	1	1	1	1	0	1	0	0	0	455	238	130	130	162	0	85	0	0	0
20	1	1	1	1	1	1	1	1	0	0	455	303	130	130	162	80	85	55	0	0
21	1	1	0	1	1	1	1	1	0	1	455	278	0	130	162	80	85	55	0	55
22	1	1	0	0	1	1	1	0	0	0	455	318	0	0	162	80	85	0	0	0
23	1	1	0	0	0	0	0	1	0	1	455	335	0	0	0	0	0	55	0	55
24	1	1	0	0	0	0	0	0	0	0	455	345	0	0	0	0	0	0	0	0
Total cost = 20082$																				

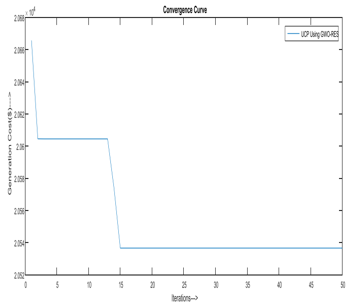
Table-5: Combined scheduling and dispatch for 10-unit system with 10% spinning reserve using hGWO-RES

Hour	Commitment Status of Combined Generating Units										Generation Scheduling for Combined Generating units									
	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
1	1	1	1	0	1	0	0	0	0	0	286	150	20	0	162	0	0	0	0	0
2	1	1	1	0	1	0	0	0	0	0	308	150	20	0	162	0	0	0	0	0
3	1	1	1	0	1	1	1	0	0	0	271.6	150	20	0	162	80	85	0	0	0
4	1	1	1	0	1	1	1	1	0	0	289.2	150	20	0	162	80	85	55	0	0
5	1	1	1	0	1	1	1	0	0	0	364.9	150	20	0	162	80	85	0	0	0
6	1	1	1	0	1	0	0	0	0	0	455	259.3	130	0	162	0	0	0	0	0
7	1	1	1	1	1	0	0	0	0	0	455	169.5	130	130	162	0	0	0	0	0
8	1	1	1	1	1	0	0	1	0	0	455	170.72	130	130	162	0	0	55	0	0
9	1	1	1	1	1	0	1	1	0	0	455	178.26	130	130	162	0	85	55	0	0
10	1	1	1	1	1	0	1	1	1	1	455	156.02	130	130	162	0	85	55	55	55
11	1	1	1	1	1	0	1	1	0	0	455	279.06	130	130	162	0	85	55	0	0
12	1	1	1	1	1	1	1	1	0	0	455	260.84	130	130	162	80	85	55	0	0
13	1	1	1	0	1	1	1	1	0	0	455	296.896	130	0	162	80	85	55	0	0
14	1	1	1	0	1	1	0	0	0	0	455	264.74	130	0	162	80	0	0	0	0
15	1	1	0	0	1	1	0	0	1	0	455	296.66	0	0	162	80	0	0	55	0
16	1	1	0	0	1	1	0	0	1	0	455	150.435	0	0	162	80	0	0	55	0
17	1	1	0	0	1	1	0	0	0	0	455	161.94	0	0	162	80	0	0	0	0
18	1	1	0	0	1	1	0	0	0	0	455	267.02	0	0	16	80	0	0	0	0

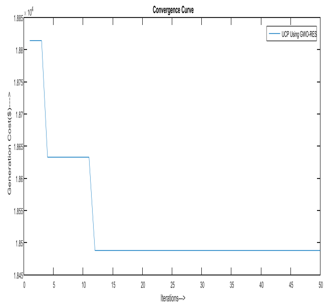
															2					
19	1	1	0	0	1	0	1	0	1	0	455	312.5	0	0	16 2	0	85	0	55	0
20	1	1	1	1	1	0	1	0	1	0	455	264.7	130	130	16 2	0	85	0	55	0
21	1	1	1	1	1	0	1	0	0	0	455	237.9	130	130	16 2	0	85	0	0	0
22	1	0	1	1	1	1	0	1	1	1	455	0	58.543 46	79.356 54	16 2	80	0	55	55	55
23	1	0	1	1	1	1	0	0	0	0	455	0	48.327 37	69.672 63	16 2	80	0	0	0	0
24	1	0	1	1	1	1	0	0	0	0	455	0	20.000 01	34.699 99	16 2	80	0	0	0	0
Total cost = 18246$																				



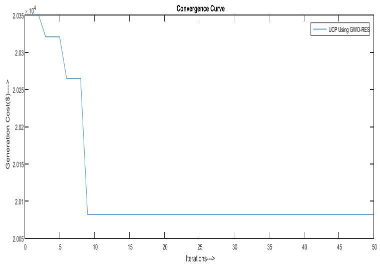
Multi-Source Unit with 5% spinning reserve



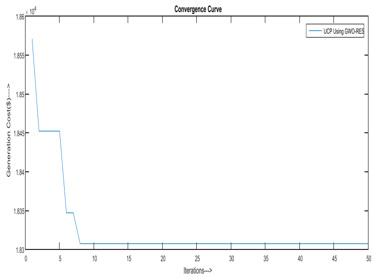
Multi-Source unit with 10% spinning reserve



Wind- Multi-Source generation scheduling



Solar- Multi-Source generation scheduling



Combined generation Scheduling

Fig.2: Convergence Curve for UCP of 10 Unit System using hGWO-RES

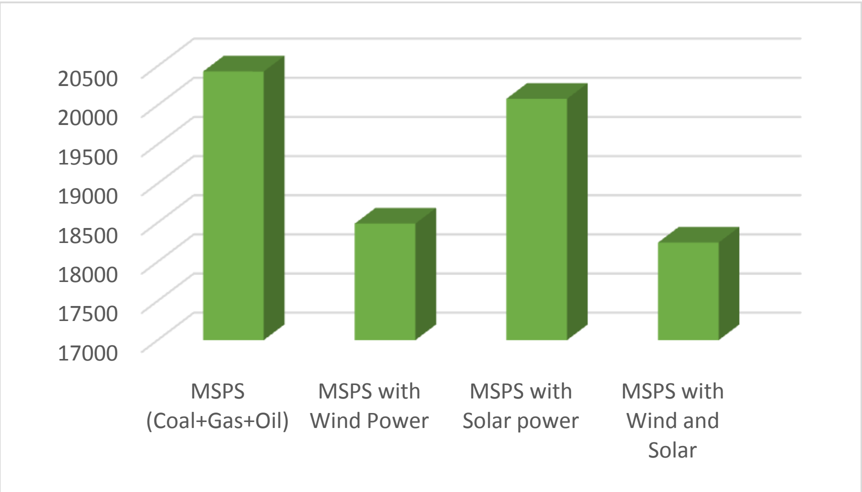


Fig.3: Impact of solar and wind power on overall generation cost for MSPS

VII. Conclusion

The paper has focused on a hybrid version of Grey Wolf Optimizer (GWO) algorithm for solving the generation scheduling and dispatch problem of Multi-Source power system. In the proposed research, the GWO algorithm is combined with random exploratory search algorithm and presented to find the result of combinatorial scheduling and dispatch problem of multi-source power system. The feasibility of proposed algorithm has been tested on 10 generating unit test system consisting of coal, gas and oil based generating units. Also, the impact of renewable sources (i.e. solar and wind) has been taken into consideration for different spinning reserve requirements and it has been found that the proposed algorithm has significant impact on overall generation cost.

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