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A Novel Approach Based Optimal Power Scheduling of GENCOs to Improve the Profit in Electricity Market Considering Wind Power Generation

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Abstract

Objectives: The main objective of this present work is to maximize the profit of Power Generation Companies (GENCOs) and minimize the environmental emissions in a competitive electricity Market. The unit commitment methodology is considered to enhance the profit of GENCOs. Here, the steam plants are integrated with wind farms to improve the income of GENCOs. **Methods:** A novel nature-inspired human-based optimization algorithm of Corona Virus Herd Immunity Optimizer (CVHIO) is proposed for solution of this problem. Initially, the searching parameters of CVHIO determine the best scheduling of thermal and wind generators. Then the CVHIO efficiently optimizes the thermal and wind variables like real power, reserve power allocation and wind speed. **Findings:** Numerical example with IEEE 39 bus test system (10 thermal units 24 hours) integrated with two wind generating forms is considered to assess the performance of planned CVHIO. The obtained simulation results of Thermal power, Wind power; Reserve power, Emission level, Revenue, Total operating cost and Profit are tabulated. **Novelty:** The CVHIO is recently developed powerful optimizer and parameter free algorithm, so easily reaches the global optimal solutions. The final outcomes of this approach are analyzed with other conventional and intelligent techniques for validating the superiority of devised algorithm.

Keywords: Deregulation; Profit Based Unit Commitment; Profit maximization; wind power generation; Corona Virus Herd Immunity Optimizer

1 Introduction

In deregulated power system, the generation companies (GENCOs) adopt Unit Commitment for maximizing their own profit with different objectives not concentrating and considering the reduction of total production price of the centralized electric network. The problem is termed as Profit Based Unit Commitment (PBUC) problem. PBUC is defined as an optimal process for proper scheduling of its generators econom ically based on forecasted information such as spot price, reserve price, and demand and unit data with a prime objective to maximize the GENCOs profit. So, the methodology of PBUC problem in bringing the solution seems more complex than traditional UC problem [1].

A variety of numerical and soft computing optimization approaches can be found in the literature to solve the generation scheduling problem considering rentable energy sources. Quite promising results in terms of fuel cost savings have been reached in most works. However, among these works imported power tariffs were not involved in the generation scheduling problem and at the same time renewable energy systems were not taken into account.

The researchers developed various approaches for solution of PBUC problems which are Stochastic optimization approach [2], Branch and reduce optimization navigator [3], robust optimizations [4], Emerald algebraic modeling system with BARON solver [5], Two-layer nested optimization method [6], moth fly optimization with levy flight search [7], Monarch butterfly optimization [8], modified bald eagle search Algorithm [9], binary differential evolution and binary local search optimizer [10], IPPD table and Analytical Hierarchy method [11], BARON solver [12,13], Enhanced-interval linear programming [14] and Harris Hawks Optimizer [15].

Nowadays, renewable sources integrated PBUC problem is described by many researchers with different approaches. Improved Shuffled Frog Leaping Algorithm [16,17] has been applied to solve PBUC with wind integration. Here profit and emission was considered and applied IEEE 39 bus system with 2 wind system. Binary Sine Cosine optimization algorithm [18] was used in CBUC and PBUC integrating with wind forms. In this paper 10 unit and multi-unit system has been adopted with more computational time. The same problem has been analyzed by Vineet Kumar, et al. using ANTIGONE solver under GAMS environment [19].

Manisha Hooda1 et al applied CUCKOO- GWO technique [20] for IEE 30 bus and 75 bus systems to display PBUC solutions. Computational time and emissions are not considered in the objective functions. Wind power and energy storage system have been considered in CBUC with wind integration and solved by MILP approach. [21]. A practical approach was implemented in PBUC problem considering air energy storage and solar power units [22]. Wind integrated CBUC was analyzed using CEPLEX MIP solver [23] has been employed for its solution.

The contribution of the present work simultaneously maximizes the profit and minimizes the environmental emissions of GENCOs under deregulated environment. The PBUC process is considered for obtaining the optimal solutions. The 10 thermal (IEEE 39 bus system) with 2 wind generators are considered in the proposed investigation. A new intelligent and natural inspired optimization tool of CVHIO algorithm is proposed to optimize the thermal and wind variables for improving the profit and reducing the emission level. Comparative study of UC schedule, power generation, profit, emission and computational time with proposed method and other available techniques are presented in this work to prove the performance of the CVHIO algorithm.

2 Methodology

2.1 Objective function 1: Profit maximization of GENCOs

The profit functions of the proposed work are mathematically defined as,

$$max\,PF \;=\; TR \;-\; TC \tag{1}$$

where,

$$\begin{aligned} TR = \textstyle\sum_{i=1}^{T} \sum_{i=1}^{N_{TG}} \left(P_{TG}(i,t)\,.\,SP(t)\right\} U(i,t) + \sum_{i=1}^{T} \sum_{i=1}^{N_{TG}} \left(P_{TGR}(i,t)\,.\,RP(t)\right\} U(i,t) \\ + \textstyle\sum_{i=1}^{T} \sum_{i=1}^{N_{WG}} \left(P_{WG}(j,t)\;.\,SP(t)\right\} V(i,t) \end{aligned} \tag{2}$$

$$\begin{aligned} TC = \textstyle\sum_{i=1}^{T} \sum_{i=1}^{N_{Ti}} \left(F\left(P_{TG}(i,t) + P_{TG}R(i,t)\right) + SU_{TG}(i,t) + SD_{TG}(i,t)\right\} U(i,t) \\ + \textstyle\sum_{i=1}^{T} \sum_{i=1}^{N_{WG}} \left(\left(P_{WG}(j,t)\;.\,OCWG(j)\right) + FCWG(j)\right\} V(i,t) \end{aligned} \tag{3}$$

The fuel cost of the steam plants is formulated by the quadratic equation as

$$MinF_{it}\left(P_{it}\right) = a_i + b_i P_{it} + c_i P_{it}^2 \tag{4}$$

2.2 Objective function -2: Emission limitation of GENCOs

The emission function of GENCOs is incorporated with the objective function and it is formulated as in Equation (5).

$$Emission(EM) = min \textstyle\sum_{t=1}^{T} \sum_{i=1}^{N} E\left(P_{it}\right)\;.\,U_{it} \tag{5}$$

The Emission reduction is one of the important tasks in the electrical power generation system. The emission curve of the thermal plants is represented by the quadratic form as follows.

$$E\left(P_{it}\right) = \alpha_i + \beta_i P_{it} + \gamma_i P_{it}^2 \tag{6}$$

2.3 System and Unit constraints

2.3.1 Power balance constraints

The addition of generated power of steam plants and wind turbine is lesser than or equal to the system load demand.

$$\sum_{i=1}^{N_{TG}} P_{TG}(i,t)\ .\ U(i,t) + \sum_{j=1}^{N_{WG}} P_{WG}(j,t)\ .\ V(j,t) \le P_D(t) \tag{7}$$

2.3.2 Thermal unit generation limits

Each thermal generator generate the power of P_{TG}^{min} to P_{TG}^{max} and given in following equation

$$P_{TG}^{min}(i,t)U(i,t) \le P_{TG}(i,t) \le P_{TG}^{max}(i,t)U(i,t) \tag{8}$$

2.3.3 Thermal unit up/down spinning reserve contribution constraints

The thermal unit up/down spinning reserve contribution constraints is represented as

$$US(i,t) \le min\left(US_{max}(i), P_{max}(i,r) - P_{TG}(i,t)\right\} \tag{9}$$

$$DS(i,t) \le min\{DS_{max}\ (i), P_{TG}\ (i,t) - P_{min}\ (i,r)\} \tag{10}$$

Where,

$$US_{max}(i) \le d\% \times P_{max}(i,r) \tag{11}$$

$$DS_{max}(i) \le d\% \times P_{min}(i,r) \tag{12}$$

2.3.4 Minimum up/down time of steam plants

It is mathematically described by

$$(t_{ON}(i,(t-1)) - MU(i)] \times [U(i,(t-1)) - U(i,t)] \ge 0 \tag{13}$$

$$(t_{OFF}(i,(t-1)) - MU(i)] \times [U(i,t) - U(i,(t-1))] \ge 0 \tag{14}$$

2.3.5 Wind power curve constraints

The wind power curve constraints is mathematically defined as

$$P_{WG}{}^{*}(j,t) = \left(\begin{array}{c} 0,\ v(t) \le v(I,j) or v(t) > v(O,j) \\ \varphi(j,v(t)),\ v(I,j) \le v(t) \le v(R,j) \\ P_{WG}^{max}(j),\ v(R,j) \le v(t) \le v(O,j) \end{array}\right. \tag{15}$$

Where,

$$\varphi\left(j, v(t)\right) = P_{WG}^{max}\left(j\right)\left(A + Bv(t) + Cv(t)^2\right] \tag{16}$$

and A, B, C are the constants.

2.3.6 Total available wind power generation

The total available power is equal to sum of power generation of wind plants and it represented as

$$P^*_{WGT}(t) = \sum_{j=1}^{N_{WG}} P^*_{WG}(j,t) \tag{17}$$

2.3.7 Total actual wind power generation limit

This power lies between zero and actual wind power and it is written as

$$0 \leq P_{WGT}(t) \leq P^*_{WGT}(t) \tag{18}$$

2.4 Corona Virus Herd Immunity Optimizer (CVHIO)

A new nature-inspired human-based optimization algorithm of Corona Virus Herd Immunity Optimizer (CVHIO) is proposed in this research work[16]. The motivation of CVHIO is originated from the herd immunity concept as a way to tackle corona virus pandemic (COVID-19). The speed of spreading corona virus infection depends on how the infected individuals directly contact with other society members. In order to protect other members of society from the disease, social distancing was suggested by health experts. Herd immunity is a state which mentions the result of prevention, implementation of immune system so that, how for population was prevented from the spreading of disease transmission. Here, three types of individual cases are utilized for herd immunity: susceptible, infected and immuned. This is to determine how the newly generated solution updates its genes with social distancing strategies. The structure of Herd immunity and Population hierarchy of CVHIO are represented in Figure 1 and Figure 2. The basic theory about proposed Optimization method and its drawbacks are clearly reported in[16].

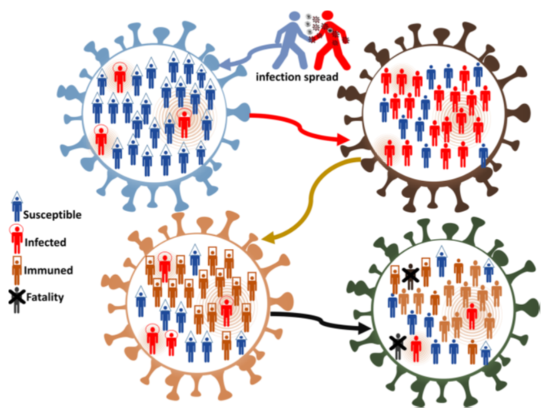

Fig 1. Herd immunity of CVHIO

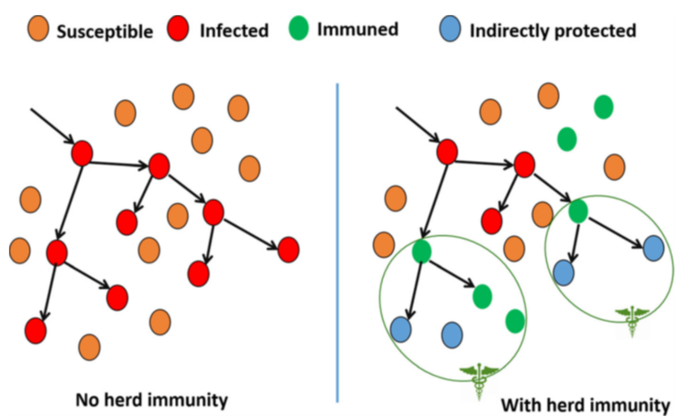

Fig 2. Population hierarchy of CVHIO

This research work proposed a new human based nature-inspired algorithm coronavirus herd immunity optimizer (CVHIO). Nowadays, human-based nature-inspired phenomenon is being emerged as algorithms and achieves pleasing results when compared to other nature inspired algorithms. The CVHIO is modeled as a continuous optimization algorithm which reduces the computational time. It is a parameter free algorithm, so it easily achieves the global optimal solutions. But GA, PSO, ACO ABC etc. have more number of control parameters. Solutions mainly depend upon setting of control parameters. So these algorithms sometimes provide local optimal and premature solutions.

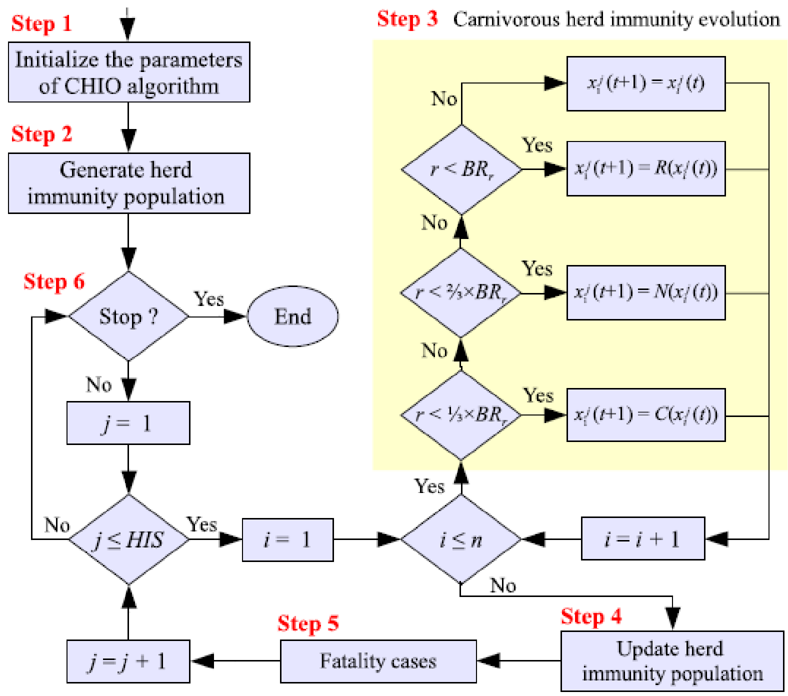

Fig. 5 Flowchart of CHIO algorithm

Fig 3. Flow diagram of proposed CVHIO algorithm

The algorithm has six main steps discussed as follows:

- Step 1: Initialize parameters of CHIO and optimization problem. In this step, the optimization problem is formulated in the context of objective function.
- Step 2: Generate herd immunity populations.
- Step 3: Coronavirus herd immunity evolution
- Step 4: Update herd immunity population
- Step 5: Diversify the current population and thus escaping local optima.
- Step 6: Stop criterion CHIO repeats Step 3 to step 6 until the termination criterion which normally depends if the maximum number of iteration is reached.

2.5 Implementation of Proposed CVHIO Algorithm

The step by step procedure for profit maximization of GENCOs using CVHIO algorithm has been explained by the following steps.

1. Read the thermal-wind generators data and market information such as market price, load and reserve demand, cost and emission coefficients of thermal units, start-up/shut-down cost of thermal units, operating limits of wind and thermal units, cut-in, rated and cut-out speed, fixed and operating cost of wind units.

2. Initialize the CVHIO parameters: like population size (N), number of variables, random number and maximum number of iterations etc. In this step, the optimization problem is formulated in the context of objective function is defined as

$$\min_{x} f(x) x \in [lb, ub] \tag{19}$$

3. Generate herd immunity population using the Equation (20).

$$HIP = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_n^1 \\ x_1^2 & x_2^2 & \cdots & x_n^2 \\ \vdots & \vdots & \cdots & \vdots \\ x_1^{HIS} & x_2^{HIS} & \cdots & x_n^{HIS} \end{bmatrix} \tag{20}$$

4. Corona virus herd immunity evolution is obtained using the Equation (21).

$$x_i^j(t+1) = \begin{pmatrix} & x_i^j(t) \;\; r \geq BR_r \\ C\left(x_i^j(t)\right) & r < \frac{1}{3} \times BR_r.Infectedca\,se \\ N\left(x_i^j(t)\right) & r < \frac{2}{3} \times BR_r.susceptibl\,ecase \\ R\left(x_i^j(t)\right) & r < BR_r.imiunedcas\,e \end{pmatrix} \tag{21}$$

5. Set Count= 1 and Time interval t=1

6. Compute the feasible units of wind and thermal for the given forecasted load demand, reserve demand and market price using CVHIO algorithm.

7. Check, whether all constraints of hybrid electric systems are satisfied. If yes go to step 12 otherwise go to next step.

8. Call CVHIO algorithm and determine fitness value of each populations (Maximum profit and minimum emission of GENCOs).

9. Compute best PBUC schedule, steam power dispatch, Reserve power allocation, wind power dispatch, Revenue, total cost, profit and emission level of proposed hybrid system.

10. Check, whether all intervals are over. If yes go to next step otherwise go to step 4.

11. Check, whether the optimal solution is reached. If yes go to next step else go to step 3.

12. Save the best solutions & Print the results and STOP.

The flow diagram of proposed methodology for solving wind-thermal integrated generation scheduling problem is represented in Figure 4.

2.6 Wind Power Generation Curve

The basic wind power curve of the wind turbine is shown in Figure 5. Generally, the dispatch power of each wind turbine is varied and depends upon the velocity of wind and location of wind farm. This equipment is designed to generate the power through cut-in and cut-out speed of device. It is started to generate the power at the cut-in speed v(l, j) and are de-committed due to safety precautions at the cut-out speed v(o, j). The maximum power (P^{max}) is produced only at turbine speed which lies between rated speed and the cut-out speed. No power is produced in the before cut-in speed of the turbine. The dispatch power is increased from cut-in speed to the rated speed of the turbine. This power dispatches represent a linear function with quadratic function.

In Tamil Nadu state, wind speed profile for five days is taken from the sample data in September 2012 and it is graphically represented in Figure 6. From the graph, the day 5 has given a maximum wind speed of 30.9 m/s at 16th hour during the 24-hour period. From the curve, the wind speed varies from the cut-in speed to the rated speed. So that It is decided as the non-linear characteristics of wind power production. The delivered output power of wind turbine is calculated using the Equations (15) and (16). The objective function is also satisfying the all constraints of the wind plants and performs as the real experimental setup.

3 Results and Discussions

In this section, the optimal self-scheduling of GENCOs to maximize the profit is analyzed using CVHIO through the impact of inclusion of wind plants. The proposed test system consists of 10 thermal units (IEEE 39 bus system) and 2 wind farms with 24

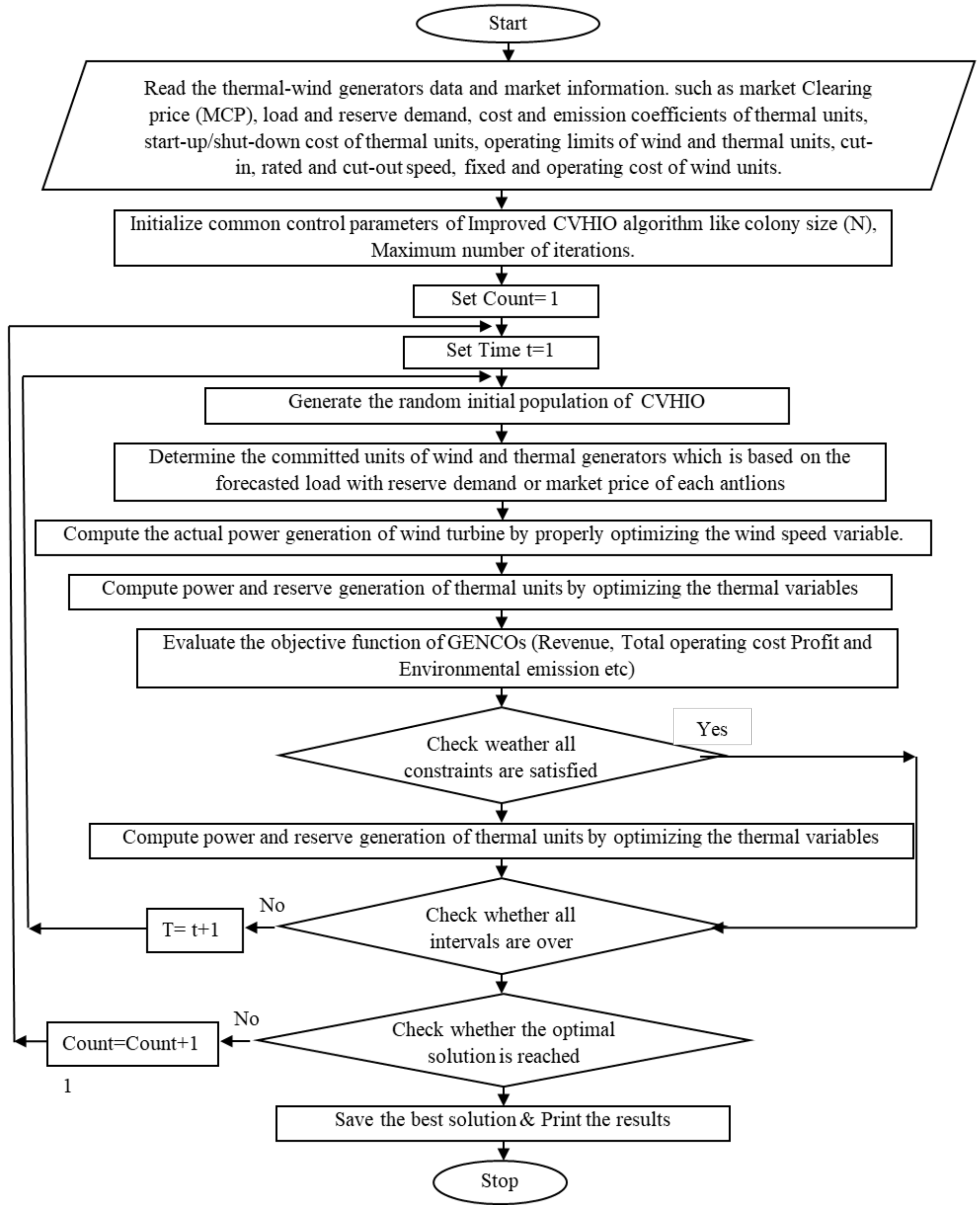

Fig 4. Flow chart for wind integrated PBUC by proposed CVHIO algorithm

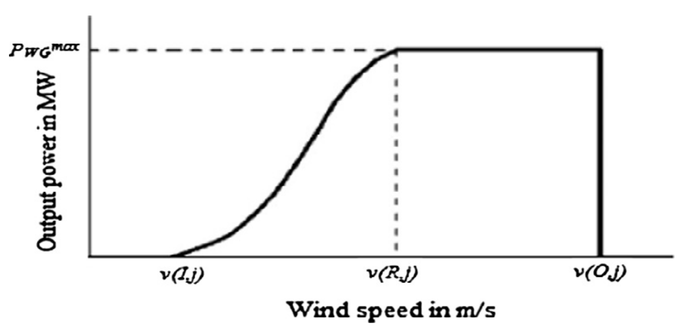

Fig 5. Wind power curve of a wind turbine

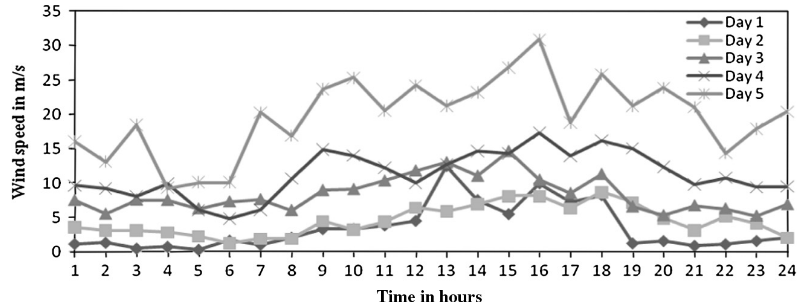

Fig 6. Wind speed profiles on five sample days in September 2012

hour time period. The unit data, load demand, market price, cost and emission coefficients of thermal and wind generators are taken from reference [12]. Each wind farm contains 30 wind turbine units the dispatching capacity of 2 MW respectively. The wind generators' operating characteristics and wind speed profile taken from [10] and are given in Tables 1 and 2. The simulations are carried out using MATLAB software.

Table 1. Wind generator operating characteristics

Wind units	P_{max} (MW)	P_{min} (MW)	Fixed cost (Rs/MW yr)	Operating cost (Rs/MW hr)	Cut-in speed (m/s)	Rated speed (m/s)	Cut-out speed (m/s)
W1	60	0	50,000	625	3.5	12.5	25
W2	60	0	45,000	560	3.5	12.5	25

Table 2. Wind speed profile of two wind farms

Hours	Wind Speed (m/s) in farm 1	Wind Speed (m/s) in farm 2	Hours	Wind Speed (m/s) in farm 1	Wind Speed (m/s) in farm 2
1	0.90	1.46	13	14.17	7.73
2	2.68	1.88	14	8.41	4.32
3	3.64	2.92	15	12.41	9.27
4	2.11	1.04	16	10.49	4.68
5	2.46	1.40	17	10.07	4.11
6	1.14	1.94	18	7.90	4.36
7	1.99	3.13	19	6.67	2.48
8	3.57	4.36	20	4.39	3.30
9	4.97	3.77	21	3.77	2.84
10	5.25	4.65	22	2.77	1.88
11	4.85	3.57	23	2.89	5.55
12	7.90	5.39	24	2.87	2.23

The CVHIO is a parameter less algorithm and contains only two conmen control parameters such as Basic reproduction rate and maximum numbers of iterations. The values of common control parameters are obtained by trial and error method and its basic reproduction rate is 0.05 and maximum numbers of iterations is 100 respectively.

Initially, influential searching operators of CVHIO algorithm determines the optimal UC schedule for both thermal and wind units based on forecasted load demand and market price. The obtained feasible UC schedule GENCOs are represented in Table 3.

Here, the thermal units 6 to 10 are de-committed for entire 24 hours to reduce the start-up cost, incremental cost and environmental emissions of thermal units. The two wind farms are also de-committed up to 7 hours, while the steam plants alone satisfy the load demand. After 7^{th} hour the wind units are delivering the power up to 23^{rd} hour. After, CVHIO optimizes the thermal-wind system variables which are real power, reserve power and environmental emissions of thermal units, wind

Table 3. Unit commitment schedule for 10 thermal 2 wind test system

H (h)	Thermal units										Wind units	
	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	W1	W2
1	1	1	0	0	0	0	0	0	0	0	0	0
2	1	1	0	0	0	0	0	0	0	0	0	0
3	1	1	0	0	0	0	0	0	0	0	0	0
4	1	1	0	0	0	0	0	0	0	0	0	0
5	1	1	0	0	0	0	0	0	0	0	0	0
6	1	1	0	1	0	0	0	0	0	0	0	0
7	1	1	1	1	0	0	0	0	0	0	0	1
8	1	1	1	1	0	0	0	0	0	0	0	1
9	1	1	1	1	1	0	0	0	0	0	1	1
10	1	1	1	1	1	1	0	0	0	0	1	1
11	1	1	1	1	1	1	0	0	0	0	1	1
12	1	1	1	1	1	1	0	0	0	0	1	1
13	1	1	1	1	1	1	0	0	0	0	1	1
14	1	1	1	1	1	0	0	0	0	0	1	1
15	1	1	1	1	0	0	0	0	0	0	1	1
16	1	1	1	1	0	0	0	0	0	0	1	1
17	1	1	0	1	0	0	0	0	0	0	1	1
18	1	1	0	1	0	0	0	0	0	0	1	1
19	1	1	0	1	0	0	0	0	0	0	1	0
20	1	1	0	1	0	0	0	0	0	0	1	1
21	1	1	0	1	0	0	0	0	0	0	1	1
22	1	1	0	1	0	0	0	0	0	0	1	1
23	1	1	0	0	0	0	0	0	0	0	1	1
24	1	1	0	0	0	0	0	0	0	0	0	0

speed for different load demand and market price. The optimized steam plant power, reserve power and wind power are given in Table 4.

Table 4. Power generation of 10 thermal 2 wind farms test system

H (h)	Thermal Power Generations (MW)										Wind generation (MW)	
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	W1	W2
1	454.84	245.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	296.20	453.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	405.31	444.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	455.00	455.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	455.00	455.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	455.00	455.00	0.00	130.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	455.00	455.00	129.99	109.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.99
8	455.00	455.00	130.00	130.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	24.99
9	455.00	455.00	130.00	130.00	130.00	0.00	0.00	0.00	0.00	0.00	20.01	20.99
10	454.00	454.00	130.00	130.00	152.00	80.00	0.00	0.00	0.00	0.00	20.99	24.99
11	455.00	455.00	130.00	130.00	162.00	80.00	0.00	0.00	0.00	0.00	20.01	20.01
12	455.00	455.00	130.00	130.00	162.00	80.00	0.00	0.00	0.00	0.00	34.99	20.01
13	454.00	454.00	130.00	130.00	152.00	80.00	0.00	0.00	0.00	0.00	60.01	29.99
14	454.99	452.99	130.00	130.00	134.99	0.00	0.00	0.00	0.00	0.00	35.01	34.99
15	455.00	455.00	130.00	130.00	0.00	0.00	0.00	0.00	0.00	0.00	50.01	44.99

Continued on next page

Table 4 continued

16	454.99.	452.99.	130.00	37.99	0.00	0.00	0.00	0.00	0.00	0.00	44.99	20.01
17	454.00	454.00	0.00	87.99	0.00	0.00	0.00	0.00	0.00	0.00	40.01	20.01
18	455.00	455.00	0.00	130.00	0.00	0.00	0.00	0.00	0.00	0.00	29.99	20.01
19	455.00	455.00	0.00	130.00	0.00	0.00	0.00	0.00	0.00	0.00	24.99	0.00
20	455.00	455.00	0.00	130.00	0.00	0.00	0.00	0.00	0.00	0.00	14.99	14.99
21	455.00	455.00	0.00	130.00	0.00	0.00	0.00	0.00	0.00	0.00	10.01	14.99
22	455.00	455.00	0.00	130.00	0.00	0.00	0.00	0.00	0.00	0.00	10.01	10.01
23	451.99	447.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.01	20.01
24	346.25	453.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

The simulation results of thermal and wind profit, emissions and computational time of the spinning reserve and emission constrained wind integrated thermal system are presented in Table 5. The total profit and emission level of the projected system is $ 121296.60 and 25378.28 tons respectively and the computational time is 105 sec. The simulation results are compared with two different cases to prove the efficiency of the projected method. Total profit, total emission level and computational time of the 10 thermal test systems is compared with other recent published methods and is displayed in Table 6.

Table 5. Simulation results of 10 Thermal 2 Wind Considering Reserve Power Generation

Hour hr	Thermal Generators Profit ($/hr)	Wind form Profit ($/hr)	Total Profit ($/hr)
1	2150.789	0	2150.789
2	2284.244	0	2284.244
3	3666.2	0	3666.2
4	3256.733	0	3256.733
5	3802.689	0	3802.689
6	3652.333	0	3652.333
7	3217.378	337.4667	3554.844
8	2807.889	553.7111	3361.6
9	3515.822	387.7556	3903.578
10	12391.27	799.4889	13190.76
11	13520.8	679.4889	14200.29
12	15638.64	819.4	16458.04
13	5684.756	634.6	6319.356
14	5780.067	793.6667	6573.733
15	3217.378	821.2889	4038.667
16	2554.178	264.9778	2819.156
17	2924.4	283.4222	3207.822
18	2716.4	5312.8	3529.2
19	2872.4	103.044	2975.44
20	3340.356	284.6667	3625.022
21	3808.333	314.2444	4122.578
22	3652.333	195.7778	3848.111
23	3347.733	419.2667	3767.000
24	2988.422	0	2988.422
Total profit ($/24 hr)			**121296.60**
Total Emission (tons/24)			**25378.28**
Computational time (s)			**105.00**

Table 6. Comparison of Total profit and total emission level of 10 thermal (IEEE39 Bus) test system

Methods	Total Profit ($/24hr)				Total Emission (tons)	Computational time (s)
	Best Profit	Worst Profit	Mean Profit	STD		
Traditional UC	81365.65	-	-	-	28244.15	187
GA	99058	-	-	-	-	152
TS-RP	101086	-	-	-	-	-
TS-IRP	103261	-	-	-	-	-

Continued on next page

Table 6 continued

Muller Method	103296	-	-	-	-	-
ACO	103890	-	-	-	-	-
PSO	104356	-	-	-	-	-
PPSO	104556.23	-	-	-	-	-
NACO	105549	-	-	-	-	-
PABC	105878	-	-	-	-	-
ICA	104,328	-	-	-	26,955.00	110
SFLA	105442.4	-	-	-	26617.56	124
MPPD – ABC	105446.6	-	-	-	26646.85	112
AIS	105869.7	-	-	-		118
PNACO	105942	-	-	-	-	-
IALO	106266.60	-	-	-	26180.99	115
Parallel BSC-OPL Algorithm	107356.00	-	-	-		
Binary Fireworks Algorithm	106850.00	-	-	-		
CVHIO (Proposed method)	**107350.50**	**107110**	**107253**	**10.235**	**26120.00**	**101**

The two winds integrated 10 thermal units total profit and emissions are numerically and graphically compared with other recent methods and are displayed in Table 7. From the table we come to know that the suggested algorithm provides maximum profit, minimum emission and less computational burden when analyzed and compared with other methods which are in literature.

Table 7. Comparison of Total profit and total emission level of 10 thermal with 2 wind farms test system

Methods	Total Profit ($/24hr)				Total Emission (tons)	Computational time (s)
	Best Profit	Worst Profit	Mean Profit	STD		
LR-method	97945.25	-	-	-	-	135
Genetic algorithm	115214.60	-	-	-	-	120
ANTIGONE solver	109412.37	-	-	-		-
Shuffled Frog Leaping	110827.00	-	-	-	26303	-
LR-DE	112818.93	-	-	-	-	-
Hybrid CUCKOO-GWO A	118764.47	-	-	-	-	-
CVHIO (Proposed method)	**120590.50**	**120152**	**120373**	**12.173**	**25378.28**	**115.20**

4 Conclusion

This paper solves the Wind integrated PBUC problem which has been described under deregulated environment. The best optimization algorithm CVHIO is proposed to maximize the profit and minimize the emission level of GENCOs. The CVHIO properly identifies the most economical scheduling plan for GENCOs by considering wind plants and market price. The reliability of the method has been tested using 10 thermal units and 2 wind farms with 24 hours respectively. Results are obtained for the optimal UC schedule for both wind and thermal units and MW values of real power, hourly profit and also the total profit of the GENCOs. At the end of the study results have been compared with other soft computing and hybrid methods. This results show that, the proposed algorithm provides maximum profit, minimum emission with less computational time compared to other existing methods.

5 Appendix A: Nomenclature and abbreviations

a_i, b_i, c_i	Cost co-efficient of ith generator
$\alpha_i, \beta_i, \gamma_i$	Emission co-efficient of ith generator
N_{TG}	Number of thermal units in the system
N_{WG}	Number of wind units in the system
P_{TG} (i,t)	Power generation of thermal unit i at hour t, in MW
P_{wGG} (j,t)	Actual power generation of wind unit j at hour t, in MW
P_{WG} * (j,t)	Available power generation of wind unit j at hour t, in MW
U(i,t)	Commitment status of thermal unit i at hour t
V(i,t)	Commitment status of wind unit j at hour t
RP(t)	Forecasted reserve price at hour t, in Rs//MW hr
U(i,t)	Up spinning reserve contribution of thermal unit i, at hour t, in MW
DS(i,t)	Down spinning reserve contribution of thermal unit i, at hour t, in MW
P_{WGT} (t)	Total actual wind power generation at hour t, in MW
P^{*}_{WGT} (t)	Total available wind power generation at hour t, in MW
P_{TG}^{min} (i,t)	Minimum generation of thermal unit i at hour t, in MW
P_{TG}^{max} (i,t)	Maximum generation of thermal unit i at hour t, in MW
US_{max} (i)	Up spinning reserve contribution of thermal unit i, at hour t, in MW
DS_{max} (i)	Down spinning reserve contribution of thermal unit at hour t, in MW
P_{max} (i,r)	Upper Bound On The Output Power Of Thermal Unit I
P_{min} (i,r)	Lower Bound On The Output Power Of Thermal Unit I
UR_{max} (i)	Maximum Ramp-Up Rate Of Thermal Unit I
DR_{max}	Maximum Ramp-Down Rate Of Thermal Unit I
P_{WG}^{max} (j)	Upper Generation Limit Of Wind Unit J
v(I,j)	Cut-in wind speed of wind unit j
v(R,j)	Rated wind speed of wind unit j
v(O,j)	Cut-out wind speed of wind unit j
v(t)	Wind speed at hour t
SDR(t)	System ramping down capacity at hour t
SUR(t)	System ramping up capacity at hour t
d%	Percentage of maximum unit capacity
MU(i)	Minimum up time of thermal unit i
MD(i)	Minimum down time of thermal unit i
ADSR	Additional down spinning reserve requirement considering wind power generation
AUSR	Additional up spinning reserve requirement considering wind power generation
OCWG(j)	Operating cost of wind unit j, in Bs//MW hr
FCWG(j)	Fixed cost of wind unit j, in Rs//MWyr
F(P_{TG} (i,t))	Operating fuel cost of thermal unit i at hour t

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