Profit based Unit Commitment Problem solving using Hybrid CUCKOO- GWO Algorithm

Manisha Hooda\textsuperscript{1}, Y K Awasthi*\textsuperscript{2}, Niharika Thakur\textsuperscript{1}, A S Siddiqui\textsuperscript{3}

\textsuperscript{1}High Power Electrical Laboratory, Department of Electronics & Communication Engineering, Manav Rachna University, Faridabad, HR, 121005 India
\textsuperscript{2}Department of Electronics & Communication Engineering, Manav Rachna International Institute of Research and studies, Faridabad, HR, 121005 India
\textsuperscript{3}Department of Electrical Engineering, Jamia Millia Islamia (Central University), New Delhi 110025, India
*yogendra@mru.edu.in

Abstract—This paper proposes a hybrid approach using cuckoo search ahead with GWO to resolve PBUCP for a restructured power market. Under this structure, the issues in profit are improved using objective functions such as maximize profit using revenue and the total cost of the system and system constraints such as power demand constraints, reserve constraints, generator, and reserve limits and a minimum up and downtimes are determined. Here, two types of test systems such as IEEE-30 bus and IEEE-75 bus system is utilized. After the determination of the above objective functions, a hybrid method called Cuckoo- GWO algorithm is used for optimization. The simulations are done to demonstrate the performance of the proposed technique. At last, the comparison of the proposed and existing algorithms is evaluated in terms of profit and total operating cost for IEEE 30 bus system of 6-units and IEEE 75 bus system of 15-units respectively.

Keywords—Deregulated environment, PBUCP, objective measures, Cuckoo –GWO algorithm.

Nomenclature

| Abbreviations | Description |
|---------------|-------------|
| UC            | Unit Commitment |
| PBUC          | Profit Based Unit Commitment |
| DR            | Demand Response |
| PL            | Priority List |
| BB            | Branch and Bound |
| LR            | Lagrangian relaxation |
| DP            | Dynamic Programming |
| GA            | Genetic Algorithm |
| DEA           | Differential Evolution Algorithm |
| PSO           | Particle Swarm Optimization |
| SFLA          | Shuffled Frog Leap Algorithm |
| QIEA          | Quantum-Inspired Evolutionary Algorithm |
| GSA           | Gravitational Search Algorithm |
| FA            | Fireworks Algorithm |
| BWOA          | Binary Whale Optimization Algorithm |
| BSCA          | Binary Sine–Cosine Algorithm |
| MBDE          | Modified Binary Differential Evolution |

1. INTRODUCTION

UC is an enhancement issue utilized to decide the schedule of operation for the generating units at consistently interim with changing burdens in various limitations and conditions [1]. Over the due course of time, especially over the past 10 years, PBUC increased significant intrigue and numerous streamlining strategies are proposed [2]. Typically, the UC is applied to limit the age cost by means of organizing the on/off states and yields that all units gives in specific scheduling horizon [3]. The general goal of the UC is to limit all out working the expense of framework while fulfilling the majority of the imperatives with the goal that a given security level can be met [4]. In a restructured power framework, the UC has an unexpected goal in comparison to that of UCP in a conventional domain and is alluded to as PBUCP [5].
The principle point of the restructuring strategy is to raise a challenge among various organizations, explicitly power generation companies (GENCOs), to give less expensive just as top-quality decisions for power clients [6]. In the restructured market GENCOs will effectively partake in at least one market, relying on the estimated day ahead costs and burden to amplify their benefit by considering the generator cost qualities thereby upgrades its age plan for the coming 24 h. The anticipated vitality and hold costs are critical contributions to a PBUC issue that are utilized to decide the GENCOs income, which influences the normal benefit (PF) [7]. In this way in the restructured power market showcases that the generating units booked to amplify their profit margin while submitting their units, it is not important to fulfill the power request [8].

DR can assume a significant job to diminish expenses related to discharge decrease exercises [9]. A study of writing on the UC issue uncovers that different numerical streamlining systems, for example, PL, BB methods, LR technique, DP and constraint logic programming were utilized to approach the UC issue [10]. As of late, different meta-heuristic techniques, for example, GA, DEA, PSO, SFLA, QIEA, GSA and FA, advanced by researchers so as to settle numerous non-direct power framework enhancement issues.

Among these, the new hybrid cuckoo-GWO is utilized to improve the profit using objective functions such as maximize profit and system constraints such as power demand constraints, reserve constraints, generator and power limits, minimum up and downtime constraints [11,12,13]. These meta-heuristic advancement techniques pull in lot of consideration due to their capacity to look through neighborhood ideal arrangements as well as the worldwide ideal arrangement and effectively managing different troublesome nonlinear imperatives [14]. The diagram structure of the paper is composed as pursues: Section-2 surveys the related works as for the proposed strategy. In section-3, a brief talk about the proposed methodology is presented, section-4 examines the preliminary outcomes and section-5 finishes up the paper.

2. LITERATURE REVIEW

2.1 Related Works

Srikanth Reddy K et al [15] his article exhibits a meta-heuristic approach, the BWOA, to explain unpredictable, obliged, non-raised, the PBUC (binary nature) improvement issues of a price taking GenCo in the power advertising. To reproduce the binary-nature PBUC issue, the consistent, genuine worth whale position or area is mapped into parallel hunt space through different exchange capacities. This article presents three variations of BWOA utilizing digressive hyperbolic, reverse digression and sigmoidal exchange capacities. The viability of the BWOA methodologies is inspected in test frameworks with various market systems, for example, a vitality just market, and vitality and hold advertise cooperation with various save installment strategies.

Himanshu Anand et al [16] shows a method based on BSA and CSO to exhibit profit 15 based PBUC issue. This methodology 21 diminishes the computational weight while looking through the ideal unit status. The age 22 calendar from the submitted unit is looked by the CSO system. The CSO is a coordinated 23 procedure of PSO and society humanized calculation (SCA) method.

K Srikanth Reddy et al [17] The GENCO tackles PBUC issue in the day-ahead market of vitality and hold advertises by duty and booking of warm units with a goal of profit expansion at the arrangement of given cost and burden estimates. In this way, the arrangement quality and adequacy of the PBUC improvement issue assume an imperative job in guaranteeing the most extreme comes back to the GENCO. This paper introduces a scientific model-propelled heuristic methodology called BSCA for tackling the PBUC issue.

Jatinder Singh Dhaliwal et al [18] show a MBDE motivated by the possibility of the esteem of conveyance and differential development calculations to understand the multi-compelled unit responsibility issue. The refreshing technique of standard DE is held in the given MBDE so the magnificent attributes of DE, for example, simple execution and parameter tuning, are acquired. Another likelihood estimator administrator is applied in MBDE, which proficiently protects the decent variety of the populace and lift the worldwide inquiry capacity. Further, this paper additionally investigates different need techniques dependent on unit attributes in unit planning and distributing the ability to submitted units.

K Srikanth et al [19] showed a model based on “quantum propelled binary grey wolf optimizer” (QI-BGWO) to resolve a UC issue. The approach followed by wolves for updating the positions at different powerful structure levels are supplanted by “Q-bit's individual probabilistic delineation” near to noteworthy turn edge and sort out change portal.
2.2 Contribution

In the existing work, the profit and operating cost of the system is poor, it is improved in the proposed work only. Therefore, the different objective constraints under UCP are utilized. The main contribution of the proposed work is given below:

- Objective functions such as maximize profit using revenue and the total cost, system cost and system constraints such as power demand constraints, reserve constraints, generator, and reserve limits and the minimum up and downtimes are determined.
- There are two test systems like IEEE 30 and IEEE 57 bus systems are utilized.
- The optimization using a hybrid method called Cuckoo-GWO algorithms

3. PBUCP FOR DEREGULATED ELECTRICITY MARKET

In our work, a hybrid approach employing cuckoo search ahead with GWO to resolve PBUCP under the deregulated power market is proposed. In the initial step objective functions such as maximize profit using revenue and the total system cost and system constraints such as power demand constraints, reserve constraints, generator, and reserve limits and the minimum up and downtimes are determined. After the determination of the above objective functions, a hybrid method called cuckoo-GWO algorithms is used for optimization. The results are taken for the test systems such as "IEEE 30 bus and IEEE 75 bus system" is utilized. At last the proposed work is compared with the existing algorithm are evaluated.

![Flow diagram](image)

Fig. 1. The proposed work Flow diagram

3.1 Objective Measures

3.1.1 PBUCP

The GENCO’s profit is processed as the distinction of total revenue (RV) got from power and hold selling in the energy market and save the market individually. The primary goal of PBUCP is scientifically expressed as pursues:

$$\maximize \, PF = (RV) - (TOC)$$

(1)

Where $RV$ is depicted as “revenue” and the $TOC$ is “total operating cost”. The revenue can be calculated in an equation (2):

$$RV = \sum_{i=1}^{N} \sum_{t=1}^{T} (P_{SP,i} \cdot X_{it}) + \sum_{i=1}^{N} \sum_{t=1}^{T} (R_{PF,i} \cdot R_{i} \cdot X_{it})$$

(2)

Here, “SP” is the Forecasted spot cost” mentioned in $/MWh, $X_{it}$ is the “Status of the unit”, $R$ is the “Probability of the reserve units”, $PF_{i}$ is the “Forecasted reserve price” ($/MW), $P_{i}$ is the output power and $R_{i}$ is the “Reserve power of $i^{th}$ generator” at $t^{th}$ hour (MW), $N$ and $T$ are the total numbers of units and hours.

The total operating cost is determined using equation (2a) is given below:

$$TOC = (1 - r) \sum_{i=1}^{N} \sum_{t=1}^{T} F(P_{i} \cdot X_{it}) + r \sum_{i=1}^{N} \sum_{t=1}^{T} F(P_{i} + R_{i} \cdot X_{it}) + ST \cdot X_{it}$$

(2a)
Here “ST” is start-up cost ($) and \( F(p_i) \) is the cost of fuel for \( i^{th} \) generating unit. The fuel cost of the equation is given in (3)
\[
F(p_i) = a_i + b_i P_n + c_i P_n^2
\]
Where, \( a_i, b_i, c_i \) are coefficients of fuel cost for \( i^{th} \) generating unit. The start-up cost of \( i^{th} \) generating unit is given in equation (4)
\[
ST_i = \begin{cases} HSU_i, & T_{i,up} \leq T_{i,down} + T_{i,cool} \\ CSU_i, & T_{i,up} \geq T_{i,down} + T_{i,cool} \end{cases}
\]
Where “HSU\(_i\)” is the Hot start-up cost and “CSU\(_i\)” is the Cold start-up cost of \( i^{th} \) generating unit”.

3.1.2 System constraints

3.1.2.1. Power demand constraint (PD)
PD of PBUC is regularly communicated as
\[
\sum_{i=1}^{N} P_i X_i \leq D_i \quad t = 1, ..., T.
\]
Where \( D_i \) is forecasted power demand.

3.1.2.2. Reserve constraint (R)
The R is given in equation (6)
\[
\sum_{i=1}^{N} R_i X_i \leq SR_i \quad t = 1, ..., T.
\]
Where \( R_i \) is the reserve power generation of \( i^{th} \) unit; \( SR_i \) total reserve power demand.

3.1.2.3. Generator and reserve limits
A generating company needs to generate power within its limits.
\[
P_{i,\text{min}} \leq P_i \leq P_{i,\text{max}} \quad i = 1, ..., N.
\]
\[
0 \leq R_i \leq P_{i,\text{max}} - P_{i,\text{min}} \quad i = 1, ..., N.
\]
\[
R_i + P_i \leq P_{i,\text{max}} \quad i = 1, ..., N.
\]
Where, \( P_{i,\text{min}} \) and \( P_{i,\text{max}} \) are minimum and maximum points of confinement of \( i^{th} \) generator.

3.1.2.4. Minimum up/downtimes
The other operational requirement of thermal units involves the minimum up and downtimes related to responsibility activity. This can be communicated as:
\[
T_{i,up} \geq T_{i,lap}
\]
\[
T_{i,off} \geq T_{i,down}
\]
Where, “\( T_{i,lap}, T_{i,down} \)” are minimum values of up and down times of \( i^{th} \) the generator separately. The condition of this relation is given below:
\[
X_{i,d} = \begin{cases} 1 \quad \text{if} \quad T_{i,up} \geq T_{i,lap} \\ 0 \quad \text{if} \quad T_{i,off} \geq T_{i,down} \text{or} \text{otherwise} \end{cases}
\]

A. Optimization using Hybrid Cuckoo-Gwo Algorithm
This method is based on the way the cuckoo bird search to find best appropriate home for laying their eggs so as to expand endurance rate. Each cuckoo lays each egg in turn. The cuckoo arbitrarily picks the home situation to lay eggs utilizing conditions (13-14). Here the position is to learn to utilize the objective values from equation (1)
\[ V_{pq}^{new} = V_{pq}^{gen} + S_{pq} \times L'e_{vy}(\lambda) \times \alpha \]  \hspace{1cm} (13)

\[ L'e_{vy}(\lambda) = \left( \frac{\Gamma(1 + \lambda) \times \sin\left( \frac{\pi \times \lambda}{2} \right)}{\Gamma\left( \frac{1 + \lambda}{2} \right) \times \lambda \times S^{\frac{1 - \lambda}{2}}} \right) \]  \hspace{1cm} (14)

Where \( \lambda \) is consistent (1 < \( \lambda \) ≤ 3) and \( \alpha \) is an irregular number created among [-1, 1]. Additionally, \( s > 0 \) is the step that ought to be identified with the issue of interests sizes. If \( s \) is too huge, at that point, the new arrangement created will be excessively different from the previous arrangement. If it is too small, such a search isn't effective. The step size is determined to utilize the condition (15).

\[ S_{pq} = V_{pq}^{gen} - V_{pq}^{gen} \]  \hspace{1cm} (15)

Utilizing condition (13) the cuckoo picks the home, and lay egg which is assessed. The host feathered creatures distinguished the outsider egg and choose the best caliber egg among others, worth related with that nature of an egg, utilizing condition (16).

\[ Pr_{a} = (0.9 \times \text{Fit}_p / \max(\text{Fit})) + 0.1 \]  \hspace{1cm} (16)

Where, \( \text{Fit}_p \) is the fitness value of the solution \( p \) which is corresponding to the nature of egg in the home position \( p \). A totally new home utilizing condition (17).

\[ V_p = V_{p_{min}} + \text{rand}(0,1) \times (V_{p_{max}} - V_{p_{min}}) \]  \hspace{1cm} (17)

Where, \( V_{p_{min}} \) and \( V_{p_{max}} \) are the optimized parameter.

GWO: When structuring GWO, expect the fittest arrangement as the “alpha (a)”. Subsequently, the best arrangements are named “beta (b) and delta (d)”, individually. As referenced above, grey wolves surround prey during the chase. So as to numerically show surrounding conduct, the associated conditions are utilized as

\[ D = \left[ \hat{C}, \hat{X}_{\text{prey}}(t) - \hat{X}_{\text{Gwolf}}(t) \right] \]  \hspace{1cm} (18)

\[ \hat{X}_{\text{Gwolf}}(t + 1) = \hat{X}_{\text{prey}}(t) - \tilde{A} \tilde{D} \]  \hspace{1cm} (19)

Where, \( t \) shows the present iteration, \( \tilde{A} \) and \( \tilde{C} \) are coefficient vectors, \( \hat{X}_{\text{prey}} \) and \( \hat{X}_{\text{Gwolf}} \) are the grey wolf position vector.

The vectors \( \tilde{A} \) and \( \tilde{C} \) are determined as pursues:

\[ \tilde{A} = 2\hat{a} \tilde{r} - \hat{a} \]  \hspace{1cm} (20)

\[ \tilde{C} = 2\tilde{r}_2 \]  \hspace{1cm} (21)

Where, parts of \( \hat{a} \) are straightly diminished from 2 to 0 and \( \tilde{r}_2 \) are arbitrary vectors in the range 0 and 1.

Subsequently, the position of the grey wolf is updated around the prey inside the space in any irregular area using equations (18) and (19). The score and positions of the first three search agents can be updated using Equations. (22), (23) and (24), separately.

\[ \tilde{D}_{\text{alpha}} = \left[ \tilde{C}, \tilde{X}_{\text{alpha}} - \tilde{X} \right] \]  \hspace{1cm} (22)

\[ \tilde{D}_{\text{beta}} = \left[ \tilde{C}, \tilde{X}_{\text{beta}} - \tilde{X} \right] \]  \hspace{1cm} (23)

\[ \tilde{D}_{\text{delta}} = \left[ \tilde{C}, \tilde{X}_{\text{delta}} - \tilde{X} \right] \]  \hspace{1cm} (24)

The position vector of prey is determined is given below:

\[ \tilde{X}_1 = \hat{X}_{\text{alpha}} - \tilde{A}_1(\tilde{D}_{\text{alpha}}) \]  \hspace{1cm} (25)

\[ \tilde{X}_2 = \hat{X}_{\text{beta}} - \tilde{A}_2(\tilde{D}_{\text{beta}}) \]  \hspace{1cm} (26)

\[ \tilde{X}_3 = \hat{X}_{\text{delta}} - \tilde{A}_3(\tilde{D}_{\text{delta}}) \]  \hspace{1cm} (27)
The best position is determined using equation (28) is given below:
\[
\hat{X}(t+1) = \frac{\hat{X}_1 + \hat{X}_2 + \hat{X}_3}{3}
\] (28)

In figure 2 the Cuckoo and GWO algorithm of fitness value for given objective functions are evaluated. Then the fitness value of both algorithms is compared to give the best solutions. The combination of both algorithms is called hybrid model is given in section A.

![Flow chart of hybrid Cuckoo-GWO Algorithm](image)

**Fig.2. Flow chart of hybrid Cuckoo-GWO Algorithm**

4. **RESULT AND DISCUSSION**

The implementation of the proposed work is accomplished using MATLAB platform. Simulations are done by utilizing "two test systems (IEEE 30 and 75 bus systems)". The first system comprises of six generating units, 12-hours scheduling periods where as the second system comprises of fifteen generating units, 24-hour scheduling periods. Here, the PBUCP objective function and system constraints for the proposed and existing algorithm are determined. The comparison of existing algorithms i.e BWOA, LR-DE with the proposed is done.

4.1 **Example of our proposed method illustration**

The operating cost and the profit of the proposed and existing for the these two test bus system is given below:

**Table1: Operating Cost of the proposed work using IEEE 30 bus System for 12–hour period**

| Hour | Demand | Operating cost of the existing Methods | Operating cost of proposed Method |
|------|--------|---------------------------------------|---------------------------------|
|      |        | BWOA  | LR-DE   |                                |
| 1    | 166    | 702.6 | 531.4   | 126.5                          |
| 2    | 196    | 743.4 | 570     | 352.9                          |
| 3    | 229    | 496.3 | 300     | 103.6                          |
In table 1 the operating Cost of the proposed work using IEEE 30 bus system for 12–hour period is given. The demand is considered as 166, 196, 229, 267, 283.4, 272, 246, 213, 192, 161, 147, and 160. For the 12-hour period the operating cost is determined. The table 1, It is shown that the proposed work has small operating cost when compared to other algorithms.

Table 2: The operating cost of the proposed work using IEEE 75 bus System for 24–hour period

| Hour | Demand | Operating cost of existing Methods | Operating cost of proposed method |
|------|--------|----------------------------------|----------------------------------|
| 1    | 3352   | 708.9                            | 537.7                            |
| 2    | 3384   | 752.3                            | 570                              |
| 3    | 3437   | 508.5                            | 300                              |
| 4    | 3489   | 582.1                            | 390                              |
| 5    | 3659   | 422.3                            | 215.7                            |
| 6    | 3849   | 1620.5                           | 1350                             |
| 7    | 3898   | 1680.3                           | 1380                             |
| 8    | 3849   | 1306.6                           | 990                              |
| 9    | 3764   | 1208.1                           | 810.4                            |
| 10   | 3637   | 1271.9                           | 829.8                            |
| 11   | 3437   | 1220.4                           | 817.4                            |
| 12   | 3384   | 1437.2                           | 945                              |
| 13   | 3357   | 1498.1                           | 975                              |
| 14   | 3394   | 1582.5                           | 1082.34                          |
| 15   | 3616   | 1602.23                          | 1182.90                          |
| 16   | 3828   | 1782                             | 1202.1                           |
| 17   | 3828   | 1808                             | 1282                             |
| 18   | 3786   | 1969                             | 1329                             |
| 19   | 3659   | 2079                             | 1482.9                           |
| 20   | 3352   | 2176                             | 1522                             |
| 21   | 3394   | 2212.8                           | 1672                             |
| 22   | 3334   | 2389                             | 1789                             |
| 23   | 3329   | 2456                             | 1832                             |
| 24   | 3348   | 2572                             | 1906                             |

In table 2 the operating Cost of the proposed work using the IEEE 75 bus system for a 24–hour period is given. The demand is considered as 3352, 3384, 3437, 3489, 3659, 3849, 3898, 3849, 3764, 3637, 3437, 3384, 3357, 3394, 3616, 3828, 3828, 3828, 3659, 3352, 3394, 3334, 3329 and 3348. For a 24-hour period, the operating cost is determined. The table 2 depicts that the operating cost of our work is small compared to the existing algorithms.
In figure 3 the operating Cost of the proposed work using the IEEE 30 bus System for 12–hour period is plotted. Compare to the existing algorithm like BWOA and LR-DE the proposed operating Cost is small to provide a better result.

In figure 4 the operating Cost of the proposed work using IEEE 75 bus System for 24–hour period is plotted. Compare to the existing algorithm like BWOA and LR-DE the proposed operating Cost is small to provide a better result.

Table 3: profit for IEEE 30 bus System of 6 generating units for the existing and proposed algorithm

| Methods   | profit       |
|-----------|--------------|
| BWOA      | 107838.57    |
| LR-DE     | 112818.93    |
| PROPOSED  | 128764.47    |

In table 3 the Profit of PBUC for the proposed and existing algorithm for the 6-unit of the IEEE 30 bus system for 12 hours is given. The proposed profit value is 128764.47 is determined. The other existing such as BWOA is 107838.57 and the hybrid LR-DE is 112818.93 is determined. Compare to the existing algorithm like BWOA and LR-DE the proposed profit is high to provide a better result.

Table 4: profit for IEEE 75 bus System of 15 generating units for the existing and proposed algorithm
Table 4: Profit of PBUC for the 15-unit of the IEEE 75 bus system for 24 hours.

| Methods | Profit       |
|---------|-------------|
| BWOA   | 1587353.66  |
| LR-DE  | 172537928   |
| PROPOSED | 1892426.92 |

In table 4 the Profit of PBUC for the given work and other algorithm for the 15-unit of the IEEE 75 bus system for 24 hours is given. The profit value for the purposed algorithm is 1892426.92. The other existing algorithms such as BWOA has profit value 1587353.66 and the hybrid LR-DE has profit value 172537928. As Compared with the existing algorithm like BWOA and LR-DE, the proposed method has high profit and thus provide a better result.

4.2 Evaluation and comparison

The profit of the proposed and existing for the "IEEE 30 bus System and IEEE 75 bus system" is given below:

Fig. 5. Profit of PBUC for the proposed and existing algorithm for the 6-units of IEEE 30 bus system for 12-hour

Fig. 6. Profit of PBUC for the proposed and existing algorithm for the 15-units of IEEE 75 bus system for 24 hour

In figure 5, the Profit of PBUC for the proposed and existing algorithm for the 6-units of the IEEE 30 bus system for 12 hours is plotted. In comparison with the existing algorithm like BWOA and LR-DE, the profit of proposed algorithm is high to provide a better result. In figure 6 the Profit of PBUC for the proposed and existing algorithm for the 15-units of the IEEE 75 bus system for 24 hours is plotted. In comparison with the existing algorithm like BWOA and LR-DE, the proposed algorithm profit is improved.
5. Conclusion

The Profit based UC problem is solved utilizing hybrid cuckoo search – GWO algorithm under the deregulated environment. To achieve this, at first different objective parameters, for example, maximize profit using revenue and total operating cost of the system and system constraints such as power demand constraints, reserve constraints, generator, and reserve limits and the minimum up and downtimes are determined. After that, the objective functions of the proposed work are improved using a hybrid cuckoo search – GWO algorithm. The competency of the proposed work has been investigated on IEEE 30 bus system of 6-units for 12 hours period and for the IEEE 57 bus system of 15-units for 24 hour duration. The results of this work are justified by comparing with the other existing algorithms used to solve the "PBUCP". Further, the results of simulation of cuckoo search – GWO algorithm shows better results over "BWOA and LR-DE algorithm".

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