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A novel CSHO algorithm-based Profit Maximization of GENCOs considering PEVs and RES under Deregulated Environment

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Abstract
In deregulated power markets, the Profit-Based Unit Commitment (PBUC) problem has emerged as a critical optimization problem for power Generation Companies (GENCOs) aiming to maximize profit while ensuring system reliability. The increasing penetration of Plug-in Electric Vehicles (PEVs) and Renewable Energy Sources (RESs) introduces additional uncertainty and complexity due to their stochastic and time-varying characteristics. This paper presents a novel approach to solving the PBUC problem in a deregulated environment by integrating the dynamic impacts of PEV charging/discharging behaviors and RES intermittency. A metaheuristic algorithm, the Chaotic Sea Horse Optimizer (CSHO), is employed to determine optimal generation schedules that maximize profit while accounting for market prices, operational constraints, spinning reserve requirements, and environmental considerations. The proposed CSHO framework effectively handles the nonlinear, non-convex nature of the PBUC problem and adapts to the uncertainties associated with RES output and PEV load profiles. Simulation studies on standard test systems such as the IEEE-39 bus system (10 generators and 24 hours) with an equivalent PEV and Wind farm. The proposed approach is tested with different test cases to analyze its performance. The outcomes such as UC schedule, Real power output of thermal, wind and PEV units, fuel cost, startup cost, revenue and profit of the proposed test system are numerically and graphically reported. The obtained simulated results are compared with other mathematical and intelligent computational approaches for proving the efficiency and performance of the proposed CSHO technique.

Keywords: *Deregulation, Profit Based nit Commitment, PEVs and RES, Profit of GENCOs, Chaotic Sea-Horse Optimizer.*

INTRODUCTION

The integration of EVs and RES in a deregulated power system introduces both challenges and opportunities in solving the PBUC problem**.** The PBUC optimization problem needs to account for the variability of renewable generation, the uncertainty of EV demand, and the fluctuating prices in deregulated markets. However, when managed well, EVs can offer valuable demand-side flexibility and storage capabilities, while RES can provide cleaner, low-cost generation. Optimal power scheduling model of EVs and RES constrained PBUC is shown in Fig 1. Together, they contribute to a more resilient and sustainable power system [1]. The PBUC problem aims to determine the optimal schedule for power generation units to maximize profits while considering factors such as generation costs, electricity demand, and market prices. When PEVs are introduced into this framework, their charging and discharging behaviour create both opportunities and challenges. Here are the key impacts of PEVs in the PBUC problem[2].

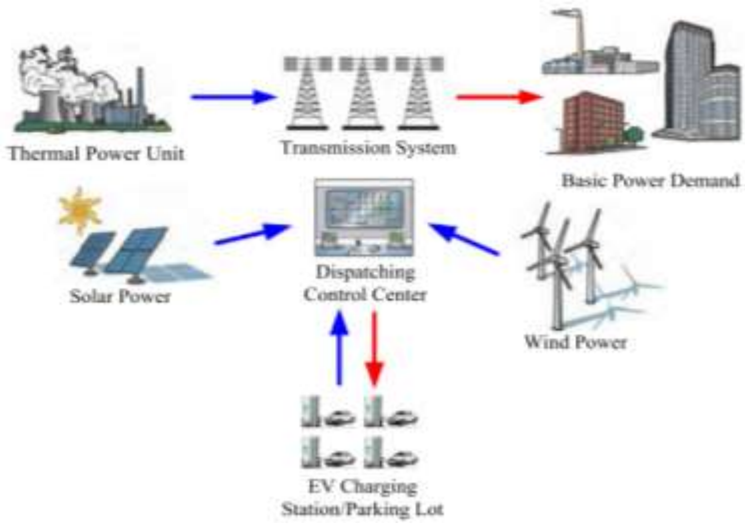

Fig. 1. Optimal power scheduling model of EVs and RES constrained PBUC

The PBUC has evolved significantly with the liberalization of electricity markets. Its complexity grows with market sophistication, renewable, and risk considerations. Ongoing research is focused on developing robust, intelligent methods to handle uncertainty, strategic behavior and environmental impacts. Currently researchers apply various approaches such as the Hybrid Particle Swarm Optimization Algorithm [3], Binary Grey Wolf Optimizer [4], Ant line optimizer [5], a hybrid recurrent neural network, support vector machine and the lightning search algorithm [6], Exchange market algorithm [17],Corona Virus Herd Immunity Optimizer [8].In the regulated power sector, a hybrid Monte Carlo method combined with the Cuckoo search algorithm [9] has been employed in the CBUC framework, considering the uncertainties associated with electric vehicles and photovoltaic systems. The simulation was conducted across various scenarios to evaluate the overall operating costs of integrated power systems. An enhanced interval linear programming method [10] has been utilized to address the renewable energy sources and electric vehicles constrained unit commitment problem. The analysis included wind and solar units to evaluate fuel costs across various case studies.

Pravin G. Dawdle and colleagues have introduced a system that effectively integrates renewable energy generation with traditional and plug-in electric vehicles to meet power utilization demands. This method was evaluated using unimodal, multimodal, and fixed-dimension benchmark functions across systems of 10, 20, 40, and 100 units, employing chaotic arithmetic optimization algorithms [11].The Harris Hawks optimizer has been combined with the sine-cosine algorithm [12] to address the photovoltaic constrained unit commitment problem in electric power systems. The sine-cosine algorithm was utilized to facilitate power generation, while the economic load dispatch was achieved through the Harris Hawks optimizer. Particle Swarm Optimization [13] was employed to reduce the operational costs of integrated power plants. In this context, a significant proportion of renewable energy sources, including wind and solar, were incorporated into short-term power system planning and management in urban regions where electric vehicle charging stations and traditional demand coexist. Recently, Syed Vasiyullah S. F and Bharathidasan S. G have proposed an Improved Pre-prepared power demand (IPPD) table and Analytical Hierarchy (AHP) method [14] for the solution of thermal generators, EVs and RES integrated PBUC problems. The IPPD table has been implemented to determine fusible units for power generation and schedule committed units.The AHP approach was used to find economic operation of fuel cost, revenue and expected profit estimation. Kumar

V. and colleagues introduced a BARON solver [15] designed to address the PEVs and RES constrained PBUC problem. This method aims to optimize the profits of generation companies (GENCOs) amidst the uncertainties associated with wind, solar energy, and PEVs. To manage the unpredictable aspects of wind speed, solar irradiance, and plug-in hybrid electric vehicles (PHEVs), the Monte Carlo Simulation technique was employed. The effectiveness of the BARON solver was evaluated using various solving methodologies. The same BARON solver [16] was used to solve the PBUC problem which includes the RES, Energy Storage System (ESS) and PEVs to maximize the GENCOs profit under deterministic and stochastic environments. The wind and solar units have been integrated with thermal units to reduce the environmental emissions.

A modified shuffled frog leaping algorithm [17] has been proposed to solve the multi-objective PBUC problem considering uncertainties in demand and energy prices. The energy storage system and RES were integrated with thermal units to enhance the profit of GENCOs. Chaotic maps with Harris Hawks Optimizer, Sine Cosine Algorithm and Slime Mould Algorithm [18] have been applied in PEVs and RES constrained PBUC and analyze the profit in summer and winter seasons. Numerical example of small type to large type test systems like 10, 40 and 100-generating unit was considered. Mathematical methods involving benders and integer cuts [19] have been employed to address the PBUC problem while accounting for the uncertainties associated with wind energy. This approach aims to optimize both real and reserve power generation to enhance profitability. The heuristic optimization algorithm [20] has been applied to address the PBUC problem, taking into account thermal units, combined heat and power (CHP) units, and heat-only units, as well as the prices in energy and spinning reserve markets.This paper proposes a powerful tool of Chaotic Sea Horse Optimizer (CSHO),to solve the PEV and RES-contained Profit-Based Unit Commitment (PBUC) problem. By leveraging its ability to handle nonlinearities, uncertainty, and chaotic dynamics, CSHO can optimize PEV charging/discharging, improve RES integration, and enhance the profitability of GENCOs. By applying the CSHO to the IEEE-39 bus system with PEVs, wind, and solar power, the objective is to optimize the unit commitment and maximize profits for GENCOs. CSHO is expected to outperform traditional algorithms such as GA, PSO, and ACO in terms of profit maximization, solution quality, and robustness, especially in handling uncertainty and nonlinearity. However, it may require more computational time compared to algorithms like PSO or DE.

PROBLEM FORMULATIONS

OBJECTIVE FUNCTION The PBUC is utilized to establish the generating unit schedule aimed at maximizing the profits of GENCOs. The anticipated profit value is calculated by subtracting the total operating costs incurred from the expected revenue over a specified timeframe. The PBUC issue can be expressed mathematically as

$$Max\ Profit = Total\ Revenue\ cost - Total\ Operating\ Cost$$

$$Max\ Profit = Energy\ market\ Revenue + Reserve\ Market\ revenue - Total\ Operating\ Cost$$

Can be rewritten as

$$Energy\ Market\ Revenue = \sum_{t=1}^{T} \left(P_T^{(i,t)}\right) MCP^{(t)}$$

$$P_T^{(i,t)} = \sum_{t=1}^{T} \left(P_{gen}^{(i,t)} + P_s^t + P_w^t + P_{EV}^t \right) MCP^{(t)}$$

$$Reserve\ Market\ Revenue = \sum_{t=1}^{T} \left(P_T^{(i,t)} \right) MCR^{(t)}$$

$$MCP^{(t)} = \frac{max\left(c_i + b_i P_{gen}^{(i,t)}\right)}{P_{gen}^{(i,t)}}$$

$$MCP^{(t)} = \frac{max\left(c_i + b_i P_{res}^{(i,t)}\right)}{P_{res}^{(i,t)}}$$

$$TOC = \sum_{t=1}^{T} \sum_{t=1}^{T} \left\{ (1-r). F\left(P_{gen}^{(i,t)}\right) + r. \left[F\left(P_{gen}^{(i,t)}\right) + F\left(P_{res}^{(i,t)}\right) \right] \right\} S^{(i,t)} + SU^{(i,t)}$$

Where, $F\left(P_{gen}^{(i,t)}\right) = a_i + b_i \left(P_{gen}^{(i,t)}\right) + c_i \left(P_{gen}^{(i,t)_2}\right)$ *and*

$$F\left(P_{res}^{(i,t)}\right) = a_i + b_i \left(P_{res}^{(i,t)}\right) + c_i \left(P_{res}^{(i,t)_2}\right)$$

MATHEMATICAL REPRESENTATION OF WIND, SOLAR AND PEVS SYSTEM

FUNCTION OF OUTPUT POWER OF WIND ENERGY SYSTEM

The function of output power of wind energy system with respect to wind speed is given by [24]

$$P_w^{(t)} = 0.15 \times A \times R^2 \times v^3 \times \rho \times \eta$$

Function of Output Power of Solar Energy System

The function of output power of solar energy system with respect to solar radiation is given by [25, 26]

$$P_S^{(t)} = 0.5 \times G \times A_{PV} \times \xi_{PV}$$

Power Output Limit on Electric Vehicle System

Electric vehicles will serve two significant functions when integrated with the smart grid. During the charging process, these EVs will function as a load, and they can also act as energy storage units to meet additional load demands, provided that their batteries have adequate surplus energy. The battery of an electric vehicle serves as a reservoir of stored energy, enabling it to deliver various ancillary services, including voltage regulation. As chemical storage devices, electric vehicle batteries exhibit exponential behavior over time. The power output function related to the energy consumption of electric vehicles while in transit is defined as follows.

$$P_{EV}^{(t)} = 0.5 \times \xi_{N_{Ev2G} P_V (\Psi_{pre} - \Psi_{dep})}$$

OPERATING CONSTRAINTS

Power Demand Constraint

The total power output of the thermal generators and other sources may be less than or equal to the load of the corresponding hour.

$$\sum_{i=1}^{n} P_{gen}^{(i,t)} + P_s^{(t)} + P_w^{(t)} + P_{EV}^{(t)} \leq PD^{(t)}; 1 \leq i \leq n$$

Generator Limits Constraint

$$P_{gen}^{min\,(i,t)} \leq P_{gen}^{(i,t)} \leq P_{gen}^{max\,(i,t)}; 1 \leq i \leq n$$

Reserve Constrain

$$\sum_{i=1}^{n} \left(P_{res}^{(i,t)} . S^{(i,t)}\right) \leq SR^{(t)}; \quad 1 \leq i \leq n$$

$$0 \leq P_{res}^{(i,t)} \leq \left(P_{gen}^{max\,(i,t)} - P_{gen}^{min\,(i,t)}\right); 1 \leq i \leq n$$

$$P_{res}^{(i,t)} + P_{gen}^{(i,t)} \leq P_{gen}^{max\,(i,t)}$$

Minimum Up/down time

$$T_{on_i} \geq M_{up_i}; \quad i = 1 \ldots . n$$

$$T_{off_i} \geq M_{down_i}; \quad i = 1 \ldots . n$$

SOLUTION METHODOLOGY

Seahorse Optimizer (SHO)

The SHO is the nature-inspired population based optimization methodology developed by Zhao, S*et. al* in the year 2023 [21-22]. The SHO is based on the natural life cycle of a sea horse searching for prey, movement and breeding behavior in the sea. Natural behavior of Seahorse Optimizer is shown in Fig. 2. The solution of the optimization problem is mainly based on the four behaviors of SHO, such as

- Movement Behaviour
- Foraging Behaviour and
- Breeding Behaviour

The performance of SHO is evaluated on 23 well-known functions and CEC2014 benchmark functions compared with six state-of-the-art meta-heuristic algorithms. Finally, five real-world engineering problems are utilized to test the effectiveness of SHO. The mathematical modeling of the initialization function, creating of populations, current positions, updating of search agents and representation of searching agents, are clearly described in the following sections.

The initial population of the SHO algorithm is mathematically represented as follows:

$$Sh=\begin{bmatrix} x1,i & \dots & x1,Dim-1 & x1,Dim \\ x2,i & \dots & \dots & x2,Dim \\ \vdots & \vdots & \vdots & \vdots \\ xN & \dots & xN,Dim-1 & xN,Dim \end{bmatrix}$$

$$Sh_{ij}=Rand\times(UBj-LBj)+LBj$$

$$Sh_{elite}=(f(X_i))$$

The mathematical representations of Movement Behavior, Foraging Behavior and Breeding Behavior are clearly represented [21-22]. The flow diagram of SHO is presented in Fig.

Fig. 2.Natural behavior of Seahorse Optimizer

Chaotic Sea- Horse Optimizer (CSHO)

Chaotic maps are very important for optimization problems. Avoid local optima, improve convergence, speed up convergence and improve the searching behaviour of SHO [23]. In this article, the logistic type chaotic map is used to replace the $rand$in SHO algorithm. The mathematical equation of the logistic type chaotic map is as follows:

$$(i+1)=a\times(i)(1-ylog(i))$$

Where $a$is 4. So, the chaotic map variable with range [0,1] is obtained. So, the movement of SHO is represented as follows.

$$\theta=ylog\times2\pi$$

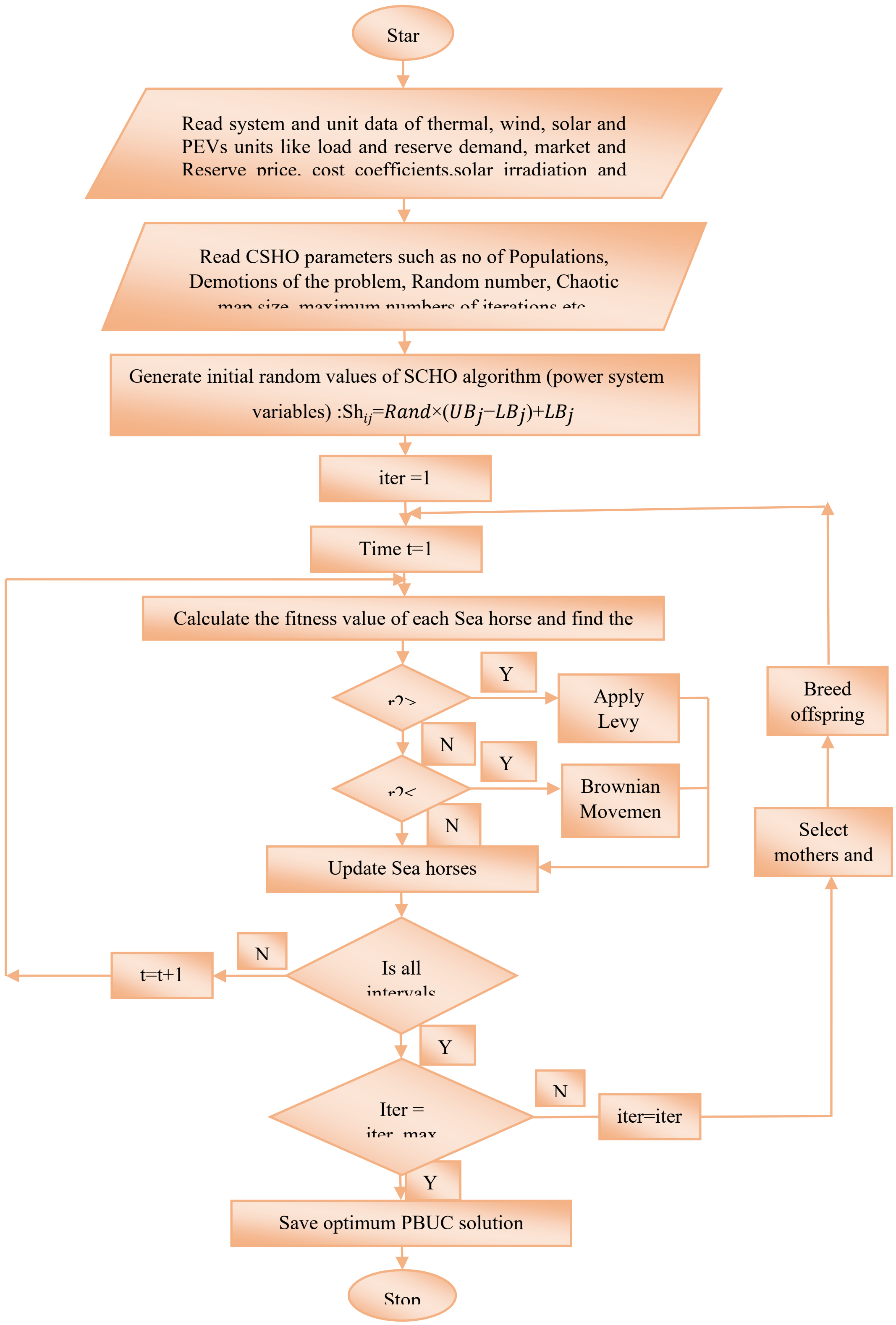

Fig. 3 Flow chart for RES and PEVs constrained PBUC problem using CSHO

Implementation steps for solution to RES and EVs constrained PBUC problem Using CSHO approach

The RES and EVs constrained PBUC problem is analyzed using the CSHO by taking the following steps:

1. Read system and unit data includes, forecasted load and reserve demand, market clearing price, reserve price, cost and emission coefficients, generator limits start-up and showdown cost, solar irradiation and wind speed, sources and load value of PEVs.
2. Read CSHO parameters, such as population size, problem demotions, system variables and maximum numbers of iterations, etc.
3. Generate initial random values of shares (power system variables) for all shareholders: Xij (j=1, 3,…m, i=1, 2,…n).
4. Modelling the wind, solar and PEVs units for integrating with thermal units.
5. Compute the feasible units for forecasted load and reserve or market price considering wind, solar and PEVs for each population.
6. A logistic chaotic map is used to introduce controlled randomness during search iterations, improving diversity and exploration.
7. Calculate the objective function using CSHO (real and reserve power generation of thermal units, solar power, wind power, charging and discharging of PEVs, total operating cost and revenue etc).
8. In each iteration, the algorithm evaluates fitness (profit) for each candidate, modifies the population based on chaotic behaviour, and retains the best solutions through elitism.
9. Check the time interval for 24 hours completed. If satisfied, go to the next step; otherwise go to step 4.
10. Evaluate the fitness values of objective functions (maximum profit and minimum operating cost) of the PBUC problem.
11. Updates the new positions (Exploration and Exploitation phase) of the CSHO parameters
12. Verify whether an optimal solution is reached. If all constraints are satisfied and obtain the maximized profit go to next step; otherwise go to step 3.
13. Save the best simulation results and stop.

The flow diagram of RES and EVs constrained PBUC problem is represented in Fig. 3.

RESULTS AND DISCUSSION

The goal of this study is to solve the Profit-Based Unit Commitment (PBUC) problem for Generation Companies (GENCOs) in a deregulated environment**,** considering the incorporation of Renewable Energy Sources (solar and wind) and Plug-in Electric Vehicles (PEVs)**.** The optimization approach utilizes a Chaotic Sea Horse Optimizer (CSHO)**,** which is a nature-inspired algorithm based on the chaotic behavior of sea horses. This study aims to maximize GENCOs' profits by minimizing operational costs while fulfilling the power generation and reserve requirements, considering market conditions and uncertainties associated with RES and PEVs.

Table 1 Unit data for IEEE 39 bus test system

Quantities	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10
P_{max} (MW)	455	455	130	130	162	80	85	55	55	55
P_{min} (MW)	150	150	20	20	25	20	25	10	10	10
a ($/h)	1000	970	700	680	450	370	480	660	665	670
b ($/MWh)	16.19	17.26	16.60	16.50	19.70	22.26	27.74	25.92	27.27	27.79
c ($/MW^{2}h)	0.00048	0.00031	0.00200	0.00211	0.00398	0.00712	0.00079	0.00413	0.00222	0.00173
MUT (h)	8	8	5	5	6	3	3	1	1	1
MDT (h)	8	8	5	5	6	3	3	1	1	1
H_{cost} ($)	4500	5000	550	560	900	170	260	30	30	30
C_{cost} ($)	9000	10,000	1100	1120	1800	340	520	60	60	60
Initl Stu (h)	8	8	-5	-5	-6	-3	-3	-1	-1	-1

Table 2 Forecasted load demand and Market price for IEEE 39 bus test system

Hour (h)	Load Demand (MW)	Reserve Demand (MW)	Hour (h)	Load Demand (MW)	Reserve Demand (MW)
1	700	70	13	1400	140
2	750	75	14	1300	130
3	850	85	15	1200	120
4	950	95	16	1050	105
5	1000	100	17	1000	100
6	1100	110	18	1100	110
7	1150	115	19	1200	120
8	1200	120	20	1400	140
9	1300	130	21	1300	130
10	1400	140	22	1100	110
11	1450	145	23	900	90
12	1500	150	24	800	80

Table 2 Market clearing price and Reserve Price for 10 unit 24 hour test system

Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
MCP($)	21.63	20.59	19.72	21.73	21.73	21.73	21.73	21.73	21.73	21.73	21.73	21.73
MCR($)	32.45	30.88	29.58	32.59	32.59	32.59	32.59	32.59	32.59	32.59	32.59	32.59
Hour	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
MCP($)	23.72	23.72	23.72	23.72	20.26	21.98	21.98	21.98	21.98	21.98	20.35	21.38
MCR($)	35.58	35.58	35.58	35.58	30.40	32.97	32.97	32.97	32.97	32.97	30.52	32.08

Table 3 Data for solar irradiation and wind speed

Hour	**1**	**2**	**3**	**4**	**5**	**6**
G(W/m^2)	0	0	0	0	0	0
v (m/s)	16.94	8.8	5.0	8.8	11.89	5.0
Hour	**7**	**8**	**9**	**10**	**11**	**12**
G(W/m^2)	90	414	756	1819	1205	1006
v (m/s)	5.0	25.3	31.9	29.1	31..1	36.87
Hour	**13**	**14**	**15**	**16**	**17**	**18**
G(W/m^2)	4262	4982	3450	2428	718	36
v (m/s)	36.98	35.4	36.2	36.9	33.26	23.03
Hour	**19**	**20**	**21**	**22**	**23**	**24**
G(W/m^2)	0	0	0	0	0	0
v (m/s)	28.19	26.0	22.3	33.4	32.54	32.54

The input date of thermal units such as cost coefficients, generator limits, up/down time limits is showing Table 1. System load demand, reserve demand, energy and reserve price is shown in Table 2. The wind and solar data like wind, speed and irradiations are given in Table 3. The EVs charging/ discharging power is displayed in Table 4. The data of thermal, wind, solar and PEVs are taken from reference [10 -12].

Table 4 distribution of electric vehicles in 24 h where acting as sources and load

Hr (h)	**No of vehicles participated**	**Ev2G/ G2Ev output power**	**Hr (h)**	**No of vehicles participated**	**Ev2G/ G2Ev output power**
1	7204	-22.96	13	4714	15.03
2	5990	-19.09	14	5258	16.76
3	4914	-15.66	15	4730	15.08
4	6954	-22.16	16	6718	21.34
5	7892	-25.15	17	11,698	37.33
6	5498	-17.52	18	5158	16.27
7	4236	-14.08	19	5380	19.34
8	5368	28.32	20	15,918	50.73
9	9758	31.07	21	7798	24.98
10	7038	23.77	22	4894	-15.59
11	6438	20.56	23	11,058	-35.22
12	22,932	73.10	24	17,658	-56.28

The Chaotic Sea Horse Optimizer (CSHO) has been implemented with 50 population members, 10 system variable random numbers taken from 0 to 1 and 500 iterations. The algorithm works by simulating the chaotic movement of sea horses, which provides efficient search capabilities to find the global optimal solution in a complex, high-dimensional search space. The inclusion of chaotic search techniques ensures better exploration and exploitation of the search space compared to traditional methods. The simulation was performed using MATLAB 21.0 with an8 GB RAM system, providing an efficient platform for solving the optimization problem and obtaining meaningful insights.

Table 5 PBUC schedule integrated standard ten thermal, wind and solar system

Hour	T_1	T_2	T_3	T_4	T_5	T_6	T_5	T_8	T_9	T_{10}	W	S	EVs
1	1	1	0	0	0	0	0	0	0	0	1	0	0
2	1	1	0	0	0	0	0	0	0	0	1	0	0
3	1	1	0	0	0	0	0	0	0	0	1	0	0
4	1	1	0	0	0	0	0	0	0	0	1	0	0
5	1	1	0	0	0	0	0	0	0	0	1	0	0
6	1	1	0	1	0	0	0	0	0	0	1	0	0
7	1	1	1	1	0	0	0	0	0	0	1	1	0
8	1	1	1	1	0	0	0	0	0	0	1	1	1
9	1	1	1	1	1	0	0	0	0	0	1	1	1
10	1	1	1	1	1	1	0	0	0	0	1	1	1
11	1	1	1	1	1	1	0	0	0	0	1	1	1
12	1	1	1	1	1	1	0	0	0	0	1	1	1
13	1	1	1	1	1	1	0	0	0	0	1	1	1
14	1	1	1	1	1	0	0	0	0	0	1	1	1
15	1	1	1	1	0	0	0	0	0	0	1	1	1
16	1	1	1	1	0	0	0	0	0	0	1	1	1
17	1	1	0	1	0	0	0	0	0	0	1	1	1
18	1	1	0	1	0	0	0	0	0	0	1	1	1
19	1	1	0	1	0	0	0	0	0	0	1	0	1
20	1	1	0	1	0	0	0	0	0	0	1	0	1
21	1	1	0	1	0	0	0	0	0	0	1	0	1
22	1	1	0	1	0	0	0	0	0	0	1	0	0
24	1	1	0	0	0	0	0	0	0	0	1	0	0

The Table 5 shows the optimal unit commitment schedule, which allocates generation resources (thermal, RES, and EVs) across 24- hour time slots while considering the specific energy demands and reserve requirements. This table 6 reports the optimal power generation for each resource, such as Real Power, Reserve Power, Wind and Solar Power and PEVs Power. The combination of thermal generation, RES, and EVs allows GENCOs to meet demand with lower fuel costs, improving profit margins. The hourly power generation and percentage of power generation are graphically represented in Fig.4 and Fig.5. Total power generations of thermal, wind, solar and EV system are tabulated in Table 6.

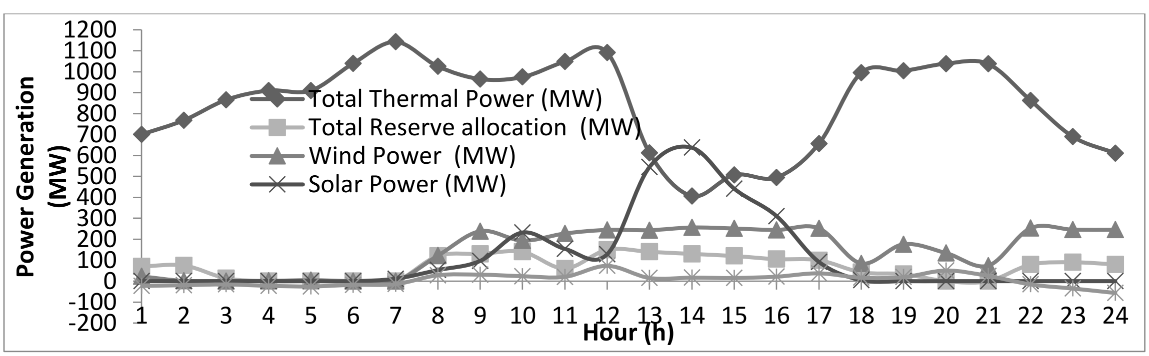

Fig. 4 Hourly Power generation of thermal with wind, solar and EVs

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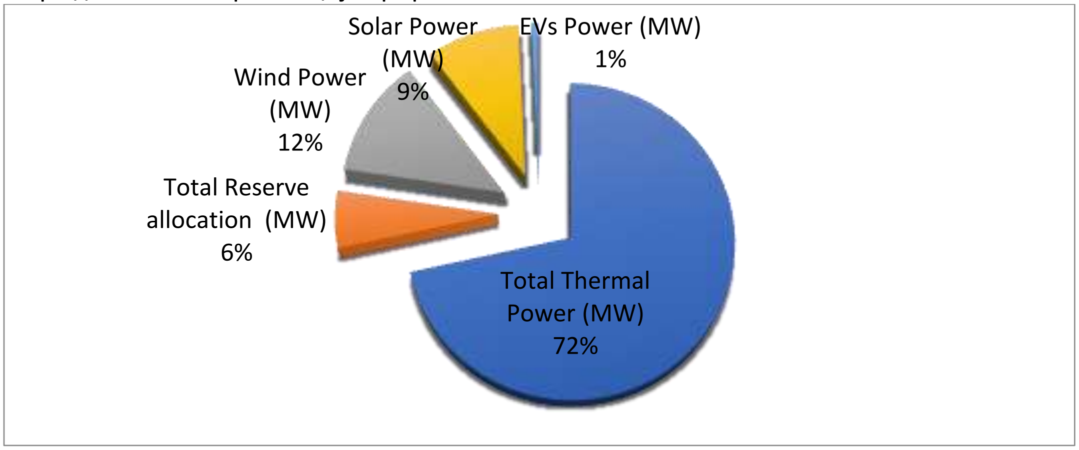

Fig. 5 Percentage of Power generation of thermal with wind, solar and EVs

Table 6 Simulation results of proposed test system

Hour	Power Demand (MW)	Reserve Demand (MW)	Total Thermal Power (MW)	Total Reserve allocation (MW)	Wind Power (MW)	Solar Power (MW)	EVs Power (MW)
1	700	70	700.2	70	22.76	0	-22.96
2	750	75	767.88	75	1.21	0	-19.09
3	850	85	865.56	13.6846	0.1	0	-15.66
4	950	95	909.987	0	1.21	0	-22.16
5	1000	100	909.8318	0	4.69	0	-25.15
6	1100	110	1039.429	0	0.1	0	-17.52
7	1150	115	1142.313	0	0.1	11.51	-14.08
8	1200	120	1025.276	120	121.77	52.95	28.32
9	1300	130	964.723	130	238.58	96.7	31.07
10	1400	140	974.216	140	193.5	232.28	23.77
11	1450	145	1047.741	60.4215	227.57	154.13	20.56
12	1500	150	1090.59	150	244.73	128.68	73.1
13	1400	140	611.4407	140	243.41	545.15	15.03
14	1300	130	406.6124	130	256.14	637.25	16.76
15	1200	120	507.3088	120	251.4	441.29	15.08
16	1050	105	495.0569	105	244.38	310.57	21.43
17	1000	100	656.0621	100	252.1	91.84	37.33
18	1100	110	994.6001	42.3089	84.53	4.6	16.27
19	1200	120	1004.381	33.7645	176.28	0	19.34
20	1400	140	1038.197	0	134.51	0	50.73
21	1300	130	1036.9	0	74.15	0	24.98
22	1100	110	862.54	78.8166	253.05	0	-15.59
23	900	90	689.37	90	245.85	0	-35.22
24	800	80	610.84	80	245.44	0	-56.28
Total Cost (Rs/24h)							**437218.40**
Total Revenue (Rs/24h)							**698642.70**
Total Profit (Rs/24h)							**261424.00**

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The simulation results of 10 thermal units integrated with equivalent wind, solar and EVs for a 24 -hour planning period are presented in same Table 6. It includes the revenue, total cost and profit of GENCOs and also graphically reported in Fig.6. The CSHO algorithm helps achieve this by minimizing the fuel and operational costs of thermal plants while maximizing the use of renewable and PEVs, which have lower operational costs. Including RES and EVs in the scheduling will likely reduce the total cost, as these resources typically have no or low operational costs (especially when compared to thermal plants). By leveraging these resources, GENCOs can also reduce their dependence on fossil fuels, leading to both cost savings and potential revenue from green energy incentives.

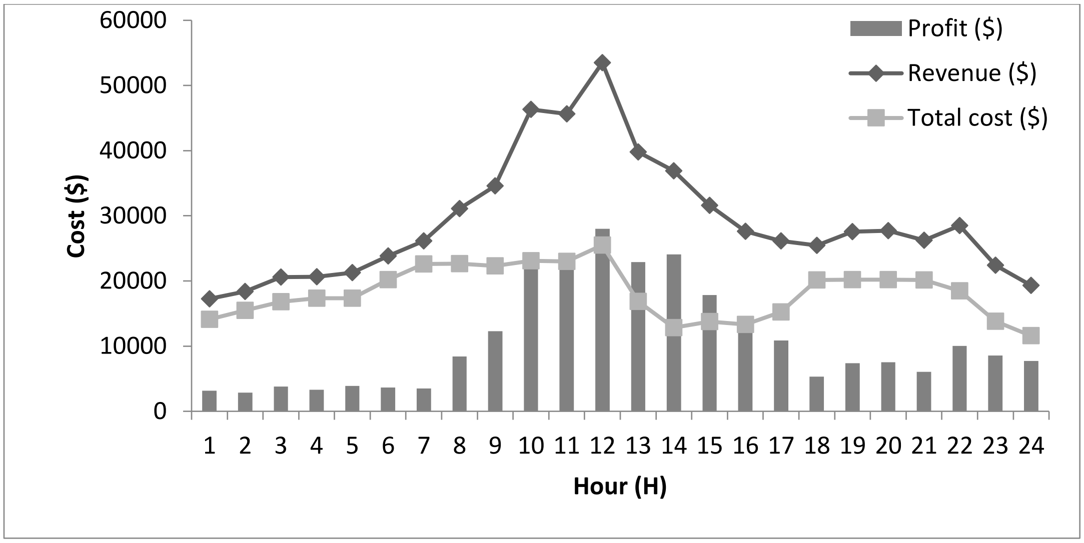

Fig6Revenue, total cost and profit 10 thermal with RES and EVs

Table 7 Comparison of Total profit of proposed method with the Existing methods

Different Cases	Method	Profit (Rs/24h)
PBUC	LR-method	95095.56
	Genetic algorithm	99058.00
	MPPD – ABC	105446.60
	Artificial immunize system (AIS)	105869.70
	GA-AIS	107317.60
	EMA	111078.50
	IALO	111205.90
	CSHO (Proposed)	**115847.00**
PBUC with RES and EVs	IPPD- AHP	239884.00
	CSHO (Proposed)	**261424.00**

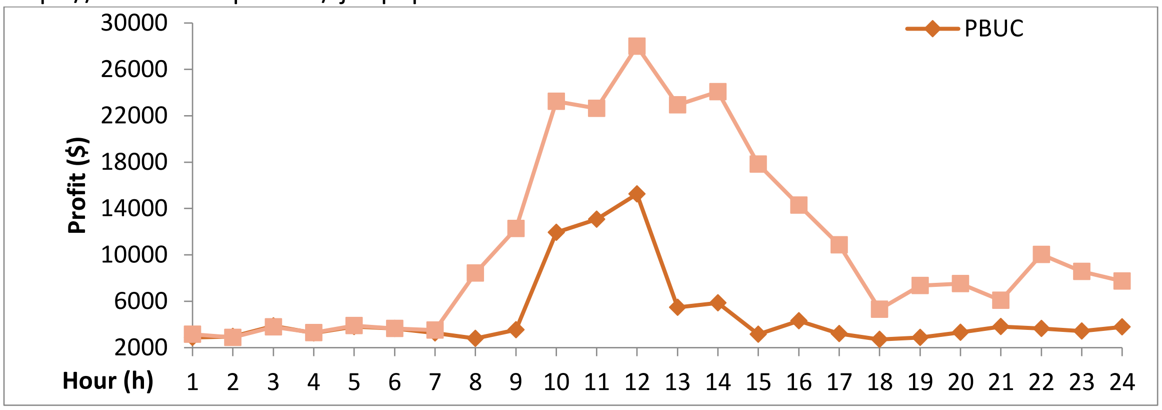

Fig.7 Comparison of profit of with and without integration of RES and EVs

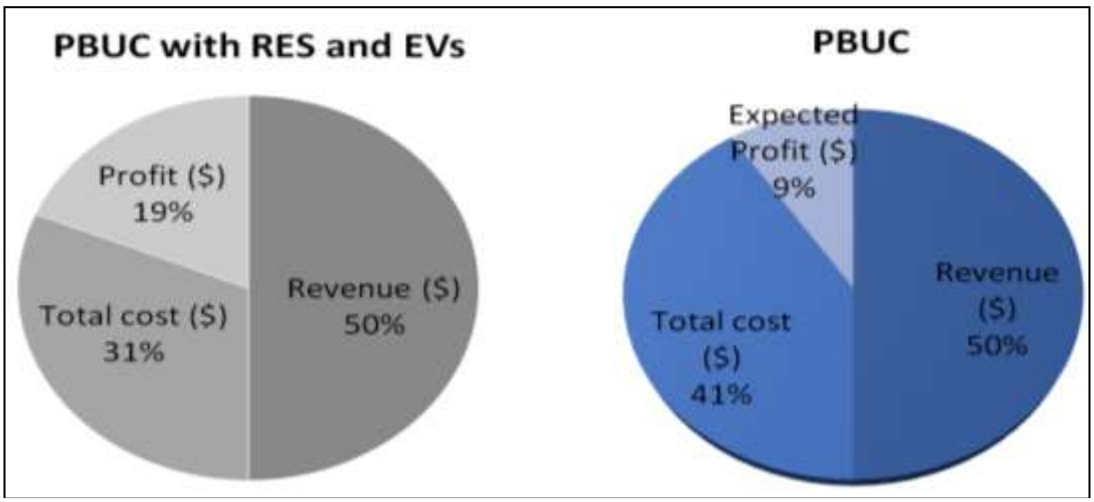

Fig 8 Cost- Benefit analysis of PBUC with and without RES and EVs

The CSHO enhances the traditional Seahorse Optimizer (SHO) by incorporating chaotic dynamics (e.g., logistic map), which improves solution diversity and convergence behavior. The chaotic component introduces a controlled random ness that helps avoid premature convergence and local optima traps, a known issue in metaheuristics like GA, PSO, and ACO. The obtained results are compared with and without RES and EVs and given in Table 6. The hourly profits of GENCOs are compared with and without integration of RES and EVs are shown in Fig. 7. It is also represented in the Pie-chart representation and shown in Fig. 8. From Fig. 8, the profit is 10% improved when considering the RES and EVs in the thermal units. From the comparison, the proposed method provides more profit with less computational time compared with other existing approaches.

CONCLUSION

In this study, a novel Chaotic Sea Horse Optimizer (CSHO) algorithm has been successfully developed and applied to solve the Profit-Based Unit Commitment (PBUC) problem for generation companies (GENCOs) operating in a deregulated electricity market. The approach uniquely integrates Plug-in Electric Vehicles (PEVs) and Renewable Energy Sources (RES), reflecting the dynamic and uncertain nature of modern power systems. By adopting chaotic maps within the Sea Horse Optimizer framework, the CSHO enhances exploration and exploitation capabilities, effectively avoiding local optima and achieving faster convergence. Numerical example with the IEEE-39 bus test system (10 thermal units with a 24-hour test system) with an equivalent wind, solar and PEVs system.

The proposed methodology demonstrates several key contributions and findings:

- Effectively Integrates the PEVs and RES:
- Price based scheduling of thermal, wind, solar and PEVs
- Cost-Benefit analysis of GENCOs
- Enhanced profit of GENCOs
- Robustness and Superiority of CSHO
- Adaptability to Deregulated Markets
- Minimized Environmental emissions.
- Comparative study with other existing approaches.

The proposed method provides maximum profit with a minimum total operating cost for the GENCOs. Comparative study was also made to analyze the performance of the CSHO approach. From the results, it can be concluded that CSHO is a promising optimization technique for the solution of complex optimization problems.

REFERENCES

1. Abdi, H. (2021). Profit-based unit commitment problem: A review of models, methods, challenges, and future directions. *Renewable and Sustainable Energy Reviews*, *138*, 110504.
2. Nepomuceno, L. S., de Oliveira, L. M., da Silva Junior, I. C., de Oliveira, E. J., & de Paula, A. N. (2023). Modified Genetic Algorithm for the Profit-Based Unit Commitment Problem in Competitive Electricity Market. *Energies*, *16*(23), 7751.
3. Prabakaran, S., SenthilKumar, V., & Kavaskar, S. (2017). Hybrid particle swarm optimization algorithm to solve profit based unit commitment problem with emission limitations in deregulated power market. *Int. J. Comput. Appl*, *167*(5), 37-49.
4. Reddy, S., Panwar, L. K., Panigrahi, B. K., Kumar, R., & Alsumaiti, A. (2019). Binary grey wolf optimizer models for profit based unit commitment of price-taking GENCO in electricity market. *Swarm and evolutionary computation*, *44*, 957-971.
5. Anbazhagi,T., Asokan, K., and Ashok Kumar, R., (2020), Hydro-Thermal-Wind Integrated Optimal Generation Scheduling of GENCOs in a Competitive joint Energy and Reserve Market, *GEDRAG & ORGANISATIE REVIEW*, Vol. 33(2), pp. 942- 962.
6. Senthilvadivu, A., Gayathri, K., & Asokan, K. (2019). Modeling of bidding strategies in a competitive electricity market: A hybrid approach. *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields*, *32*(5), e2594.
7. Senthilvadivu, A., Gayathri, K., & Asokan, K. (2018). Exchange Market algorithm based Profit Based Unit Commitment for GENCOs Considering Environmental Emissions. *Int. J. Appl. Eng. Res*, *13*, 14997-15010.
8. Kamalanathan, V., & Asokan, K. (2023). A Novel Approach Based Optimal Power Scheduling of GENCOs to Improve the Profit in Electricity Market Considering Wind Power Generation. *Indian Journal of Science and Technology*, *16*(36), 2952-2964.
9. Maghsudlu, S., & Mohammadi, S. (2018). Optimal scheduled unit commitment considering suitable power of electric vehicle and photovoltaic uncertainty. *Journal of Renewable and Sustainable Energy*, *10*(4).610-621.

10. Pan, J., & Liu, T. (2022). Optimal scheduling for unit commitment with electric vehicles and uncertainty of renewable energy sources. *Energy Reports*, *8*, 13023-13036.
11. Dhawale, P. G., Kamboj, V. K., Bath, S. K., Raboaca, M. S., & Filote, C. (2024). Integrating renewable energy and plug-in electric vehicles into security constrained unit commitment for hybrid power systems. *Energy Reports*, *11*, 2035-2048.
12. Nandi, A., & Kamboj, V. K. (2021). A meliorated Harris Hawks optimizer for combinatorial unit commitment problem with photovoltaic applications. *Journal of Electrical Systems and Information Technology*, *8*, 1-73.
13. Salman, D., Siyad, A. A., Kusaf, M., & Elmi, Y. (2024). Day Ahead Unit Commitment with High Penetration of Renewable Energy Sources and Electric Vehicle Charging Stations. *International Journal of Engineering Trends and Technology*, *72*(6), 361-379.
14. Vasiyullah, S. S., & Bharathidasan, S. G. (2021). Profit based unit commitment of thermal units with renewable energy and electric vehicles in power market. *Journal of Electrical Engineering & Technology*, *16*(1), 115-129.
15. Kumar, V., Naresh, R., & Sharma, V. (2022). Stochastic profit-based unit commitment problem considering renewable energy sources with battery storage systems and plug-in hybrid electric vehicles. *International Journal of Energy Research*, *46*(12), 16445-16460.
16. Singh, A., Sharma, V., Kumar, V., Naresh, R., Rahi, O. P., & Kumar, V. (2023). Investigation of PBUC problem with RES and EV in restructured environment. *Wind Engineering*, *47*(6), 1096-1109.
17. Lotfi, H., & Nikkhah, M. H. (2024). Multi-objective profit-based unit commitment with renewable energy and energy storage units using a modified optimization method. *Sustainability*, *16*(4), 1708.
18. Nandi, A., Kamboj, V. K., & Khatri, M. (2022). Hybrid chaotic approaches to solve profit based unit commitment with plug-in electric vehicle and renewable energy sources in winter and summer. *Materials Today: Proceedings*, *60*, 1865-1873.
19. Elkamel, M., Ahmadian, A., Diabat, A., & Zheng, Q. P. (2021). Stochastic optimization for price-based unit commitment in renewable energy-based personal rapid transit systems in sustainable smart cities. *Sustainable Cities and Society*, *65*, 102618.
20. Nazari, M. E., & Ardehali, M. M. (2017). Profit-based unit commitment of integrated CHP-thermal-heat only units in energy and spinning reserve markets with considerations for environmental CO2 emission cost and valve-point effects. *Energy*, *133*, 621-635.
21. Nandi, A., Kamboj, V. K., & Khatri, M. (2022). Hybrid chaotic approaches to solve profit based unit commitment with plug-in electric vehicle and renewable energy sources in winter and summer. *Materials Today: Proceedings*, *60*, 1865-1873.
22. Aribowo, W. (2023). A novel improved sea-horse optimizer for tuning parameter power system stabilizer. *Journal of Robotics and Control (JRC)*, *4*(1), 12-22.
23. Özbay, F. A. (2023). A modified seahorse optimization algorithm based on chaotic maps for solving global optimization and engineering problems. *Engineering Science and Technology, an International Journal*, *41*, 101408.