A Novel Improved HBMO Algorithm Regarding Generation Expansion Planning in Deregulated Energy Networks

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Abstract— *Electric energy demand is increasing rapidly in developing countries, making the installation of additional generating units necessary. Private generating stations are encouraged to add new generations in deregulated energy networks. Planning for transmission expansion must ensure increased market competition while maintaining high levels of dependability and system operation safety. New objectives and demands have been made for the transmission expansion issue as a result of the deregulation of the energy network. This study has attempted to provide a new population-base algorithm; called Modified Honey Bee Mating Optimization (MHBMO) for expansion development in deregulated energy systems that are applied in multi-objective processes. In addition, to diminish the elaborateness of the issue the benders decomposition is used in this study which categorize the original issue into two subproblems. First maximizing the profits of each PBGEP (GENCO) and second, satisfying security network constraints (SCGEP). Therefore, using the suggested MHBMO algorithm, value of each GENCO's profit and overall profit could be obtained. To demonstrate the viability and capabilities of the suggested algorithm, the planning methodology has been evaluated using the IEEE 30-bus test system. The results of the current study served as an example of the effectiveness of the suggested methodology.*

Keywords— *Benders Decomposition, Generation Expansion Planning, MHBMO, optimization.*

NOMENCLATURE

Parameters

δ_{bt}	CO_2 emission acceptable limit in year t
κbt	Curtailment acceptable level in year t
Δ	Threshold of convergence
εbt	EENS' acceptable level
B	Load blocks' number
Capi	Unit i capacity
CCjbt	Cost coefficient of curtailment for load j in year t at load block b
CG	Candidate units' number
CIit	Investment in candidate unit i throughout the course of the year t
Cit	Year t's capital investment
CS	Candidate sites' set
CTi	Construction time frame required for candidate unit i
Dkm	Line k's sensitivity to bus m's generation
DTbt	Load block b duration in year t
EG	Existing units' number
Eibt	Unit i CO_2 emission amongst committed units in year t at load block b
FOMi	Unit i fixed O&M cost
ND	Load points' number
NG	Committed units' number
NL	Transmission lines' number
OCibt	Unit i operating cost amongst committed units in year t
PD,bt	Estimated system load in year t
PD,jbt	Estimated load point j in year t

PGi	Maximum Upper limit of unit i generation
PGi	Minimum Lower limit of unit i generation
PL,bt	Necessary system load in year t
PLk	Capacity of Line k
PR,bt	Estimated system reserve in year t
T	Plan horizon
TCk	The charge of transmission of line k
$ULACt$	Maximum amount of newly added generating capacity for the year t
$ULAUt$	Maximum number of units to be added in year t

Indices

φ	Scenario
b	Load block
I	Candidate unit or existing
j	Load point
k	Line of transmission
m	Bus
n	Trial
t	year of planning

Variables

Eit	State variable related to current unit i in year t; 0: out of service, 1: on service
$Iibt$	Unit i Commitment in year t at load block b; 0: out of service/decommitted, 1: committed.
PC, jbt	Load j curtailment in year t at load block b
PG,ibt	Committed unit i dispatched capacity in year t at load block b
PL,kbt	At load block b, line k flow in year t
Rbt	Sale cost of electricity in year t at load block b
Xit	State variable related to candidate unit i in year t; 0: rejected. (Xi (t−1) _ Xi t), 1: selected.

Dual variables

λ^n_{ibt}	Marginal drop in unserved energy with a 1MW rise in candidate unit i in year t
μ^n_{ibt}	Marginal drop in unserved energy with a 1MW rise in commitment unit i in year t
π^n_{ibt}	Marginal drop in profit with a 1 MW rise in candidate unit i in year t

1. INTRODUCTION

By reorganizing the current energy market, energy deregulation aims to increase competitiveness and prevent energy monopolies. This expanding trend enables consumers to select from a variety of energy suppliers based on rates that meet their demands and unique product offers. Reverse auctions, in which each company offers to sell its energy at the lowest price feasible, are how energy deregulation operates. Independent agencies buy the energy needed to meet the predicted demand and then determine the best rates for their clients [1, 2]. Hence, while growing electrical loads, to accelerate and enhance competition, generation expansion planning (GEP) must be conducted regularly. This study, mainly attempted to investigate the optimization and planning within restructured energy systems. To enhance the effectiveness of this system, a majority of factors should be included like load alternations, limitation of generator capacity, the restriction of line distribution, voltage regulation, limitation of despicable load, the expense of generation rescheduling, the expense of load diminishes, contacts of multilateral energy which are shaped and are taken as a restriction. Consequently, the designer could delineate a program for the most affordable transmission regarding the specific reliability standards [3–5]. Recently, composite energy system expansion planning through vastly accessibility to transmission access has been a controversial topic in the industry of electricity power [6–8]. Accessibility of electric market has revolutionized traditional monopolistic electricity markets and created competitive markets [9]. The main factors for success in business in a competitive market are delivered power expense and power supply qualification, such as voltage quality and stability of supplements. Also, the orientation toward purchasers' requirements and preparedness to purchase a quality is a critical factor in competitive environment [10]. Because of the fact that generation and transmission sector highly influence the consistency on energy systems and results in high expenses and operation–associated sections, economic and technical restrictions are taken into account in the promotion of sections [9–11]. Therefore, it aimed to diminish the investment rate for a new tool to present a load based on an optimal level of consistency which in turn present operating conditions. In order to investigate the issues in Refs. [12, 13], different methods namely branch and bound, Bender decomposition, Genetic Algorithms (GA), sensitivity resolution have been employed. One of the strategic plans that every country needs to implement is the GEP. Its goal is to reduce system cost (investment and operating expenses) while still meeting system demands (least cost analysis). Many prior notions are redefined as a result of the restructuring of energy systems. Each GENCO, in the newly organized environment, seeks to maximize its profit whilst independent system operator (ISO) monitors the security and reliability of the systems [4]. Since minimum cost does not equal maximum profit, analysis of least cost cannot address all of GEP's aspects. The GEP is therefore a nonlinear mixed integer problem with multiple constraints [14]. So, it will be quite challenging to solve this issue. Furthermore, the relationship between GEP and transmission expansion planning (TEP) can be another effort for designers [15]. In order to solve this complex issue, the Benders' decomposition along with different optimization methods including decomposition method [16–19], GA [20–23], as well as artificial neural networks [24–28], etc. have been were used. In the present research, Benders' decomposition was implemented to decouple the main issue into two discrete problems. Regarding above discussions, Modified Honey Bee Mating Optimization (MHBMO) was presented to obtain the final optimal solution. The characteristics and benefits of MHBMO algorithm, including fleeing from regional optima snares, appropriate robustness, universal optimization, modest mechanism and fast convergence ability, will turn MHBMO method into an outstanding optimization method. Finally, a 30-bus test system is used to test and validate the proposed planning algorithm.

2. MATERIAL AND METHODS

2.1. Description of the model

This study categorized the load duration diagram predicted for a planning period into several load blocks. Three load blocks—peak, medium, and base—are used, as shown in Fig. 1. The marginal expense of the highly costly unit presenting the safety of a system, is considered as the pseudo market clearing price (MCP). And for the simulation of MCP, the security-constrained unit commitment (SCUC) algorithm is applied.

Fig. 2 demonstrates the decomposition pattern for fixing GEP within restructured energy networks.

2.2. Expansion planning of cost-based generation

Every GENCO should begin its planning procedure to optimize its profit after assessing their expansion value while also taking future load into consideration. Throughout this research, profit is described as the difference between cost and revenue. In advance to planning of GENCOs, the generated data should be prepared. The data of available and candidate units is comprised of unit type (coil, gas), unit life, unit size, limits on the additional unit per type, building duration, constant expense of units, flexible expense of operation costs, forced outage rate of every unit, and each GENCO's CO_2 emission. So, the PBGEP equation is presented
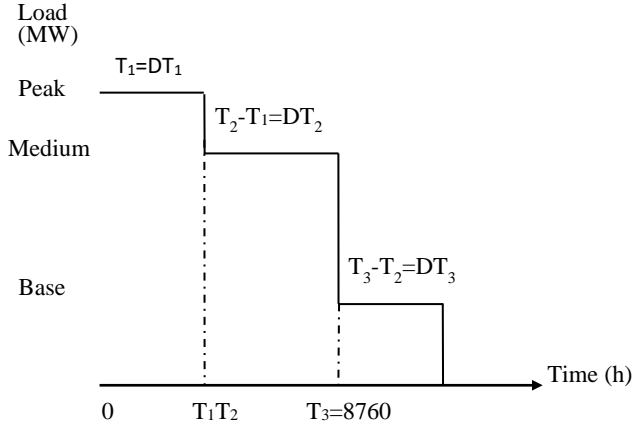
Fig. 1. A planning year's load duration curve

below [29]:

$$
\begin{aligned}
minY = & -E\left\{\sum_{t=1}^{T}\sum_{b=1}^{B} DT_{bt}\left[\sum_{i=1}^{NG}\left(R_{bt}\,P_{G,ibt}-OC_{ibt}\right.\right.\right. \\
& \left.\left.*P_{G,ibt}\right)-\sum_{j=1}^{ND} CC_{jbt}\,^{*}P_{C,jbt}\right]\right\} \\
& -\sum_{t}^{T}\sum_{i}^{CG} CI_{it}*\left(X_{it}-X_{i(t-1)}\right) \\
& -\left(\sum_{t}^{T}\sum_{i}^{CG}\left[FOM_{i}\,^{*}X_{\widehat{it}}\right]\right. \\
& \left.-\sum_{t}^{T}\sum_{i}^{EG}\left[FOM_{i}*1\right]\right)
\end{aligned}
$$
$$(1)$$

$$\sum_{j=1}^{CG} CI_{it}*\left(X_{it}-X_{i(t-1)}\right)\leq CI_{t}, t=(1,2,...,T) \tag{2}$$

$$\sum_{j=1}^{CG} cap_{it}*\left(X_{it}-X_{i(t-1)}\right)\leq ULAC_{t}, t=(1,2,\dots,T) \tag{3}$$

$$\sum_{j=1}^{CG}\left(X_{it}-X_{i(t-1)}\right)\leq ULAC_{t}, t=(1,2,\dots,T) \tag{4}$$

$$X_{it}=0, if; t<CT_{i}, (i=1,2,\dots,PG)(t=1,2,\dots,T) \tag{5}$$

$$\sum_{i=1}^{EG} cap*E_{u}+\sum_{i=1}^{\infty} cap_{i}*\left(X_{it}-X_{i(t-1)}\right)\geq P_{D,bt}+P_{R,bt} \tag{6}$$

$$X_{A1t}+X_{B1t}\leq 1 \tag{7}$$

$$X_{A1t}=X_{A2t}=\cdots=X_{Amt}\ \ (t=T) \tag{8}$$

$$X_{A1t}=X_{A2t}=\cdots=X_{Ant}\ \ (t=T) \tag{9}$$

This section yields the size, type, and time for adding extra units, that serve as the inputs for the following part.

2.3. Safety-restricted production expansion planning

A) MHBMO sub-issue

In this sub-problem, ISO examines each GENCO's planning proposals to ensure that they are within an acceptable range. If each GENCO's plans fit within the parameters of the MHBMO output, ISO approves them and moves onto the subsequent sub-problem. If not, ISO sends a safety signal to GENCOs to enhance their designs. To reach the ISO's intended plans, this process will be repeated.

B) Feasibility sub-issue

Following is a formulation of the feasibility sub-problem [30]:

$$DT_{bt}*\sum_{j=1}^{ND} P_{C,jbt}\leq\kappa_{bt} \tag{10}$$

$$E\left\{DT_{bt}*\sum_{j=1}^{ND} P_{C,jbt}\right\}\leq\varepsilon_{bt} \tag{11}$$

$$min\ E\left\{DT_{bt}*\sum_{j=1}^{ND} P_{C,jbt}\right\} \tag{12}$$

$$\sum_{i=1}^{NG} P_{C,jbt}(\varphi)+\sum_{j=1}^{ND} P_{C,jbt}(\varphi)=P_{L,bt}(\varphi) \tag{13}$$

$$P_{L,kbt}(\varphi)=D_{km}(\kappa)*\left[P_{G,ibt}(\varphi)+P_{C,ibt}(\varphi)-P_{D,jbt}(\varphi)\right], i,j\in m \tag{14}$$

$$0\leq P_{C,jbt}(\varphi)\leq P_{D,jbt}(\varphi) \tag{15}$$

regarding existing units,

$$P_{Gi,min}*E_{it}\leq P_{G,jbt}(\varphi)\leq P_{Gi,max}*(E_{it}) \tag{16}$$

regarding candidate units,

$$|P_{L,kbt}(\varphi)|\leq PL_{k,max} \tag{17}$$

If constraints of (11) and (12) aren't achieved, next Benders' cut are as the equation below:

- In case DTbt* ΣNDj=1PC, jbt≤κbt isn't met, the Benders' cut will be:

$$E\left\{DT_{bt}*\sum_{j=1}^{ND} P_{C,jbt}\right\}+\sum_{i=1}^{CG}\lambda_{ibt}^{n}P_{Gi,max}\left(X_{it}-X_{it}^{n}\right)\leq\varepsilon_{bt} \tag{18}$$

In order to achieve the *n*th trial investment design, the *n*=1 to $N-1$ Bender selects from the pre-existing repetitions which are included in the main issue of source design. The whole process should be iterated until a possible design is discovered for the achievement of the ISO's needs related to network consistency.

C) Security-constrained unit commitment (SCUC) sub-issue

The electricity MCP on design horizon should be computed before solving the operation issues. It is supposed that the MCP is the peripheral expense of the highly costly items within committed items according to the system safety [13]. The SCUC is formed as follows, and if errors continue, the matching Bender cut will be provided;

$$minF=\sum_{j=1}^{NG} OC_{jbt}*P_{G,ibt} \tag{19}$$

$$\sum_{i=1}^{NG} P_{G,ibt}(\varphi)+\sum_{j=1}^{ND} P_{C,jbt}(\varphi)=P_{L,bt}(\varphi) \tag{20}$$

$$\sum_{i=1}^{NG} P_{Gi,max}\,^{*}I_{it}\geq P_{L,bt}+P_{R,bt} \tag{21}$$

$$P_{L,kbt}(\varphi)=D_{km}(\varphi)^{*}\left[P_{C,jbt}(\varphi)+P_{C,jbt}(\varphi)-P_{D,jbt}(\varphi)\right], j\in m \tag{22}$$

$$\sum_{i=1}^{NG} P_{G,ibt}=P_{L,bt} \tag{23}$$

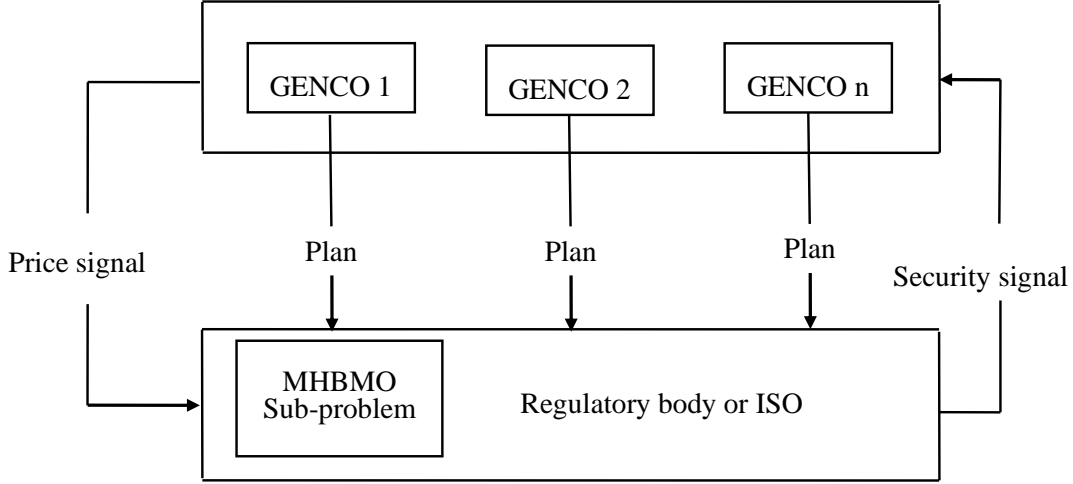$$\sum_{t=1}^{T}\left\{\sum_{i=1}^{NG} P_{G,ibt}E_{ibt}\right\}\leq\sigma_{bt} \tag{24}$$

Fig. 2. Generation expansion planning framework

$$0 \leq P_{C,jbt}(\varphi) \leq P_{D,jbt}(\varphi) \tag{25}$$

For candidate and existing units,

$$P_{Gi,min} * I_{it} \leq P_{G,ibt} \leq P_{Gi,max} * I_{it} \tag{26}$$

$$E\left\{DT_{bt} * \sum_{j=1}^{ND} P_{C,jbt}\right\} \leq \varepsilon_{bt} \tag{27}$$

$$DT_{bt} * \sum_{j=1}^{ND} P_{C,jbt} \leq \kappa_{bt} \tag{28}$$

Therefore, the infringement continues, the corresponding Bender cut would be:

- If $DT_{bt} * \sum_{j=1}^{ND} P_{C,jbt} \leq \kappa_{bt}$ is not achieved, the Bender cut will be:

$$E\left\{DT_{bt} * \sum_{j=1}^{ND} P_{C,jbt}\right\} + \sum_{i=1}^{CG} \mu_{ibt}^n P_{Gi,max}\left(I_{it} - I_{it}^n\right) \leq \varepsilon_{bt} \tag{29}$$

- If $E\left\{DT_{bt} * \sum_{j=1}^{ND} P_{C,jbt}\right\} \leq \varepsilon_{bt}$ is not achieved, the Bender cut will be:

$$E\left\{DT_{bt} * \sum_{j=1}^{ND} P_{C,jbt}\right\} + \sum_{i=1}^{CG} \mu_{ibt}^n P_{Gi,max}\left(I_{it} - I_{it}^n\right) \leq \varepsilon_{bt} \tag{30}$$

While fulfilling load demand, the SCUC's main challenge is then iteratively resolved choose the least-cost generation schedule.

D) Optimal operation sub-issue

After achieving the ideal network consistency level, computation of MCP, the equation of improved operation sub-issue for scenarios, load block as well as year will be:

$$minW_{st} = -E\left\{\sum_{t=1}^{T} \sum_{b=1}^{B} DT_{bt} * \left[\sum_{i=1}^{NG}\left(R_{bt} * P_{G;ibt}\right.\right.\right.$$
$$\left. - OC_{ibt} * P_{G,ibt}\right) - \sum_{k=1}^{NL} TC_k^* * P_{L,kbt}$$
$$\left.\left. - \sum_{j=1}^{ND}\left(CC_{jbt} * P_{C,jbt}\right)\right]\right\} \tag{31}$$

For committed existing units:

$$P_{Gi,min} \leq P_{G,ibt}(\varphi) \leq P_{Gi,max} \tag{32}$$

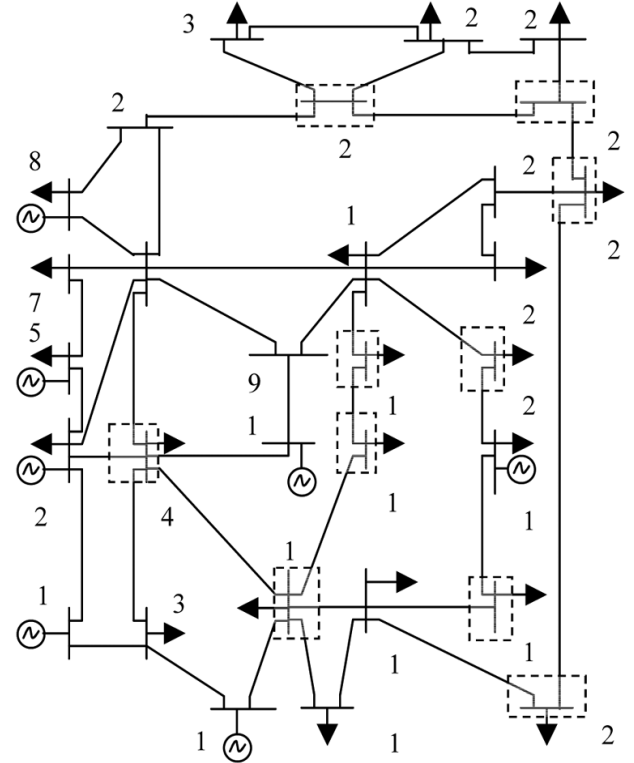

Fig. 3. IEEE 30 bus system

For committed candidate units:

$$P_{Gi,min} * X_{it} \leq P_{G,ibt}(\varphi) \leq P_{Gi,max} * X_{it} \tag{33}$$
$$|P_{L,kbt}(\varphi)| \leq PL_{k,max} \}$$

In relation to the nth trial solution, the ideal amount of operation cut will be:

$$Z \leq \sum\sum_b \left\{W_{bt}^n + \left[\sum_{i=1}^{CG} CI_{it} * \left(X_{it} - X_{i(t-1)}\right)\right.\right.$$
$$\left.\left. + \Pi_{ibt}^n P_{Gi,max}\left(X_{it} - X_{it}^n\right)\right]\right\} \tag{34}$$

Table 1. Outputs of MHBMO algorithm - each generator's contribution to the load

Load bus number	Load value (MW)	Generator contribution to load (MW)						
		G1	G2	G3	G4	G5	G6	G7
8	140	17.101	30.621	18.133	38.812	16.127	14.276	4.885
10	160	2.441	13.214	12.445	30.983	20.178	30.365	50.371
12	100	2.551	8.270	4.381	10.348	45.657	5.235	23.557
13	120	30.000	8.453	11.335	25.564	17.353	6.652	20.093
14	60	3.874	23.293	3.528	7.646	16.852	3.801	0.963
15	80	1.263	4.203	3.736	7.605	25.573	5.393	32.201
16	60	1.602	4.262	3.083	7.074	20.762	5.673	17.049
17	80	1.373	4.098	3.786	15.345	15.393	12.098	27.713
18	120	1.453	5.235	5.984	5.345	15.938	1.445	84.600
19	120	1.521	2.554	102.10	8.124	0.553	0.565	4.670
20	80	0.463	3.212	1.345	2.887	3.258	2.456	66.482
21	80	0.563	1.334	5.574	15.181	12.987	12.187	32.174
23	100	2.112	5.445	6.994	15.383	25.985	7.038	37.043
24	80	2.445	7.432	5.093	15.987	10.546	12.984	25.516
26	160	5.873	15.332	18.51	63.987	15.985	14.938	25.151
29	60	1.644	4.987	7.372	25.273	5.545	4.227	10.948
30	80	2.591	8.352	9.883	35.095	5.094	5.981	12.923
Overall generation (MW)		79.2990	149.9880	223.2690	330.9620	273.780	145.2050	477.4970

Table 2. MHBMO algorithm outputs for all buses

Bus Number	Load value (MW)	MHBMO Output
Eight	140.0	345.819
Nine	0.0	251.982
Ten	100.0	115.303
Eleven	0.0	280.273
Twelve	60.0	412.256
Thirteen	80.0	110.328
Fourteen	60.0	98.242
Fifteen	80.0	85.072
Sixteen	120.0	519.265
Seventeen	120.0	534.309
Eighteen	80.0	520.705
Nineteen	80.0	80.174
Twenty	100.0	501.232
Twenty-One	80.0	120.913
Twenty-Two	0.0	118.986
Twenty-Three	60.0	355.845
Twenty-Four	80.0	278.292
Twenty-Five	0.0	240.192
Twenty-Six	160.0	245.983
Twenty-Seven	0.0	226.286
Twenty-Eight	0.0	201.287
Twenty-Nine	60.0	215.127
Thirty	80.0	210.748

2.4. MHBMO algorithm

A) Standard HBMO

The HBMO algorithm is considered a type of optimization process which is taken from the conducts of bees while mating and reproduction [14]. Hence, the following equation is considered as the main aim of current study:

$$prob(Q, D) = e^{-\Delta(f)/S(t)} \qquad (35)$$

Regarding the above equation, $\Delta(f)$ is the absolute difference amongst the fitness of D (i.e., f (D)) and the fitness of Q (i.e., f (Q)), S(t) the queen speed at time t, and (Q, D) demonstrates the likelihood of added sperm of drone D to the spermatheca of queen Q. After every mating in space, the energy E(t) decrease and the

speed of queen S(t) will be:

$$S(t+1) = \alpha \times S(t) \ , \alpha \in [0,1] \qquad (36)$$

$$E(t+1) = E(t) - \gamma \ , \gamma \in [0,1] \qquad (37)$$

Here, basic phases of the HBMO algorithm are presented:
phase 1:
In this model, the algorithm commences while a queen (best answer) possibility chooses her mate from other male bees and ultimately begins to make offspring. Mating–flight commences it where a queen chose drones stochastically to create the sperm theca. Then, a drone is arbitrary chosen off this list to create broods.
Phase 2:
After mating flight by Eq. the algorithm begins (35). when the spermatheca (the queen's spermatheca size demonstrates the ultimate number of mating per queen) is enough, or while the speed and energy of the queen is roughly zero, the vital circumstances for the closure of mating are provided.
phase 3:
Children generation (global search): according Eq (38), children are born. The drones' genes and the queen are transferred to the *j*th individual on the basis of:

$$child = Drone + \beta(\ Queen - Drone \ ) \qquad (38)$$

While, β shows the diminish factor ($\beta \in [0, 1]$).
Phase 4:
Alteration of Broods: The brood's population is enhanced by utilizing the alteration operators based on the following equation:

$$Brood_i^k = Brood_i^k \pm (\delta + \varepsilon) Brood_i^k \qquad (39)$$

$$\delta \in [0,1], 0 < \varepsilon < 1$$

Phase 5:
In this phase, if the model catches the optimal solution, it will finish; if not in this phase the new generation will dominate the pre-existing queen.

B) Suggested modified HBMO

In the regular HBMO, appropriate selection of the queen's quickness decrease factor presents a balance among global and local consideration and manipulation, and causes lower repetition on average to discover an appropriate ideal solution. Henceforth,

Table 3. GEP algorithm outputs - The profit value of each GENCO and the total profit

Profit of GENCO1	Profit of GENCO2	Profit of GENCO3	Profit of GENCO4	Profit of GENCO5	Overall profit
260.811	840.112	416.283	0	120.761	1637.977

a new type of criteria adjustment technique for the HBMO notion which named improved HBMO through time changing vital indexes i.e., queen's speed decrease factor is created. Promotion of universal researches in the beginnings of optimization stages and willingness of small components to mix toward the global optimal are the main motivations of utilization of this method. Using the MHBMO algorithm, the quickness decrease factor (α) is restructured to compute queen's quickness in Eq. (40) in every generation:

$$\alpha(t) = \frac{Cap - cap(t)}{Cap} \quad (40)$$

When, Cap stands for the spermatheca size; cap (t) stands for the drones' overall number chosen for mating at the first t transitions. Plus, more attention has been paid to HMO technique and extended usages in various optimization areas. However, occasionally it is incorporated into the local optima. In this study, HBMO has mixed with chaotic local search (CLS) to solve this issue. So, suggested hypotheses will be:

$$c_{i+1}^j = \begin{cases} 2c_i^j \times \left(1 + \frac{g_{best}^{k-1}}{g_{best}^k}\right) \times cos\left(2\pi \frac{g_{best}^{k-1}}{g_{best}^k}\right), 0.5 < c_i^j \leq 1 \\ 0.1c_i^j \times \left(1 - cos\left(\left(1 + \frac{g_{best}^{k-1}}{g_{best}^k}\right)\right)\right), 0 < c_i^j \leq 0.5 \end{cases} \quad (41)$$

2.5. Multi-objective HBMO

A multi-objective optimization issue composed of different goals is optimized at the same time, where some equality, inequality and binary constrain are achieved. For multi-objective plan, each of two solutions x1 and x2 one of two probabilities: one controls the other or does not control the other [31]. In the offered solution, a solution x1 can dominates x2 without loss of oversimplification, if the next two cases are achieved:

$$\begin{aligned} &1. \forall i \in \{1, 2, \ldots, N_{obj}\} : f_i(x_1) \leq f_i(x_2) \\ &2. \forall j \in \{1, 2, \ldots, N_{obj}\} : f_j(x_1) \leq f_j(x_2) \end{aligned} \quad (42)$$

$$\mu_i = \frac{f_i^{max} - f_i}{f_i^{max} - f_i^{min}}$$

$$FDM_i = \begin{cases} 0 & \mu_i \leq 0 \\ \mu_i & 0 < \mu_i < 1 \\ 1 & \mu_i \geq 1 \end{cases} \quad (43)$$

While, f_i^{min} and f_i^{max} shows the minimum and maximum values of the ith aim function, in turn. to calculate FDMk the following equations were applied correspondingly:

$$FDM^k = \left(\sum_{i=1}^{N_{obj}} FDM_i^k\right) \Big/ \left(\sum_{j=1}^{M} \sum_{i=1}^{N_{obj}} FDM_i^j\right) \quad (44)$$

In the equation above, M stands for the non-dominated solutions number, and objective functions are shown by Nobj.

2.6. Case study

The optimal network which has been considered in this study can be achieved by investigating the details of Fig. 3. Ref. [32] presents the required information for generators, 5% load expansion rate and the predicted maximum demand, accessible investment with a planning horizon of at least 15 years, besides the potential locations and candidate unit types and demonstrates the construction expense of the standard construction in year one. It has been postulated that costs have increased by 3% in a year.

3. RESULTS

The selected units of this study are 4 years old each, reached to 20 years, and have a service life of 16 years. The evaluated reserve of 500 MW (the biggest unit existing) is presented for one year of planning. In order to maximize social welfare and reduce load-supply costs, the ISO will employ this figure. In the first phase, DLG matrix was computed by MHBMO. Table 1 indicates the outcomes of the study and contribution of every generator to reach the considered load.

In addition, Table 2 demonstrates the computations and comparisons for all newly added generations. Therefore, GENCOs investigating the provided data as well as other required data for solving the PBGEP problem will reach the ideal design that eventually enhances its pure profit and send it to ISO. Next, ISO applies or neglects the GENCO issues using SCGEP.

Each GENCO's profit value and overall profit is shown in Table 3. By contrasting these findings with MHBMO outputs, it can be seen that chosen units at the planning horizon are operating within appropriate limits.

4. CONCLUSIONS

Electrical energy is crucial to the advancement of both the social and the economic fronts. Due to its enormous importance, governmental agencies have historically owned and operated the power sector. Over time, it has undergone restructuring, and the energy market is currently undergoing deregulation. In the case of energy consumption, generation techniques can apply tools with higher rate of power use or diminish the effects of power generation within direct generator. This study has attempted to present a GEP for networks with limited energy according to MHBMO. The suggested approach influenced the altered 30-bus IEEE network. The outcomes of the study validate the proficiency of the suggested method. The comparison of the results of MHBMO demonstrates that chosen units at the planning horizon are operating within acceptable limits. That is to say, it is ascertained that the suggested method can achieve the optimal load regardless of congestion in transmission lines. It is shown that the recommended multi-objective optimization method has an ideal precision level, a higher convergence rate, and straightforward mathematical equations.

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