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Optimal Power Flow using Hybrid Ant Lion Optimization and Spotted Hyena Optimization Algorithm: Comparison and Analysis

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Abstract- In this paper two novel approaches has been discussed for optimal power flow solution. The hybridization of the hunting mechanism of ant lions with the arithmetic crossover operation of GA has been discussed in this study and paper. This Hybrid Ant Lion Optimization has been found to provide better quality solutions for the OPF when tested on the benchmark standard test functions and IEEE-14 standard bus test configuration. Another efficient and reliable algorithm has been considered on being inspired by the social hierarchy and hunting behavioral nature of spotted hyenas. Generation fuel cost, emission of generating units and transmission line losses are considered as objectives for optimal power flow problems. A comparative study of both the novel approached has been done and the results discussed for justifying the superiority of the proposed algorithm.

Keywords: Optimal Power Flow (OPF), Hybrid Ant lion Optimization, Spotted Hyena Algorithm

I. INTRODUCTION

Optimal power flow is an important aspect in controlling and operation of the electrical power system. The optimal operating states of any powers system is being decided by optimizing the objectives like fuel costs, emission of generating units, real power loses in transmission networks.
Generally the optimum power flow deals with large number of constraints which leads to non linear optimization techniques. NR, GS, FDLF, NLP, QP are some of the conventional methods adopted which have limitations like they are found suitable for continuous problems and observed to converge at local optima [1-8].

It has been observed in recent years that the metaheuristic methods for optimization are being used to overcome this problem of the conventional methods. A wide range of this type of algorithms such as Evolutionary Programming (EP), Particle Swarm Optimization (PSO), Biogeography Based Optimization (BBO), Genetic Algorithm (GA), Moth Flame Algorithm are being studied by various researchers to address the Optimal Power Flow problems [9-10], [13-15]

Adding to the same, with a motive to enhance the performance,existing algorithms are hybridized, modified or improved to utilize the existing algorithms to its best. On similar lines, in this paper a novel Ant Lion Optimization as proposed by Seyedali Mirjalili [11] has been chosen and is being hybridized with arithmetic crossover operation of GA to enhance its random walk and results for better solutions.

Proposed algorithm named as Hybrid Ant Lion Optimization (HALO) Algorithm has been applied and analysed on standard test functions and then implemented on IEEE-14 bus test configuration to verify its creditability. The observations and outputs obtained by applying this algorithm are compared with the existing literatures.

Similarly, a novel algorithm Spotted Hyena Optimization (SHO) which has been introduced in Ref. [12] suggests better solutions when compared with existing algorithm. In this paper SHO is implemented to solve the OPF problems for IEEE-14 bus and IEEE 30-bus test configurations. This paper presents that SHO is an effective and feasible technique.

II. 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:

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

Subject to: $g(x, y) = 0$, $h(x, y) \leq 0$

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:

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

The control vector may be represented by:

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

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:

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

$$V_{g,m}^{\min} \leq V_{g,m} \leq V_{g,m}^{\max} \text{ and } Q_{g,m}^{\min} \leq Q_{g,m} \leq Q_{g,m}^{\max} \qquad \forall m \in NGB$$

$$V_{g,m}^{\min} \leq V_{g,m} \leq V_{g,m}^{\max} \text{ and } T_m^{\min} \leq T_m \leq T_m^{\max} \qquad \forall m \in NT$$

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

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

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

III. Overview of Hybrid Ant Lion Optimization Algorithm

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

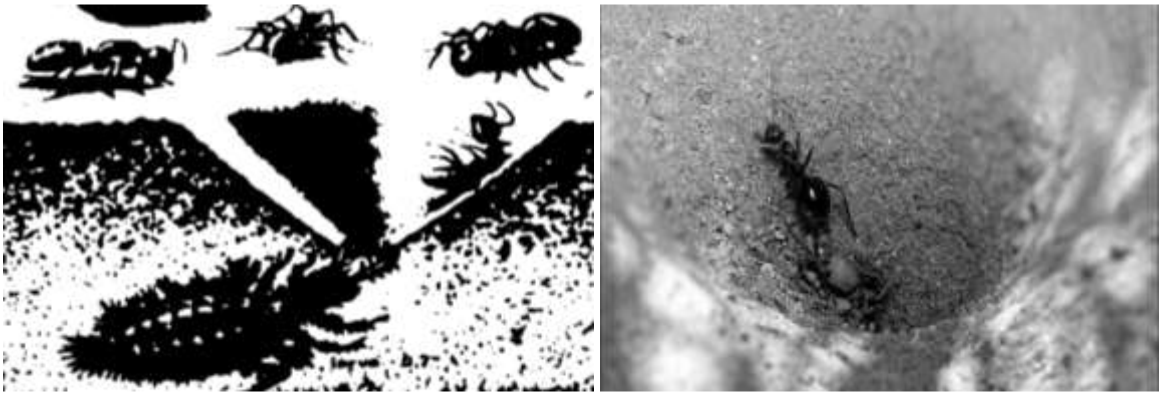

Fig: 1. Entrapments of ants in the traps formed by ant lions

3.1 Pseudo code for the proposed algorithm

1) Read bus, line and generation data of considered power system.
2) Initialize the parameters of the proposed algorithm and then initializing the random walk of ants & ant lions thereby for evaluating the objectives considered.
3) Sorting the obtained fitness's followed by identifying and allocating elite; Select an ant lion using roulette wheel at an iteration t, for each Ant lion

4) Slide ants towards ant lions given by Eq.11. 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

5) Update the random walk of ants using Eq. (4) and then normalize it using Eq.(8), followed by the fitness calculation

6) Boundary limits are checked and the crossover operation is implemented.

7) Replace the ant lion with its corresponding ant if it becomes fitter, then update the elite if the ant lion becomes more fit than elite. Update the iteration

IV. Spotted Hyena Algorithm

Spotted hyenas which are scientifically called as Crocuta, they are the large carnivore's dogs. They have the rigorous capability to rebel for food and territory [17]. They are also known as Laughing Hyena as their sounds are similar to the human laugh. The main steps of SHO are inspired by hunting behavior of spotted hyenas. Hunting mechanism is performed in four main steps discussed below:

4.1 Encircling prey, Hunting, Attacking the Prey, Search for the prey:

Initial location of prey is already known to spotted hyenas and to begin with spotted hyenas which is near the target prey is considered the best solution initially and accordingly other spotted hyenas will update positions.

Selected best spotted hyena has the information for the location of prey and other spotted hyenas forms a cluster in the direction of best.

The mathematical formulation for attacking the prey is as follows and It saves the best solution obtained and regards of which other spotted hyenas update their positions.

$$\vec{P}_{sh}(t+1) = \vec{G} / NSH$$

Generally the spotted hyenas search for the prey with respect to the cluster vector and they start diverging form each other in. Furthermore, $\vec{E}$ is deciding vector for the positioning of spotted hyenas as if |E| > 1 implies to movement diverging away from prey while |E| < 1 implies to

movement towards the prey. Then $\vec{C}$ is also a vector with random values which enhances the exploration and helps to avoid local optima.
Finally, the SHO algorithm is terminated by satisfying termination criteria.

4.2 Flowchart for the SHO algorithm

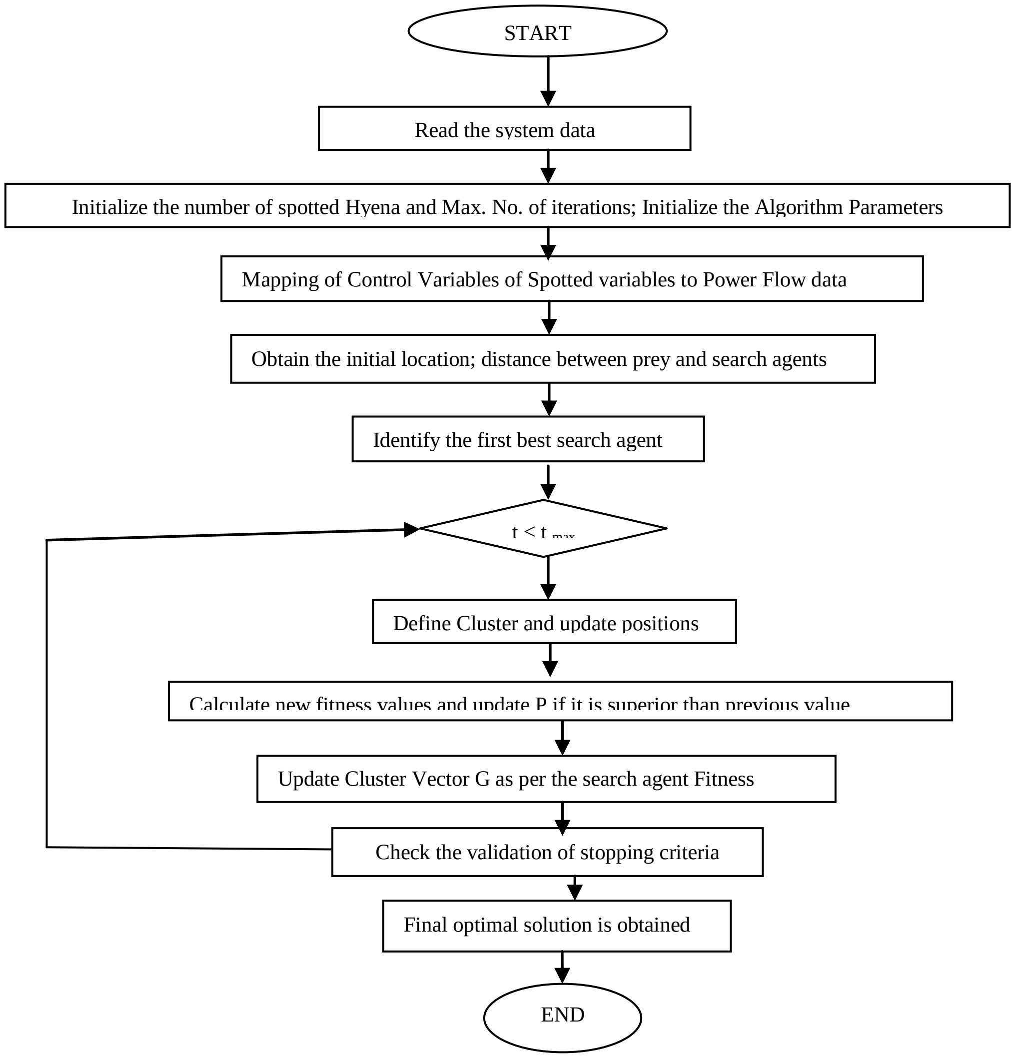

Figure 3. Flowchart of SHO

4.2.1 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. Data related to electrical test system is considered from Ref. [27].

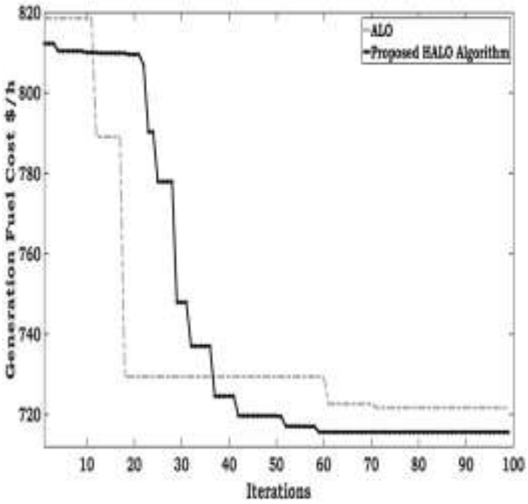

Figure 8. Convergence curve of generation fuel cost, $/h

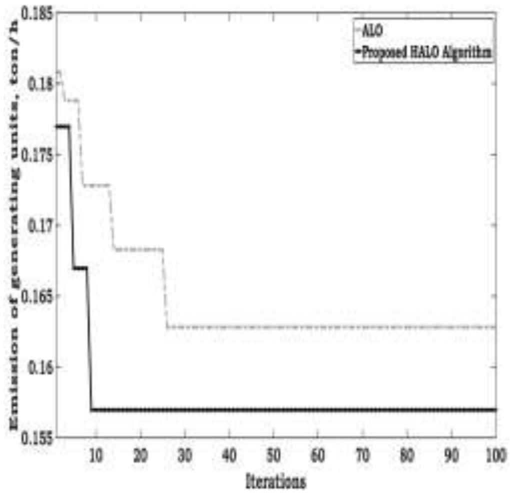

Figure 9. Convergence curve of emission of generating units, ton/h

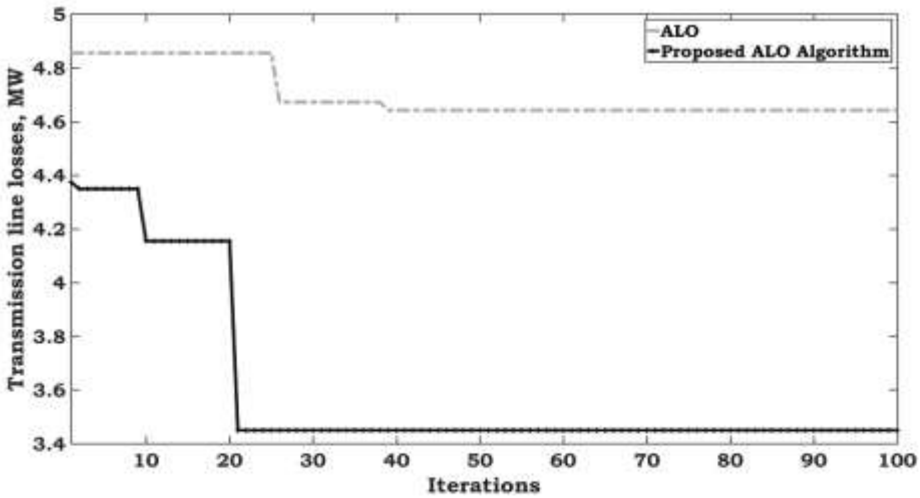

Fig 10. Convergence curve of transmission line losses, MW

4.3. Illustrative Example for Spotted Hyena Algorithm

In this paper, HALO and SHO algorithm is implemented to solve an OPF problem which includes objectives mentioned in Eqs. (1) and (2) for the standard IEEE-14 bus configuration and IEEE 30-bus test configuration and it can be seen from Table 3 for considered objectives that, values result out to be less as compared to the optimal solutions obtained using other existing algorithms.

Table 3. OPF solution for considered objective functions for IEEE-14 bus system

Variables	Generation fuel cost, $/h			Transmission line losses, MW		
	HSCA[27]	**HALO**	**SHO**	**HSCA[27]**	**HALO**	**SHO**
PG1, MW	161.4779	177.7548	176.5512	75.0517	65.42774	39.84451
PG2, MW	46.8931	47.26885	48.12015	112.0794	69.7641	106.8258
PG3, MW	20.000	22.34667	21.54344	43.9330	60	46.79028
PG6, MW	33.9437	14.92658	16.00888	23.2024	50	46.29497
PG8, MW	5.000	5.066718	5.02975	9.6166	17.25803	22.4116

			5			4
VG1, p.u.	1.05381	1.098924	1.1	1.0560	1.009454	1.06347
VG2, p.u.	0.9000	0.905943	0.9	0.9000	0.9	1.03614 7
VG3, p.u.	1.0079	1.1	1.1	1.1000	0.979317	1.03636 5
VG6, p.u.	0.9783	1.1	1.1	1.0097	0.919835	1.07425 1
VG8, p.u.	1.1000	1.1	0.90712 1	1.1000	1.058363	1.04208 2
Tap 4-7, p.u.	1.0210	1.1	0.94827 1	1.1000	0.952082	1.06004 2
Tap 4-9, p.u.	0.9000	1.044831	0.94479 7	1.0114	0.9	0.91678 4
Tap 5-6, p.u.	1.0670	1.080909	0.95695 8	0.9708	0.9	1.02482 6
Qc 9, p.u.	5.000	17.49418	29.9244	29.5561	23.57283	17.8321 3
Generation fuel cost, $/h	**721.8330**	**715.588**	**714.18 04**	**862.8203**	**881.7387**	**904.041 9**
Transmission line losses, MW	**8.314585**	**8.363622**	**8.2534 27**	**4.8830**	**3.449867**	**3.16722 3**

Hence, SHO is effective for solving OPF problems. Further we can also justify the performance of proposed algorithm by considering the convergence curve shown in Figure 11-12. We can clearly observe that convergence starts with lesser value and final result obtained very early as compared to HALO and HCSA [16-19]

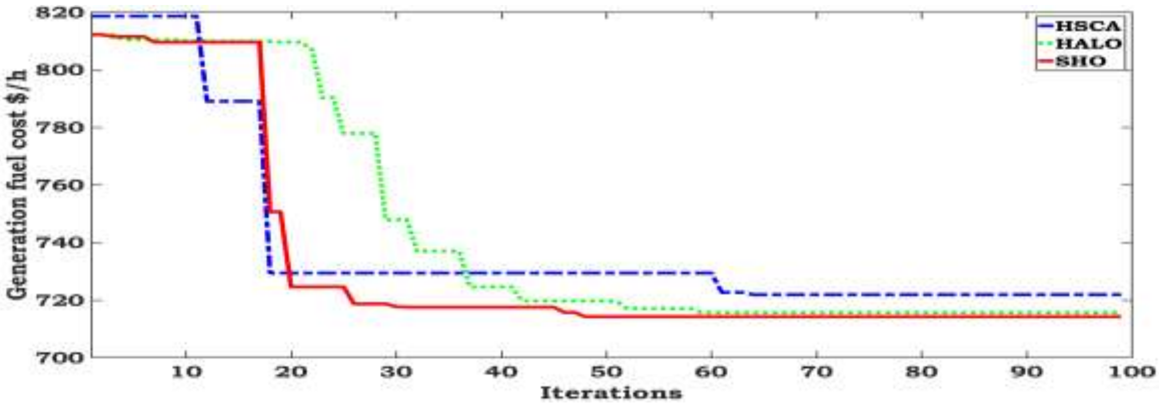

Fig 11. Convergence curve of generation fuel cost,$/h

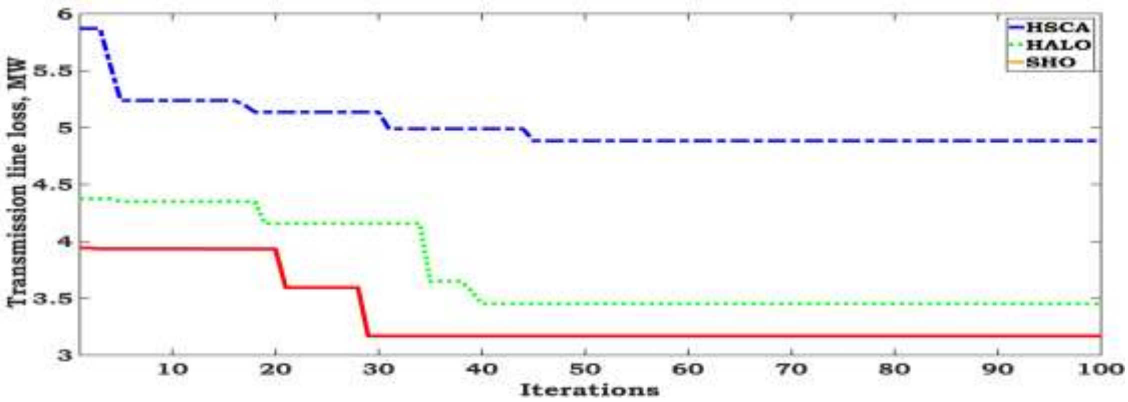

Fig. 12. Convergence curve of transmission line losses, MW

The SHO algorithm has been verified on IEEE-30 bus system by solving the OPF problems. Generally, IEEE- 30 bus system consists of 6 generators, four off-nominal tap ratio transformers placed between the buses and two shunt capacitors at buses. For each objective, proposed algorithm has run up to 100 iterations. Relevant data is taken from Ref. [26-27].

Table 4. Optimal Power Flow solutions for considered IEEE-30 bus system

Variables	Generation fuel cost, $/h				Transmission line losses, MW			
	HSCA[27]	**PSO[27]**	**HALO**	**SHO**	**HSCA[27]**	**PSO[27]**	**HALO**	**SHO**
PG1, MW	176.87	178.556	177.546	175.865	63.7401	64.326	64.5681	67.486
PG2, MW	49.8862	48.6032	48.4452	47.4864	68.2844	67.7681	68.9548	70.352
PG5, MW	21.6135	21.6697	21.6432	21.7241	50	50	46.578	40.4208
PG8, MW	20.8796	20.7414	19.8796	18.6053	35	35	32	25.7218
PG11, MW	11.6168	11.7702	12.5432	13.3922	30	30	26	21.2841
PG13, MW	12	12	12.432	12.602	40	40	37.578	35.1543
VG1, p.u.	1.057	1.1	1.124	1.097	1.0563	1.06	1.0965	1.0756
VG2, p.u.	1.0456	0.9	1.056	1.087	1.0082	1.0448	1.0622	0.8645
VG5, p.u.	1.0184	0.9642	1.022	1.059	1.0354	1.0062	1.0965	1.0549
VG8, p.u.	1.0265	0.9887	0.9986	1.070	1.0393	1.0086	1.0224	1.0141
VG11, p.u.	1.057	0.9403	1.048	0.97	1.057	1.0819	1.0967	0.9834
VG13, p.u.	1.057	0.9284	0.9982	1.099	1.0377	1.07079	1.0354	1.0963
Tap 6-9, p.u.	1.0254	0.9848	1.0196	1.02	1.0197	0.9875	1.0096	0.9565
Tap 6-10, p.u.	0.9726	1.0299	0.9234	0.945	0.9594	0.9596	0.9567	0.9752
Tap 4-12, p.u.	1.006	0.9794	0.9642	1.0086	0.9196	0.93	0.9496	0.9584
Tap 28-27, p.u.	0.9644	1.0406	0.9666	0.97887	0.9796	0.9699	0.9696	0.9798
Qc 10, p.u.	25.3591	9.0931	25.3591	25.005	22.7301	25	23.7301	24.14
Qc 24, p.u.	10.6424	21.665	11.9678	6.65638	24.5998	21.985	22.4980	17.54
Generation fuel cost, $/h	**802.034**	**803.454**	**802.547**	**800.86**	**946.5282**	**945.84924**	**942.3256**	**936.455**
Transmission line losses, MW	**9.466955**	**9.9403**	**9.6397**	**9.78778**	**3.6245**	**3.6943449**	**3.6445**	**3.5366**

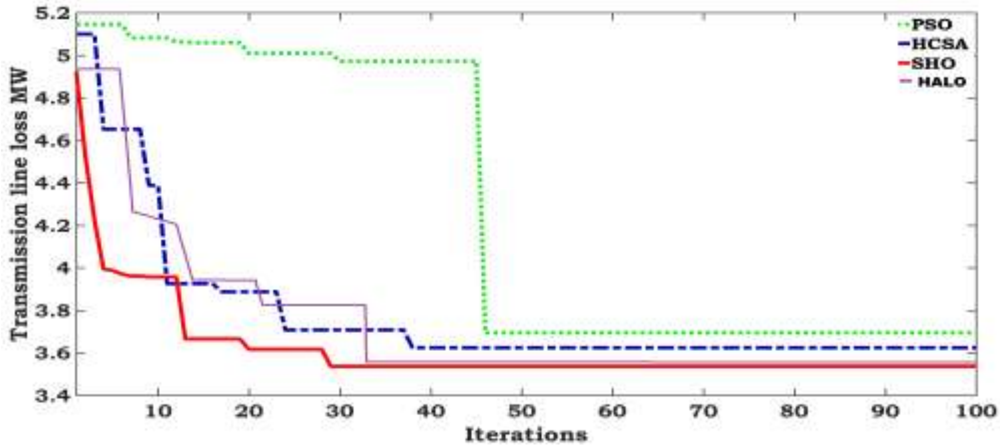

Fig 14. Convergence curve of transmission line losses, MW

V. 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 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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