Optimal Power Flow using Hybrid Ant Lion Optimization Algorithm

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Abstract

In this paper a novel Ant Lion Optimization (ALO) algorithm based on hunting mechanism of ant lions is being hybridized with the arithmetic crossover operation of Genetic Algorithm (GA) for solving optimal power flow in power systems. This hybridization leads to the better quality of solutions and improve the exploration in search space. The capability and performance of the proposed algorithm is tested on benchmark test functions and IEEE-14 bus test system. Generation fuel cost, emission of generating units and transmission line losses are considered as objectives for optimal power flow problems. Simulation results show that the proposed algorithm provides an effective and robust high-quality of solutions. The obtained results will be compared with the existing literatures for justifying the superiority of the proposed algorithm.

Keywords: *Optimal Power Flow (OPF), Hybrid Ant lion Optimization (HALO) Algorithm, arithmetic crossover operation, generation fuel cost, emission and transmission line losses.*

1. Introduction

Optimal power flow (OPF) is a vital aspect for the operation and controlling of power system. OPF problem determines the optimal operating state of a power system by optimizing objectives like generation fuel cost, emission of generating units and real power transmission losses with considering specified physical and operating constraints, with some control variables such as generators real output power and voltages, transformer tap setting, phase shifters, switched capacitors and reactors.

Basically, OPF problem consists of a great number of constraints, and it is a nonlinear, non-convex optimization method and for solving OPF problem many conventional methods and evolutionary algorithms have been proposed. Conventional methods include linear programming, non-linear programming, quadratic programming, Newton method, gradient method, and interior point methods [2-10]. They have limitations like converging at local optima and are suitable only for continuous problems. Due to these limitations, they are not suitable for the actual OPF solution. Like in [7] gradient steepest-descent method having exterior penalty functions is proposed, it causes slow convergence rate and to overcome this, Newton algorithm and Quasi-Newton method had been proposed in [8-9]. Then it was being observed that the they did not converges due to improper selection of initial condition then researchers developed linear programming method in [10] but it also fails to provide proper solutions.

However, metaheuristic optimization methods are employed which can easily overcome limitations of conventional methods. In the recent years, they had gain more momentum which leads to the origin of a wide range of heuristic algorithms such as

Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Evolutionary Programming (EP), Biogeography Based Optimization (BBO), Moth Flame Algorithm and many more listed in [11]. Furthermore to enhance the performance of existing algorithms these are hybridized, modified or improved to utilize the existing algorithms to its best, such in Ref. [12] Artificial Bee Colony (ABC) algorithm has been used but it leads to find local optima thus G-best guided ABC (GABC) algorithm in [13] had been to overcome the observed problems. Similarly, simulated annealing algorithm (SAA) [14] and its variants such as modified SSA with neighborhood generation (MSAANG) [15], and hybrid PSO and SAA (HPSO-SAA) [16] had been developed to enhance the performance of novel algorithms. Harmony search algorithm (HSA) [17] and its two modified versions have also been proposed which are presented in Refs. [18-19].

Moreover, Cuckoo Search Algorithm (CSA) [20], Fruit Fly Algorithm (FFA) [21] and Harmony search algorithm are hybridized with arithmetic crossover operation [22-24] respectively, to improve the performance of algorithms in terms of convergence rate and enhancing exploration. Considering this approach, in this paper a novel Ant Lion Optimization (ALO) proposed by Seyedali Mirjalili [25] is being hybridized with arithmetic crossover operation of genetic algorithm to enhance its random walk and yields for better solutions.

Proposed algorithm named as Hybrid Ant Lion Optimization (HALO) Algorithm is being tested on benchmark test functions and then implemented on IEEE-14 bus test system to verify its creditability. The results obtained through proposed algorithm are compared with the existing literatures.

2. Problem Formulation

Optimal Power Flow (OPF) deals to solve the steady state problem of electric power system through minimizing the objective functions with the consideration of constraints simultaneously. Mathematically OPF is represented by:

$$\text{Min } F_p(x, y) \qquad \forall p = 1,2,.......t$$

$$\text{Subject to: } g(x, y) = 0\,,$$

$$h(x, y) \le 0$$

where, 'g' and 'h' are the equality and inequality constraints respectively, 'x' is the state vector of dependent variables and 'y' is the control vector of system and t is the total number of objectives functions.

The state vector may be represented by:

$$x^T = [P_{g,1}, V_{l,1}....V_{l,NLINE}, Q_{g,1}....Q_{g,NGB}, S_{l,1}....S_{l,NTL}]$$

The control vector may be represented by:

$$y^T = [P_{g,2}.....P_{g,NGB}, V_{g,1}....V_{g,NGB}, Q_{SH,1}....Q_{SH,NC}, T_1....T_{NT}]$$

where $P_{g,1}$ is the real power, $V_{l,1}$ is the load bus voltage, , $Q_{g,1}$ is the reactive power of generator, $S_{l,1}$ is the apparent power of generator $V_{g,1}$ is the generator voltage of slack bus. *NLINE*, *NGB*, *NTL*, *NC* and *NT* are the total number of PQ buses, PV buses, transmission lines, shunt compensators and off-nominal tap transformers respectively.

2.1. Objective Functions

In this paper, three single objective functions are minimized, which are mathematically expressed below:

a. Generation fuel cost minimization

$$F_1 = \min(F_p(P_{g,m})) = \sum_{m=1}^{NGB} x_m P_{g,m}^2 + y_m P_{g,m} + z_m \$/h \tag{1}$$

where, x_m, y_m and z_m are the fuel cost coefficients of m^{th} unit.

b. Emissions of generating unit's minimization

$$F_2 = \min(E(P_{g,m})) = \sum_{m=1}^{NGB} \alpha_m + \beta_m P_{g,m} + \gamma_m P_{g,m}^2 + \xi_m \exp(\lambda_m P_{g,m}) ton/h \tag{2}$$

where, α_m, β_m, γ_m, λ_m and ξ_m are the emission coefficients of m^{th} unit.

c. Transmission line losses minimization

$$F_3 = \min(P_{loss})) = \sum_{m=1}^{NTL} P_{loss,m} MW \tag{3}$$

2.2. Constraints

The equality and in-equality constraints are as follows:

a. Equality constraints

$$\sum_{m=1}^{NGB} P_{g,m} - P_D - P_L = 0, \quad \sum_{m=1}^{NGB} Q_{g,m} - Q_D - Q_L = 0$$

b. Inequality Constraints

(i). Generator constraints

$V_{g,m}^{\min} \le V_{g,m} \le V_{g,m}^{\max}$ and

$$Q_{g,m}^{\min} \le Q_{g,m} \le Q_{g,m}^{\max} \qquad \forall m \in NGB$$

(ii). Voltage at bus and discrete transformer tap settings

$V_{g,m}^{\min} \le V_{g,m} \le V_{g,m}^{\max}$ and

$$T_m^{\min} \le T_m \le T_m^{\max} \qquad \forall m \in NT$$

(iii). Active power generation limits

$$P_{g,m}^{\min} \le P_{g,m} \le P_{g,m}^{\max} \qquad \forall m \in NGB$$

(iv). Reactive power supply by the capacitor banks

$$Q_{SH,m}^{\min} \le Q_{SH,m} \le Q_{SH,m}^{\max} \qquad \forall m \in NC$$

(v). Transmission line loadings

$$S_{l,m} \le S_{l,m}^{\max} \qquad \forall m \in NTL$$

3. Hybrid Ant Lion Optimization (HALO) Algorithm

The Basically, Ant Lion belongs to the Myrmelentidae family and Neuroptera order of insects. In their complete life span of 3 years, they have to go through two phases which includes larvae for 3-5 weeks and then rest for adulthood [24]. In the larvae phase it hunts for ants, and then they undergo metamorphosis process in a cocoon for becoming an adult. This algorithm is developed on the hunting mechanism of ant lion and entrapment of ants in ant lion traps. During hunting, a conical funnel like structure as shown in **Figure 1** is formed by the ant lions and after that at the bottom edge it waits for the ants to slip down, if ants manages to escape out then ant lion start throwing sand towards it so that ants can be easily caught. Hunger level and shape of moon are the depending parameters for the size of traps formed by ant lions.

Figure 1. Entrapments of ants in the traps formed by ant lions

Existing ALO algorithm possess following features:

1. It possesses roulette wheel and random walk which guarantee the exploration of search spaces and also leads to solve the local optima doldrums.

2. Shrinking mechanism defines the boundaries of random walks which implicit the exploitation with the increase of iteration.

3. Movements of ants are gradually reduced with the increase in iterations, which ensure convergence of the algorithm.

4. The best ant lion is saved as elite in each of the iteration which tends all the ants to move towards the elite obtained.

5. It is very flexible algorithm to solve diverse problems with very few controlling parameters.

This interaction of ants and ant lions has been hybridized with the arithmetic crossover of Genetic algorithm to enhance the performance of existing algorithm.

3.1 Operators of proposed HALO algorithm

Whenever ants search for food they randomly walk in their search space, which can be mathematically modeled as:

$$R(t) = \left[0, C(2m(t_1) - 1), C(2m(t_2) - 1), \ldots.., C(2m(t_{it}) - 1)\right] \tag{4}$$

where, C calculate the cumulative sum, *it* is the maximum number of iterations, t steps of random walk, *m(t)* is a function defined by:

$m(t) = \{1, \text{ if } rand > 0.5$

$0, \text{ if } rand \leq 0.5\}$

Ant's and ant lion's positions can be represented in matrixes below:

$$M_{ANT\_POSITION} = \begin{bmatrix} a_{1,1} & a_{1,2} & ..... & a_{1,D} \\ a_{2,1} & a_{2,2} & ..... & a_{2,D} \\ : & : & ..... & : \\ a_{N,1} & a_{N,2} & ..... & a_{N,D} \end{bmatrix} \quad (5)$$

$$M_{ANTLION\_POSITION} = \begin{bmatrix} al_{1,1} & al_{1,2} & ..... & al_{1,D} \\ al_{2,1} & al_{2,2} & ..... & al_{2,D} \\ : & : & ..... & : \\ al_{N,1} & al_{N,2} & ..... & al_{N,D} \end{bmatrix}$$

where, $M_{ANT\_POSITION}$ and $M_{ANTLION\_POSITION}$ are the matrixes representing positions of N number of ants and ant lions with D as dimension respectively.

After allocation of position, fitness is being calculated which can be represented as:

$$M_{ANT\_FITNESS} = \begin{bmatrix} f([a_{1,1}, a_{1,2}, ..., a_{1,D}]) \\ f([a_{2,1}, a_{2,2}, ..., a_{2,D}]) \\ : \\ f([a_{N,1}, a_{N,2}, ..., a_{N,D}]) \end{bmatrix} \quad (6)$$

$$M_{ANTLION\_FITNESS} = \begin{bmatrix} f([al_{1,1}, al_{1,2}, ..., al_{1,D}]) \\ f([al_{2,1}, al_{2,2}, ..., al_{2,D}]) \\ : \\ f([al_{N,1}, al_{N,2}, ..., al_{N,D}]) \end{bmatrix} \quad (7)$$

where, f is the considered objective functions mentioned in Eqs. (1)- (3)

Random walk of ants must be inside the search space, thus it is normalized as:

$$R_i^t = \frac{(R_i^t - w_i) \times (z_i^t - y_i^t)}{x_i - w_i} + y_i^t \quad (8)$$

where, w_i and x_i are the minimum and maximum of walk of i^{th} variable, y_i^t and z_i^t are the minimum and maximum of walk of i^{th} variable at t^{th} iteration.

Entrapment of ants in the pits built by the ant lion can be mathematically modeled as:

$$y_i^t = AntLion_j^t + y^t \quad (9)$$

$$z_i^t = AntLion_j^t + z^t \quad (10)$$

where, $AntLion_j^t$ is the position of j^{th} variable at t^{th} iteration.

Ant lion's ability to hunt is modeled using fitness proportional roulette wheel selection. As already discussed that ant lion throw sand to slide down the ants towards it, which can be modeled as:

$$y^t = \frac{y^t}{I} \quad (11)$$

$$Z^t = \frac{Z^t}{I} \quad (12)$$

where, I is a ratio defined as:

$$Z = \frac{10^W t}{it}$$

where, t and it represents current and maximum number of iterations respectively, w is the specified constant whose value changes with iterations which are as follows:

w= {2 if t > (0.1)it; 3 if t > (0.5)it; 4 if t > (0.75)it; 5 if t > (0.9)it; 6 if t > (0.95)it}

Then finally best ant lion in each of the iteration is considered as elite and every ant will randomly walks in the search space of selected ant lion only with its updated position by the following equation:

$$Ant_i^t = \frac{(R_A^t + R_E^t)}{2} \quad (13)$$

where, R_A^t and R_E^t random walk around the ant lion selected through roulette wheel and elite saved at t^{th} iteration.

After updating the position of ants, arithmetic crossover operation is being implemented by using below mentioned equation [21]:

$$X_i^{t+1} = (1-\lambda) \times X_i^t + \lambda \times X_i^{t+1} \quad (14)$$

where, λ is a random number between 0 and 1.

3.2 Pseudo code for the proposed algorithm

1. Read bus data, line data and generation data of considered power system.
2. Initialize the parameters of the proposed algorithm such as maximum number of iterations, dimensions, number of search agents, lower and upper bounds.
3. Start initializing the random walk of ants and ant lions using Eq. (4) and evaluate the considered objectives.
4. Then sort the obtained fitness's and identify the best ant lion and allocate it as elite.
5. At an iteration t, for each Ant_i, select an ant lion using roulette wheel.
6. Slide ants towards ant lions using equations (11) and (12).

7. The ant is trapped in ant lion hole by modelling the prey towards the ant lion that is the walk of the ant becomes bounded by the position of the ant lions which can be modeled by changing the range of ant random walk towards the ant lion position equations (9) and (10).

8. Update the random walk of ants using Eq. (4) and then normalize it using Eq. (8).

9. The fitness of all ants is calculated.

10. The limits of boundaries are checked and the crossover operation is done using Eq. (14).

11. Replace the ant lion with its corresponding ant if it becomes fitter i.e. if $f\left(Ant_i^t\right)$ is better than the $f\left(Antlion_j^t\right)$, then update the elite if the ant lion becomes more fit than elite.

12. Then update the iteration.

4. Results and Analysis

4.1. Illustrative Example

In this paper, the proposed algorithm is imposed on benchmark test functions to verify its effectiveness. Unimodal and multi modal test functions are considered having dimension 30, are listed in **Tables 1-2.**

Table 1. Unimodal benchmark test functions

Function	Range
$f_1(x) = \sum_{i=1}^{n} x_i^2$	[-100,100]
$f_2(x) = \sum_{i=1}^{n} \lvert x_i \rvert + \prod_{i=1}^{n} \lvert x_i \rvert$	[-10,10]
$f_3(x) = \sum_{i=1}^{n-1} [100(x_{i+1} - x_i^2)^2 + (x_i - 1)^2]$	[-30,30]
$f_4(x) = \sum_{i=1}^{n} (\lvert x_i + 0.5 \rvert)^2$	[-100,100]

Table 2. Unimodal benchmark test functions

Function	Range
$f_5(x) = \sum_{i=1}^{n} [x_i^2 - 10\cos(2\pi x_i) + 10$	[-5.12,5.12]
$f_6(x) = -20e(-0.2\sqrt{\frac{1}{n} \sum_{i=1}^{n} x_i^2}) - e(\frac{1}{n} \sum_{i=1}^{n} \cos(2\pi x_i)) + 20 + e$	[-32,32]
$f_7(x) = \frac{1}{4000} \sum_{i=1}^{n} x_i^2 - \prod_{i=1}^{n} \cos\left(\frac{x_i}{\sqrt{i}}\right) + 1$	[-600,600]

It can be observed from **Table 3**, that when proposed algorithm is implemented the functions got minimized to the best value as compared to existing algorithms. We can also see that proposed algorithm results out the better values as compared to novel ALO algorithm, thus it validate that the hybridization of existing algorithm with arithmetic crossover operation yields for the better solutions.

For analyzing the convergence characteristics curves are shown in **Figure 2-5**, for the $f_1(x)$, $f_2(x)$, $f_6(x)$ and $f_7(x)$ benchmark test functions, which also proves the effectiveness of proposed algorithm as with proposed algorithm, the convergence occurs fast as compared to ALO algorithm. It can also be seen that smooth variation in convergence is being observed in case of HALO algorithm.

Table 3. Comparison results of optimal value of benchmark test functions

Function	BA[25]	SMS[25]	PSO[25]	ALO[25]	HALO
$f_1(x)$	0.528134	0.014689	1.00-09	1.65E-10	1.39E-11
$f_2(x)$	3.816022	0.001577	2.26-05	6.58E-07	9.04E-08
$f_3(x)$	0.30003	0.140149	0.21625	0.109584	0.10884
$f_4(x)$	0.67392	0.084998	2.74E-06	1.09E-10	2.31E-11
$f_5(x)$	0.686447	0.326239	0.128991	8.45E-06	8.40E-07
$f_6(x)$	0.043251	8.56E-06	2.39E-11	1.50E-15	4.27E-16
$f_7(x)$	0.570309	0.70609	0.204348	0.009545	0.005669

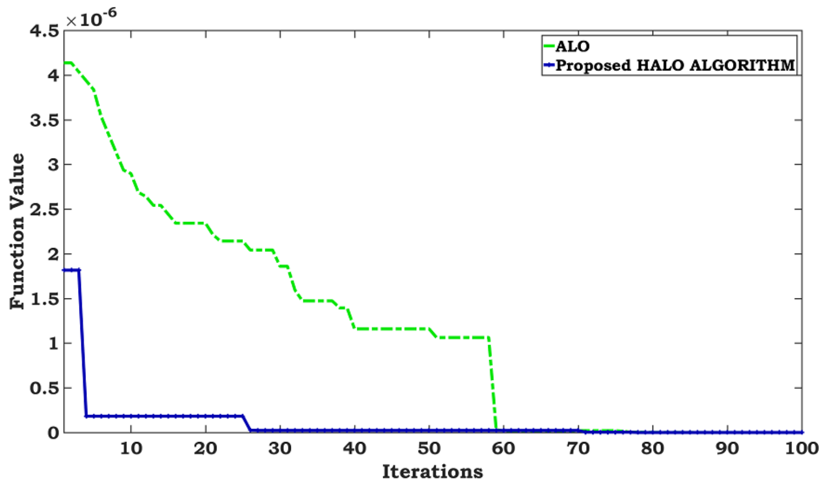

Figure 2. Convergence curve of function $f_1(x)$

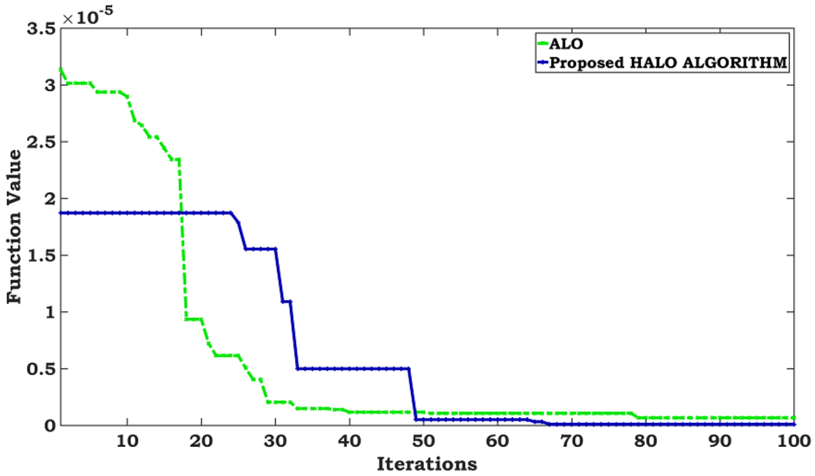

Figure 3. Convergence curve of function $f_2(x)$

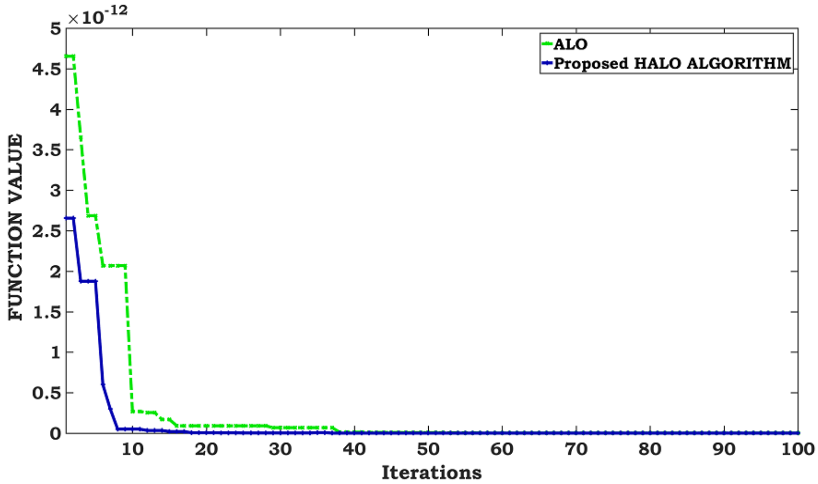

Figure 4. Convergence curve of function $f_6(x)$

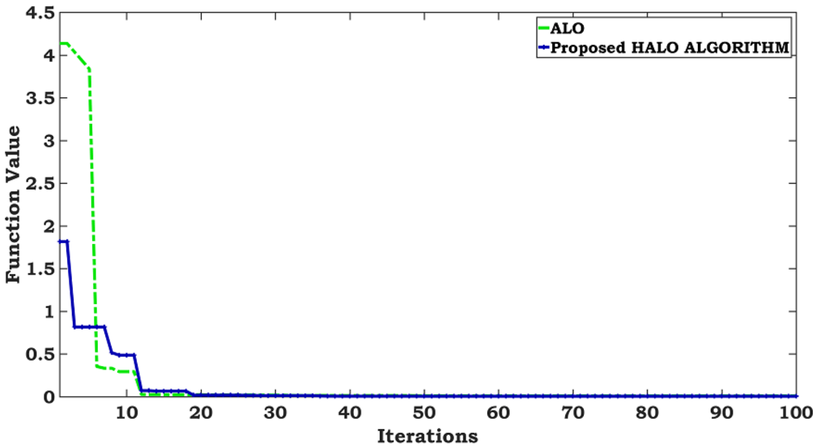

Figure 5. Convergence curve of function $f_7(x)$

4.1. Electrical test system

This section clearly describes the results on IEEE-14 bus test systems. For electrical test systems, primarily single objectives are optimized individually using proposed HALO. Basically it consists of 5 generators placed at buses 1,2,3,6 and 8, three off-nominal tap ratio transformers placed between the buses 4-7, 4-9, and 5-6 and shunt capacitor at bus 9 as shown in **Figure 6**. Data related to electrical test system is considered from Ref. [26].

OPF problems are being solved using proposed algorithm and it can be seen from **Table 4** that for considered objectives, values result out to be less as compare to the optimal solutions obtained using existing algorithms. We can see that generation fuel cost, emission of generating units and transmission line losses obtained using HALO are 715.588 \$/h, 0.156957 ton/h and 3.449867MW respectively which is less than the values obtained using ALO.

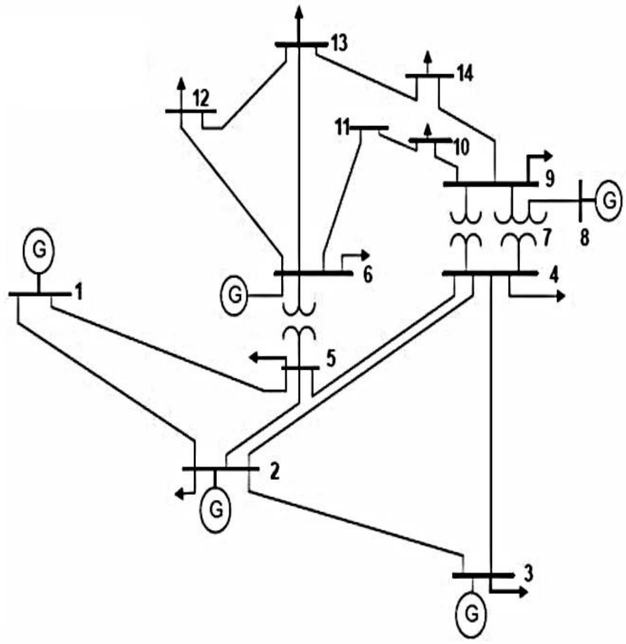

Figure 6. Single line diagram of IEEE-14 bus system

Table 4. OPF solution for considered objective functions for IEEE-14 bus system

Variables	Generation fuel cost, \$/h			Emission of generating units, ton/h			Transmission line losses, MW		
	HSCA[27]	ALO	HALO	HSCA	ALO	HALO	HSCA[27]	ALO	HALO
PG1, MW	161.4779	167.414	177.755	79.187	84.5383	34.2374	75.0517	54.7541	65.4277
PG2, MW	46.8931	50.8827	47.2689	74.4546	54.9103	80.1361	112.0794	112.663	69.7641
PG3, MW	20	20	22.3467	41.4792	47.7181	59.3358	43.933	47.1703	60
PG6, MW	33.9437	25.0818	14.9266	12.4082	19.3915	42.1206	23.2024	32.8417	50
PG8, MW	5	5	5.06672	55.3861	56.065	45.2693	9.6166	16.212	17.258
VG1, p.u.	1.05381	1.03332	1.09892	1.07539	1.00313	1.09409	1.056	0.99883	1.00945
VG2, p.u.	0.9	1.1	0.90594	0.97965	1.07647	1.01757	0.9	0.96763	0.9
VG3, p.u.	1.0079	0.9	1.1	1.07181	0.97126	1.03597	1.1	0.97005	0.97932
VG6, p.u.	0.9783	0.95682	1.1	0.99005	0.94811	1.07572	1.0097	1.04163	0.91984
VG8, p.u.	1.1	0.99876	1.1	0.91988	0.99488	1.04305	1.1	0.95735	1.05836
Tap 4-7, p.u.	1.021	1.03743	1.1	1.06428	0.97252	1.09289	1.1	0.9563	0.95208
Tap 4-9, p.u.	0.9	0.9	1.04483	0.97417	0.95717	1.05891	1.0114	0.92078	0.9
Tap 5-6, p.u.	1.067	0.9	1.08091	0.98268	0.95278	1.07179	0.9708	0.98233	0.9
Qc 9, p.u.	5	5	17.4942	16.9327	9.37607	25.4536	29.5561	6.83967	23.5728

Generation fuel cost, $/h	721.833	721.67	715.588	842.667	847.701	943.601	862.8203	897.209	881.739
Emission of generating units, ton/h	NA	0.28987	0.31623	0.16701	0.1628	0.15696	NA	0.17179	0.16265
Transmission line losses, MW	8.314585	9.37805	8.36362	3.91514	3.62307	2.0992	4.883	4.64087	3.44987

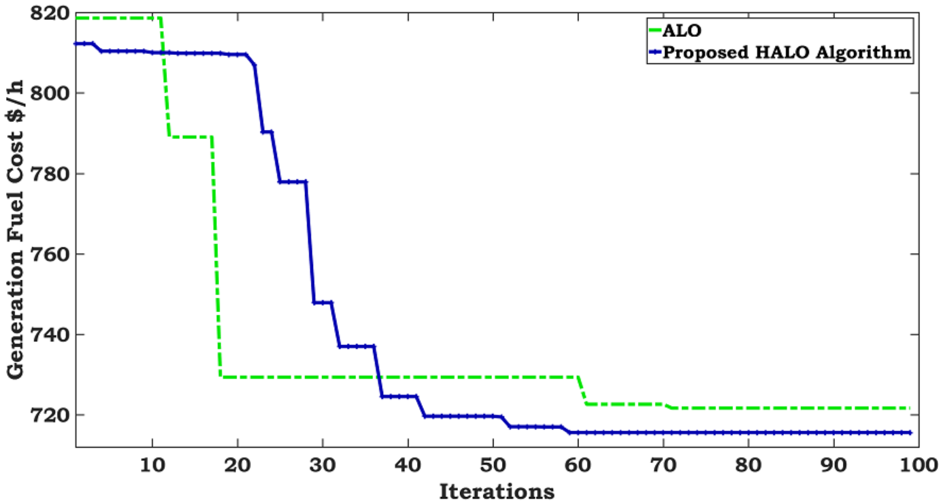

Figure 7. Convergence curve of generation fuel cost, $/h

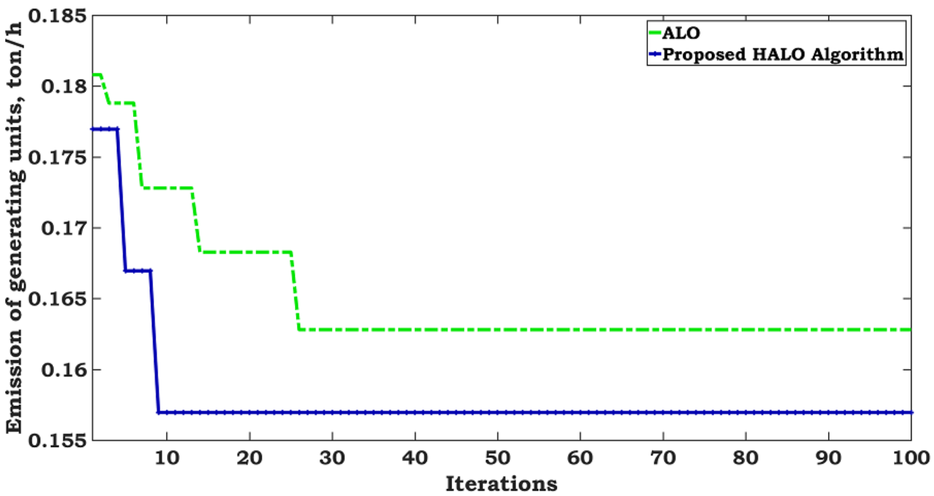

Figure 8. Convergence curve of emission of generating units, ton/h

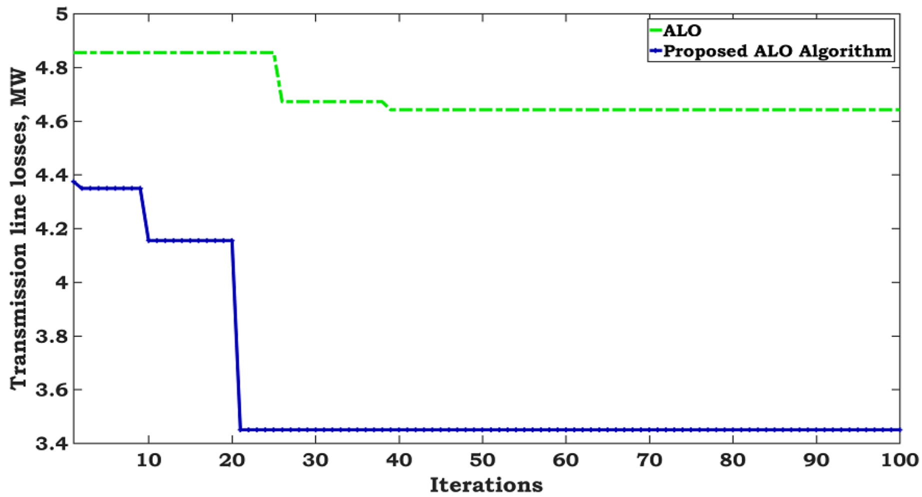

Figure 9. Convergence curve of transmission line losses, MW

5. Conclusion

In this paper, an effective algorithm is proposed with the hybridization of existing ALO and real coded Genetic Algorithm (GA) arithmetic cross-over operation, named as Hybrid Ant Lion Optimization (HALO) Algorithm. It has been being tested on unimodal as well as multi modal benchmark test functions, from which we can concluded that its performance is better as compared to other existing algorithms. Then the proposed algorithm is applied to solve the OPF problems under equality and in-equality constraints for the considered objectives which are generation fuel cost, emission of generating units and transmission line losses, from which we can conclude that solutions for considered objectives got minimized to the best values as compared to existing ALO algorithm. We can also say that hybridization enhances the rate of convergence and values obtained at initial iteration are less. Thus, the proposed algorithm is effective in terms of performance and capable to obtain the global solution.

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