Security Constrained Optimal Power Flow Problem Solution with Practical Constraints using HALOA

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***Abstract*: To solve the OPF problems with three objective functions like fuel cost minimization, emission and power loss. The proposed algorithm is hybridizing conventional Anti Lion optimization algorithm with Genetic algorithm. The considered objectives are solved by considering the equality and in-equality constraints along with practical constraints. The effectiveness of the proposed method is tested on the IEEE 30 bus test system and compared with existing literature. The proposed method gives the best optimal values for the minimizing the considered objectives.**

***Keywords* : Ant lion optimization, OPF, Practical constraints, crossover operation, generation fuel cost, emission, transmission loss.**

I. INTRODUCTION

Optimal power flow (OPF) is used in power system optimization. OPF represents the best operating levels for the existing system in order to meet the demands given throughout the transmission network, usually with the considered objectives of minimization of cost, emission and transmission losses. OPF was first introduced in the year 1962 by Carpentier. It is being discussed since then. It is considered to be a large, nonlinear mathematical programming problem. There are two types of methods in optimization: conventional and intelligent methods.

There are several optimization techniques implemented recently to solve many electrical problems, some of them like GA, DE, EP, PSO, Tabu Search (TS), SA, ACO, ABC, CSO have been suggested [1-9]. Dr. Syedali Mirjalili [10] proposed an Ant lion optimizer (ALO). This proposed algorithm was analyzed in three different forms such as mathematical functions, classical engineering problems and shapes of two propellers are optimized. A.Salhi, D.Naimi and T.Bouktir [11] proposed OPF using ant ALO technique and compared with existing literature. Khalid. H. Mohamed and K. S. Rama Rao [12] proposed optimization algorithms for OPF problem solution. They concluded that intelligent techniques are more suitable when compared to conventional methods for optimal power flow.

In the above literature while solving the OPF problem they are not considered the practical constraints such as ramp rate limits and prohibited operating zones. In this paper along with equality and in equality constraints, practical constraints has been consider for OPF problem to test the effectiveness of the proposed HALOA

II. PROBLEM FORMULATION

The optimization problems as follows:

$$Min[C_n(x,u)]; \qquad \forall n = 1,2,...., m \tag{1}$$

Subject to
$$p(x,u) = 0$$
$$q(x,u) \le 0$$

Where $'p'$ and $'q'$ are constraints, $'x'$ & $'u'$ are dependent and control variable

A. Objective Function

The objective functions are as follows:

i. Generation fuel cost

The generation cost function as follows:

$$F_i(P_{Gi}) = a_i P_{Gi}^2 + b_i P_{Gi} + c_i \;\; \$/h$$

Where a_i, b_i and c_i are generation fuel cost-coefficients of i^{th} unit.

Generation cost for all units

$$C_1 = \min(F_T) = \sum_{i=1}^{N_G} F_i(P_{G_i}) \text{ \$/h} \tag{2}$$

ii. Emission

The emission generated can be approximated as

$$C_2 = \min(E(P_{G_i})) = \sum_{i=1}^{N_G} \alpha_i + \beta_i P_{G_i} + \gamma_i P_{G_i}^2 + \xi_i \exp^{(\lambda_i P_{G_i})} \text{ ton/h} \tag{3}$$

Where α_i, β_i, γ_i, ξ_i and λ_i are emission coefficients of the i^{th} generator.

iii. Total power loss

$$A_3 = \min(TPL) = \sum_{i=1}^{N_{line}} P_{Loss,i} \quad \text{MW} \tag{4}$$

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B. Constraints

i). Equality constraints

$$\sum_{i=1}^{N_G} P_{G_i} - P_D - P_L = 0 ; \sum_{i=1}^{N_G} Q_{G_i} - Q_D - Q_L = 0$$

Where P_D , Q_D and P_L , Q_L are real and reactive demand and losses respectively.

ii). In-equality constraints

Voltage: $V_{G_i}^{\min} \le V_{G_i} \le V_{G_i}^{\max}; \quad \forall i \in N_G$

Active Power Generation:

$$P_{G_i}^{\min} \le P_{G_i} \le P_{G_i}^{\max}; \quad \forall i \in N_G$$

Transformers tap: $T_i^{\min} \le T_i \le T_i^{\max}; \quad i = 1,2,...,n_t$

Reactive power generation:

$$Q_{C_i}^{\min} \le Q_{C_i} \le Q_{C_i}^{\max}; \quad i = 1,2,....,n_C$$

Line flow: $S_{l_i} \le S_{l_i}^{\max}; \quad i = 1,2,....,N_{line}$

Reactive Power Generation limits:

$$Q_{G_i}^{\min} \le Q_{G_i} \le Q_{G_i}^{\max}; \quad \forall i \in N_G$$

Bus voltage magnitude:

$$V_i^{\min} \le V_i \le V_i^{\max} \quad i = 1,2,....,N_{load}$$

Where n_t taps, n_C VAr sources, N_{load} VAr sources

C. Prohibited operating zones (POZ) (practical constraints)

Problem formulation as follows:

$$P_i = \begin{cases} P_i^{\min} \le P_i \le P_{i,1}^L \\ P_{i,k-1}^U \le P_i \le P_{i,k}^L & k = 2,3,...,n_i \\ P_{i,n_i}^U \le P_i \le P_i^{\max} \end{cases}$$

Where n_i the forbidden zones and k index of sector of unit-i, $P_{i,k}^L$ and $P_{i,k}^U$ are the respective lower and upper limit of k^{th} prohibited zone of i^{th} generator

D. Ramp-rate limits (practical constraints)

The inequality constraints due to ramp limits are

$$\max\left(P_{G_i}^{\min}, P_i^0 - DR_i\right) \le P_{G_i} \le \min\left(P_{G_i}^{\max}, P_i^0 + UR_i\right)$$

Where P_i^0 is previous hour power generation i^{th} unit. DR_i and UR_i are the respective down and up rate limits of i^{th} unit.

The Eqn (1) in the generalized form as

$$C_{m,aug}(x,u) = C_m(x,u) + a_1\left(P_{g,slack} - P_{g,slack}^{\lim}\right)^2 + a_2 \sum_{i=1}^{N_{Load}} \left(V_i - V_i^{\lim}\right)^2 + a_3 \sum_{i=1}^{N_G} \left(Q_{G_i} - Q_{G_i}^{\lim}\right)^2 + a_4 \sum_{i=1}^{N_{line}} \left(S_{l_i} - S_{l_i}^{\max}\right)^2 \quad (5)$$

Where a_1, a_2, a_3 and a_4 are penalty coefficients. The limits are

$$x^{\lim} = \begin{cases} x^{\max}, & x > x^{\max} \\ x^{\min}, & x < x^{\min} \end{cases}$$

x is the value of $P_{g,slack}$, V_i and Q_{G_i}

III. HYBRID ANT LINE OPTIMIZATION ALGORITHM (HALOA)

ALO algorithm proposed by Dr.Syedali Mirjalili. This technique deals the searching mechanism of Ant lions in nature. These are the doodlebugs which come under myrmeleontidae family which live in two phases of larvae and adult. The total life period is up to 3 years which is mostly covered by the phase of larva and the span of adult is just 3-5 weeks. In the stage of larvae their hunting mechanism is very interesting. The small cone shape traps seen in the nature are built by ant lions to trap ants. They dig the bigger pits when they are hungry and it is the main inspiration of this algorithm. The interesting feature regarding these ant lions are the hunger level and shape of the moon. They dig a bigger trap when they are hungry and when the moon is in full shape. These ant lions are also called as “Civil Engineers” because of their talent in building the traps. These steps are described in the following sections.

IV. OPERATORS OF ALO ALGORITHM

ALO technique mimics collaborate between ants and ant lions during the hunting mechanism. In order to model those interactions the ant lions are allowed to hunt the ants and become fitter using the traps, ants are required to move over the search space. At the every step of optimization ants try to update their current position with the help of random walk. Ants basically use stochastic movement for search of food.

modeling of random walk movements of ants is given by

$$X(t) = \begin{bmatrix} 0, cumsum(2r(t_1)-1), cumsum(2r(t_2)-1), ..., \\ cumsum(2r(t_n)-1) \end{bmatrix} \quad (6)$$

r(t) function given by

$$r(t) = \begin{cases} 1 \rightarrow rand > 0.5 \\ 0 \rightarrow rand \le 0.5 \end{cases} \quad (7)$$

The ant positions are given by

$$M_{Ant} = \begin{bmatrix} B_{1,1} & B_{1,2} & \cdots & \cdots & B_{1,d} \\ B_{2,1} & B_{2,2} & \cdots & \cdots & B_{2,d} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ B_{n,1} & B_{n,2} & \cdots & \cdots & B_{n,d} \end{bmatrix} \quad (8)$$

Where M_{Ant} = position of Ant, $B_{i,j}$ = value of j^{th} variable of i^{th} Ant, n = Ants and d = number of dimensions.

The fitness function is considered for evaluation of each Ant during optimization. The following matrix stores the fitness values

$$M_{OA} = \begin{bmatrix} f([B_{1,1}, B_{1,2}, \ldots\ldots, B_{1,d}]) \\ f([B_{2,1}, B_{2,2}, \ldots\ldots, B_{2,d}]) \\ \\ \\ f([B_{n,1}, B_{n,2}, \ldots\ldots, B_{n,d}]) \end{bmatrix} \quad (9)$$

Where, MOA = matrix for saving the fitness of each Ant, $B_{i,j}$ = shows the value of j^{th} variable of i^{th} Ant, n= ants and d = dimensions.

Ant lions are also present and they are hiding at some place in search space. In order to store the position and fitness of ant lions two matrices are utilized.

$$M_{Antlion} = \begin{bmatrix} AL_{1,1} & AL_{1,2} & \cdots & \cdots & AL_{1,d} \\ AL_{2,1} & AL_{2,2} & \cdots & \cdots & AL_{2,d} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ AL_{n,1} & AL_{n,2} & \cdots & \cdots & AL_{n,d} \end{bmatrix} \quad (10)$$

Where, $M_{Antlion}$ = for position of Ant lion, $AL_{i,j}$ = value of j^{th} variable of i^{th} Ant lion, n= Ant lions and d = number of dimensions

The fitness of the matrix of ant lion is given by

$$M_{OAL} = \begin{bmatrix} f([AL_{1,1}, AL_{1,2}, \ldots\ldots, AL_{1,d}]) \\ f([AL_{2,1}, AL_{2,2}, \ldots\ldots, AL_{2,d}]) \\ \\ \\ f([AL_{n,1}, AL_{n,2}, \ldots\ldots, AL_{n,d}]) \end{bmatrix} \quad (11)$$

Where, M_{OAL}=saving the fitness of each Ant lion, $AL_{i,j}$ = shows the value of j^{th} variable of i^{th} Ant lion, n= number of Ant lions and d= number of dimensions.

A. Random walks of ants

The random walks are based on the equation (6). At the each step update their position. Every search space has its own boundary therefore; equation (6) not used directly for updating the position of ants. Therefore the random values are normalized by the given equation below in order that they are inside the search space.

$$X_i^t = \frac{((X_i - a_i) * (d_i^t - c_i^t))}{(b_i - a_i)} + c_i^t \quad (12)$$

Where, a_i & b_i - Min &Maximum random walk for variable i, c_i^t & d_i^t - Min & Maximum of all variables for Ant_i

B. Trapping in ant lion's pits

Ant lion's pits have their effect on the walks of ants. To mathematically model the following equations are used

$$c_i^t = Antlion_j^t + c_t \quad (13)$$

$$d_i^t = Antlion_j^t + d_t \quad (14)$$

Where, c_t & d_t - Min &Maximum of all variables at iteration t, c_i^t & d_i^t - Min &Max for Ant_i

Equation (13) and (14) show that the ants walk in a given search space c &d around a selected ant lion.

C. Building trap

Roulette wheel selection is used for building the traps. Select the ant lions based on their fitness. The chance of ants getting caught by the fitter ant lions is more.

D. Sliding ants

Ant lions build the traps are directly relation to their fitness and the ants move in the search space. Once the ants enter into the pit the ant lions throw the sand outwards to capture the ant. The behavior slides down the trapped ants. In order to explain this behavior mathematically, the radius of the ant's random walks hyper-sphere is reduced.

It is explained by following equations

$$x^t = \frac{x^t}{I} \quad (15)$$

$$y^t = \frac{y^t}{I} \quad (16)$$

Where, x^t =Minimum of all variables at iteration, y^t =Maximum of all variables at iteration t, I=Ratio which is defined by $I = 10^w \frac{t}{T}$.

E. Catching prey and re-building the pit

Then ant lion is required to update its position to the latest position of the hunted ant to enhance its chance of catching the new ant. This behavior is explained by the following equation

$Antlion_j^t = Ant_i^t$ If the $f(Ant_i^t)$ is better than the $f(Antlion_j^t)$ (17)

F. GA Cross over operator

GA cross over operator are used to update the result

$$x_{pq}^{new} = (1-\lambda) \times x_{1q}^{ref} + \lambda \times x_{pq}^{old} \quad (18)$$

Where 'λ' is [0 1]

G. Elitism

The elite simultaneously as follows

$$Ant_i^t = \frac{R_A^t + R_E^t}{2} \quad (19)$$

Where, R_A^t = random walk around the ant lion selected at t^{th} iteration

R_E^t = random walk around the elite at t^{th} iteration.

V. RESULTS AND ANALYSIS

This section describes the results of test systems and IEEE 30 bus test systems. The proposed and existing methods are compared with MATLAB.

A. Illustrative example-1

A test function is considered in order to analyze the HALOA method. The function has been analyzed and the steps of analysis results are given below.

$$F_1(x) = \sum_{i-1}^{n} x_i^2$$

In this problem search agents and dimension are 5 each

Step-1: Initialization of ants and ant lions

Ant lion_position=

$$\begin{bmatrix} -86.2835 & 59.6741 & 20.1678 & -0\ 0.3544 & 94.8383 \\ -40.1199 & 0.3402 & -77.5075 & -44.4778 & -60.5442 \\ 18.3167 & 30.1624 & 3.1531 & 30.5040 & -77.7630 \\ -59.3402 & 59.1910 & 67.5681 & 83.4598 & -40.5291 \\ 27.1766 & -53.3252 & 84.1580 & 1.9679 & -20.7163 \end{bmatrix}$$

ant_position=

$$\begin{bmatrix} -15.8489 & -40.9638 & -68.9557 & -91.5493 & 83.5760 \\ -37.7049 & -38.7006 & -99.8683 & 80.9444 & -72.5393 \\ 38.7686 & -78.8878 & -43.2809 & -73.8052 & 0.9465 \\ -81.6256 & 18.7655 & 10.1622 & 66.7458 & -19.0083 \\ -19.5823 & -43.4545 & 74.1804 & 60.0937 & -65.2856 \end{bmatrix}$$

Step 2: Evaluation of fitness

$$\text{Ant lions\_fitness} = \begin{bmatrix} 1.0e+04*2.0407 \\ 1.0e+04*1.3261 \\ 1.0e+04*0.8233 \\ 1.0e+04*2.0198 \\ 1.0e+04*1.1098 \end{bmatrix}$$

$$\text{sorted\_ant lion\_fitness} = \begin{bmatrix} 1.0e+04*0.8233 \\ 1.0e+04*1.1098 \\ 1.0e+04*1.3261 \\ 1.0e+04*2.0198 \\ 1.0e+04*2.0407 \end{bmatrix}$$

Sorted_ant lions=

$$\begin{bmatrix} 18.3167 & 30.1624 & 3.1531 & 30.5040 & -77.7630 \\ 27.1766 & -53.3252 & 84.1580 & 1.9679 & -20.7163 \\ -40.1199 & 0.3402 & -77.5075 & -44.4778 & -60.5442 \\ -59.3402 & 59.1910 & 67.5681 & 83.4598 & -40.5291 \\ -86.2835 & 59.6741 & 20.1678 & -0.3544 & 94.8383 \end{bmatrix}$$

Elite_ant lion_position=

$$[18.3167 \quad 30.1624 \quad 3.1531 \quad 30.5040 \quad -77.7630]$$

Elite_ant lion_fitness= $[8.2328e+03]$

Step3: Sliding ants towards ant lions

$$c^t = \frac{c^t}{I}$$

= 1.0e-04 * [-1.0000 -1.0000 -1.0000 -1.0000 -1.0000]

$$d^t = \frac{d^t}{I}$$

= 1.0e-04 * [1.0000 1.0000 1.0000 1.0000 1.0000]

Step4 (a): Trapping in ant lions pits

$$c_i^t = Antlion_j^t + c_t$$

= -40.1198 0.3403 -77.5074 -44.4777 -60.5441

$$d_i^t = Antlion_j^t + d_t$$

= 40.1200 0.3401 -77.5076 -44.4779 -60.5443

Step 4(b): Random walks of ants

$$R_A = \begin{bmatrix} -40.1198 & 0.3401 & -77.5076 & -44.4779 & -60.5443 \\ -40.1199 & 0.3403 & -77.5075 & -44.4777 & -60.5442 \\ -40.1200 & 0.3401 & -77.5074 & -44.4779 & -60.5441 \end{bmatrix}$$

$$R_E = \begin{bmatrix} 18.3168 & 30.1625 & 3.1530 & 30.5041 & -77.7631 \\ 18.3167 & 30.1624 & 3.1531 & 30.5040 & -77.7629 \\ 18.3166 & 30.1623 & 3.1532 & 30.5039 & -77.7631 \end{bmatrix}$$

Step5: Elitism

$$Ant_i^t = \frac{R_A^t + R_E^t}{2}$$

ant_position=

$$\begin{bmatrix} 10.9016 & 15.2514 & -37.1772 & -6.9868 & -69.1536 \\ -37.7049 & -38.7006 & -99.8683 & 80.9444 & -72.5393 \\ 38.7686 & -78.8878 & -43.2809 & -73.8052 & 0.9465 \\ -81.6256 & 18.7655 & 10.1622 & 66.7458 & -19.0083 \\ -19.5823 & -43.4545 & 74.1804 & 60.0937 & -65.2856 \end{bmatrix}$$

After checking the boundaries the updated ant position is given by:

ant_position=

$$\begin{bmatrix} -10.9016 & 15.2514 & -37.1772 & -6.9868 & -69.1536 \\ 22.7467 & -11.5813 & 43.6556 & 16.2360 & -49.2396 \\ 18.3167 & 30.1624 & 3.1531 & 30.5040 & -77.7630 \\ 18.3168 & 30.1625 & 3.1531 & 30.5039 & -77.7631 \\ 22.7467 & -11.5813 & 43.6556 & 16.2360 & -49.2396 \end{bmatrix}$$

new_ant_position=

$$\begin{bmatrix} -10.9016 & 15.2514 & -37.1772 & -6.9868 & -69.1536 \\ 18.9734 & -8.5723 & 34.5911 & 13.6318 & -51.4727 \\ 15.0402 & 28.4903 & -1.3695 & 26.2998 & -76.7975 \\ 15.0402 & 28.4904 & -1.3695 & 26.2998 & -76.7976 \\ 18.9734 & -8.5723 & 34.5911 & 13.6318 & -51.4728 \end{bmatrix}$$

Update ant lion positions and finesses, double_population

$$\begin{bmatrix} 18.3167 & 30.1624 & 3.1531 & 30.5040 & -77.7630 \\ 27.1766 & -53.3252 & 84.1580 & 1.9679 & -20.7163 \\ -40.1199 & 0.3402 & -77.5075 & -44.4778 & -60.5442 \\ -59.3402 & 59.1910 & 67.5681 & 83.4598 & -40.5291 \\ -86.2835 & 59.6741 & 20.1678 & -0.3544 & 94.8383 \\ -10.9016 & 15.2514 & -37.1772 & -6.9868 & -69.1536 \\ 22.7467 & -11.5813 & 43.6556 & 16.2360 & -49.2396 \\ 18.3167 & 30.1624 & 3.1531 & 30.5040 & -77.7630 \\ 18.3168 & 30.1625 & 3.1531 & 30.5039 & -77.7631 \\ 22.7467 & -11.5813 & 43.6556 & 16.2360 & -49.2396 \end{bmatrix}$$

$$\text{double\_fitness}=\begin{bmatrix} 1.0e+04*0.8233 \\ 1.1098 \\ 1.3261 \\ 2.0198 \\ 2.0407 \\ 0.6565 \\ 0.5245 \\ 0.8233 \\ 0.8233 \\ 0.5246 \end{bmatrix}$$

$$\text{ant lions\_fitness}=\begin{bmatrix} 1.0e+03*5.2455 \\ 5.2455 \\ 6.5646 \\ 8.2328 \\ 8.2328 \end{bmatrix}$$

Sorted_ant lions=

$$\begin{bmatrix} 22.7467 & -11.5813 & 43.6556 & 16.2360 & -49.2396 \\ 22.7467 & -11.5813 & 43.6556 & 16.2360 & -49.2396 \\ -10.9016 & 15.2514 & -37.1772 & -6.9868 & -69.1536 \\ 18.3167 & 30.1624 & 3.1531 & 30.5040 & -77.7630 \\ 18.3167 & 30.1624 & 3.1531 & 30.5040 & -77.7630 \end{bmatrix}$$

Update the position of elite if any ant lion becomes fitter than it

Elite_ant lion_position=[22.7467 -11.5813 43.6556 16.2360 -49.2396]

Elite_ant lion_fitness = [5.2455e+03]

Keep the elite in the population

Sorted_ant lions=

$$\begin{bmatrix} 22.7467 & -11.5813 & 43.6556 & 16.2360 & -49.2396 \\ 22.7467 & -11.5813 & 43.6556 & 16.2360 & -49.2396 \\ -10.9016 & 15.2514 & -37.1772 & -6.9868 & -69.1536 \\ 18.3167 & 30.1624 & 3.1531 & 30.5040 & -77.7630 \\ 18.3167 & 30.1624 & 3.1531 & 30.5040 & -77.7630 \end{bmatrix}$$

Ant lions_fitness=

$$\begin{bmatrix} 1.0e+03*5.2455 \\ 5.2455 \\ 6.5646 \\ 8.2328 \\ 8.2328 \end{bmatrix}$$

Update the iteration.

B. Illustrative example-2

In order to analyze the efficacy of HALO algorithm when compared to that of ALO algorithm a standard Himmelblau test function is considered and is minimized. It is observed that the best results are obtained from the HALO algorithm

From the Table 1 it is observed that proposed method gives the optimal value when compared to the existing methods.

Table- I: Himmelblau function optimal values

Variables	*Existing GA [1]*	*Existing ALO*	*Proposed HALO*
X_1	3.003	3.0003945	3.00005824
X_2	1.994	2.0089459	2.0006821
Min. function value	1.000e-3	7.5328e-004	2.039e-006
Time (sec)	--	4.7544	0.39736

C. IEEE 30 bus test system

The efficiency of the proposed method is tested on IEEE-30 bus test system [13, 14]. To identify the effect of additional constraints such as ramp-rate and prohibited operating zone limits, the single objective optimization is analyzed for the different cases:

Case-A: Without Practical constraints; Case-B: With Ramp rate; Case-C: With POZ; Case-D: with both constraints.

In order to show the usefulness of the HALOA method, the analysis is extended all the four cases. Control variables in OPF solution for four cases are obtained with generation fuel cost, emission and transmission loss minimization as objective functions are tabulated in Table 2. The convergence characteristics and the variations of active power flow for these objectives with four cases are shown in Figs. 1-3.

From Table 2, values are less without considering practical constraints than other three cases. The cost is high with POZ limits and in between with ramp-rate limits are considered, when compared to without practical limits. Further, the fuel cost increases if the ramp limit and POZ is considered. The emission is more in case-D compared to other three cases. From the observation the effect of ramp limit on the Emission is low and the effect of prohibited operated zones (POZ) is high. Further, the emission increases if the ramp limit and POZ constraints are considered. The loss is more in the Case D than the other three cases. It is also observed that, the effect of ramp limit on the power loss is low and the effect of prohibited operated zones (POZ) is high. Further, the power loss increases if the ramp limit and POZ are considered.

It is also observed that the generators are not operating in specified prohibited operating zones for all other objectives also.

From Fig. 1-3, it is notified that the iteration starts with high value also requires more number of iterations to reach the final value for case-D compared to other three cases for all four objectives.

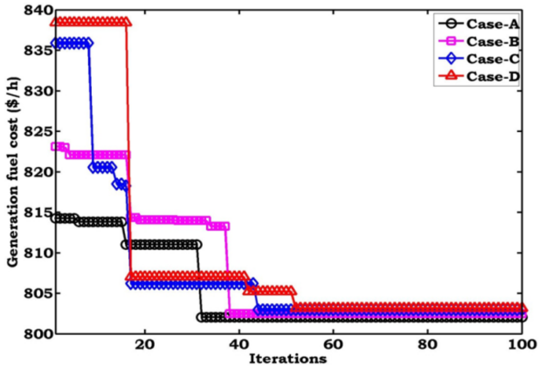

Fig. 1.Convergence characteristics of cost minimization of all cases with HALOA

Table- II: Single objective optimized result of generation cost, emission and total power loss objectives

VARIA BLES	Generation cost				Emission				Total power loss			
	CASE A	CASE B	CASE C	CASE D	CASE A	CASE B	CASE C	CASE D	CASE A	CASE B	CASE C	CASE D
P_{G1}(MW)	173.679	173.648	182.528	170.301	61.224	70.000	58.958	70.782	51.655	51.892	52.244	66.357
P_{G2}(MW)	44.425	47.898	50	46.283	71.327	61.995	73.221	61.240	80	80	80	75.441
P_{G5}(MW)	22.957	22.663	17.811	19	50	50	50	50	50	50	50	50
P_{G8}(MW)	25.953	21.438	21.054	30	35	35	35	34.998	35	35	35	35
P_{G11}(MW)	13.221	13	10	13	30	30	30	30	30	30	30	30
P_{G13}(MW)	12	14	12	14	40	40	40	40	40	40	40	30.801
V_{G1}(p.u.)	1.1	1.070	1.1	1.062	1.024	1.1	1.1	1.1	1.1	1.016	0.976	1.1
V_{G2}(p.u.)	1.049	0.933	0.998	1.012	0.9	1.1	0.982	1.1	1.099	1.001	0.9	0.901
V_{G5}(p.u.)	1.087	1.008	1.021	1.001	0.960	1.082	0.9	1.097	1.064	0.991	0.949	0.9
V_{G8}(p.u.)	1.0985	1.1	1.1	1.1	0.951	1.098	1.1	1.098	1.1	1.035	0.945	1.1
V_{G11}(p.u.)	1.1	1.1	1.092	0.9	1.083	1.1	1.1	0.9	0.903	0.9	1.1	1.028
V_{G13}(p.u.)	1.1	1.1	1.1	1.098	0.9	0.964	1.1	1.005	0.9	1.1	1.068	1.098
$T_{6\text{-}9}$(p.u.)	1.032	0.960	1.1	0.9	0.952	1.098	1.096	1.1	0.900	0.903	0.9	0.988
$T_{6\text{-}10}$(p.u.)	1.015	0.9	0.9	0.9	0.9	1.1	0.9	1.1	1.1	0.9	0.926	0.970
$T_{4\text{-}12}$(p.u.)	0.979	0.943	0.9	0.906	0.9	0.903	1.054	1.006	0.9	0.9	0.9	1.046
$T_{28\text{-}27}$(p.u.)	1.058	0.9	0.9	0.9	0.903	0.964	0.961	1.068	0.951	0.9	0.9	1.023
Q_{C10}(MVAr)	30	20.386	29.842	29.996	30	30	5.196	30	13.137	29.627	5.056	27.053
Q_{C24}(MVAr)	5.466	5	8.786	5	6.334	5.001	12.899	5	17.137	6.334	24.549	28.059
Cost ($/h)	**802.254**	**802.742**	**803.151**	**804.541**	953.076	936.842	955.631	935.865	968.032	968.599	969.441	939.689
Emission (ton/h)	0.3557	0.3555	0.3831	0.3475	**0.2052**	**0.2053**	**0.2053**	**0.2054**	0.2072	0.2072	0.2072	0.2102
TPL (MW)	8.836	9.248	9.993	9.184	4.151	3.595	3.780	3.621	**3.292**	**3.492**	**3.844**	**4.200**

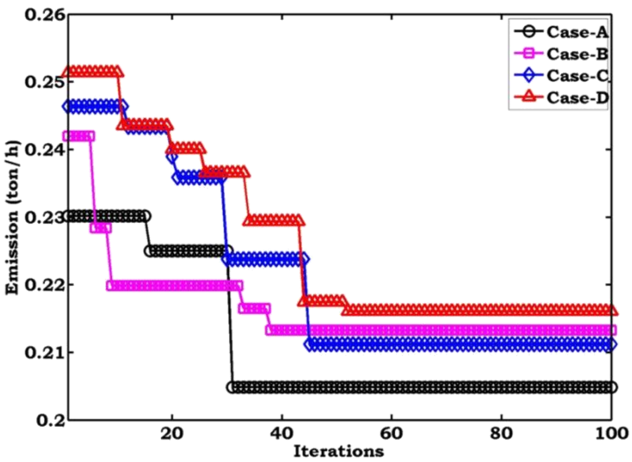

Fig. 2.Emission minimization of four cases with HALOA

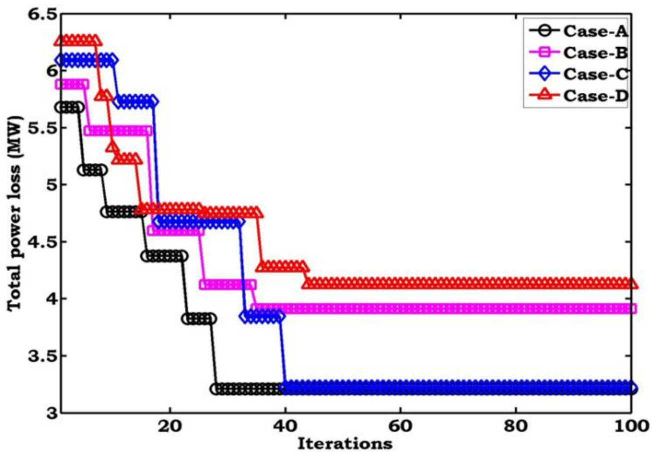

Fig. 3.Transmission loss minimization of four cases with HALOA

VI. CONCLUSIONS

In this research work, HALO algorithm has been proposed to optimize most warranted objectives such as cost, emission and loss objectives. The optimization problem is solved while satisfying conventional equality, in-equality constraints and practical constraints such as ramp-rate and POZ limits. The proposed technique has proven its efficacy by starting with decent initial value and reaches best final value with less number of iterations when compared to literature methods.

The proposed method works without considering the nature of the objectives and can be used to optimize any number of objectives. Typical test systems and electrical test IEEE-30 bus systems are tested with supporting numerical results.

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