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Optimal Power Flow Solution Using Ameliorated Ant Lion Optimization Algorithm

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Abstract

Optimal power flow (OPF) solutions are playing important role in power systems to improve power system performance. In this research article proposed a novel Ant Lion Optimization algorithm which Lévy flight operator named as, Ameliorated Ant Lion Optimization (AALO) Algorithm. It is used to solve single objective optimal power flow problems.In this paper, OPF solution AALO algorithm is used to improve load flows and focuses on minimizing the objective functions like minimization of fuel cost, emission and transmission power loss by fulfilling mentioned constraints. The proposed algorithm is validated on single benchmark test functions such as Sphere function and standard IEEE-30 bus system. Results will be examined and compared with existing methods.

1. INTRODUCTION

Optimal power flow problem can be solved by using various mathematical techniques such as linear &non-linear programming, quadratic, newton and interior point methods. For large scale security constrained optimal power flow problem a new interior point method is proposed [1].AC-DC optimal power flow problem is solved by GA [2]. Optimal power flow plays important role in power system operation, control and planning of modern power system. In optimal power flow problem objective function is minimized under certain control variables. Normally considered control variables are generator voltages, active and reactive power injections, voltage phase angles, transformer tap settings etc,. An enhanced GA for optimal power flow problem is used with continuous and discrete control variables [3].

Particle swarm optimization method is proposed for solving optimal power flow problem [4]. M.A Abido proposed tabu search method for finding the solution for optimal power flow problem [5]. Simulated annealing technique is applied for optimal power flow problem by C.A Roa –Sepulveda and B.Jpavez-lazo [6]. M.A Abido developed multi objective optimal power flow problem for economic power dispatch [7]. P.E.O Yumbla, etl al. used partial swarm optimizer to solve optimal power flow problem with security constraints [8]. Modified and improved partial swarm optimization algorithm are proposed for solving optimal power flow problem [9,10].Constrained optimal power flow with continuous and discrete variables are solved with mixed integer partial swarm optimization with mutation scheme.

2. Problem formulation of OPF

The OPF problem can be represented as follows:

$$\text{Min } \left[A_m(x,u)\right]; \qquad \forall\, m = 1,2,\ldots,J \quad (1)$$

Subjected to the constraint $g(x,u) = 0$ (2)

$$h_{\min} \le h(x,u) \le h_{\max} \quad (3)$$

Where,

$A_m(x,u)$ Function which is to be minimized

$g(x,u), h(x,u)$ represents equality and inequality constraints

x , u are dependent and independent variables

J is the number of objective functions

Optimal power flow solution gives an optimal control variable leads to the minimum generation fuel cost, emission and total power loss etc. subjected to all the various equality and inequality constraints. Here the vector x consists of slack bus real power output (P_{G1}), generator VAr output (Q_G), load bus voltage magnitude (V_L) , line flow limits (S_l)

Thus x can be written as,

$$x^T = \left[P_{G1},\ V_{L1},\ \ldots, V_{LNL},\ Q_{G1},\ \ldots, Q_{GNG},\ S_{l_1}\ \ldots\ , S_{l_{nl}}\right] \quad (4)$$

Where NL =Number of load buses

NG =Number of generator buses

nl =Number of lines

u is the independent variable vector such as continuous and discrete variables consists of

i. Generator active output P_G at all generators without slack bus

ii. Generator voltages V_G

iii. Tap settings of transformer T

iv. Shunt VAr compensation(or) reactive power injections Q_C

Here P_G, V_G are continuous variables and T and Q_C are the discrete variables Hence u can be expressed as

$$u^T = \left[P_{G2},\ \ldots, P_{GNG},\ V_{G1},\ \ldots, V_{GNG},\ Q_{C1},\ \ldots,\ Q_{CNC},\ T_1,\ \ldots, T_{NT}\right] \quad (5)$$

NT and NC are number of tap controlling transformers and shunt compensators.

3. Objective functions

Objective 1: Generation fuel cost minimization

Generators for which fuel cost characteristics are given by

$$A_1 = \min(F_T) = \sum_{i=1}^{NG} F_i(P_{Gi}) \quad \$/h \quad (6)$$

$$F_i(P_{Gi}) = a_i P_{Gi}^2 + b_i P_{Gi} + c_i \quad \$/h \quad (7)$$

Where a_i, b_i and c_i are i^{th} unit cost coefficients of generators

P_{Gi} - real power generation of i^{th} unit

Objective 2: Emission minimization

The function of emission of gasses in the boiler is represented as the sum of various gasses emitted such as NO_2, SO_2, thermal emission, etc. The amount of the gasses emitted is the function of generator output given by,

$$A_2 = \min\left(E\left(P_{G_i}\right)\right) = \sum_{i=1}^{NG} e_i \quad (ton/h) \quad (8)$$

Where e_i is the emission of the i^{th} generator

The emission curve is represented in quadratic function as

$$e_i = \alpha_i + \beta_i P_{Gi} + \gamma_i P_{Gi}^2 + \xi_i \exp(\lambda_i P_{Gi}) \quad \text{(ton/h)} \quad (9)$$

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

Objective 3: Total Power Loss minimization (TPL)

Third objective function is to minimize the total power loss in the transmission line of power system which can be expressed as,

$$A_3 = \min(TPL) = \sum_{i=1}^{nl} P_{Loss_i} \tag{10}$$

Where P_{Loss_i} is the real power loss in i^{th} line

Power loss through a line is a function of power flow through it, which can be obtained from power flow solution.

4. Constraint

Constraints made on OPF problem are usually two types. They are equality constraints and inequality constraints.

i. **Equality constraints:** These constraints mentioned in Eqn. (2.2) are usually load flow equations described as

$$P_{Gk} - P_{Dk} - \sum_{m=1}^{NB} |V_k||V_m||Y_{km}| \cos(\theta_{km} - \delta_k + \delta_m) = 0 \tag{11}$$

$$Q_{Gk} - Q_{Dk} + \sum_{m=1}^{NB} |V_k||V_m||Y_{km}| \sin(\theta_{km} - \delta_k + \delta_m) = 0 \tag{12}$$

Where,

P_{Gk}, Q_{Gk} are the active and reactive power generation at k th bus

P_{Dm}, Q_{Dm} are the active and reactive power demands at m^{th} bus

NB is number of buses

$|V_k|$, $|V_m|$ are the voltage magnitudes of k^{th} and m^{th} bus

δ_k , δ_m are the phase angles of voltages at k^{th} and m^{th} bus

$|Y_{km}|$, θ_{km} are the bus admittance magnitude and its angle between k^{th} and m^{th} bus

ii. **Inequality constraints:**

These are the constraints represents the system operational and security limits which are continuous and discrete constraints.

- **Generator Constraints**

These are the generator active and reactive power constraints.

$$P_{Gk\min} \le P_{Gk} \le P_{Gk\max}; \qquad k = 1, 2, \ldots\ldots, NG$$

$$Q_{Gk\min} \le Q_{Gk} \le Q_{Gk\max}; \qquad k = 1, 2, \ldots\ldots, NG$$

Where

$P_{Gk\min}$, $P_{Gk\max}$ are minimum and maximum active power generation limits at k^{th} bus

$Q_{Gk\min}$, $Q_{Gk\max}$ are minimum and maximum reactive power generation limits at k^{th} bus

- **Voltage Constraints**

Generation bus voltages are restricted by their upper and lower limits.

$$V_{k\min} \le V_k \le V_{k\max}; \qquad k = 1, 2, \ldots\ldots, NG$$

$V_{k\min}$, $V_{k\max}$ are minimum and maximum voltage limits at k^{th} bus

- **Transformer Tap Setting Constraints**

Tap setting of transformers are restricted by their maximum and minimum limits

$$T_{k\min} \le T_k \le T_{k\max}; \qquad k = 1,2,.....,NT$$

Where,

$T_{k\min}$, $T_{k\max}$ are minimum and maximum tap setting limits of k^{th} transformer

- **Shunt VAr Compensator Constraints**

Shunt VAr compensator constraints are given by,

$$Q_{Ck\min} \le Q_{Ck} \le Q_{Ck\max} \quad ; \qquad k = 1,2,.....,NC$$

Where,

NC represents number of compensators

$Q_{Ck\min}$ *and* $Q_{Ck\max}$ are minimum and maximum reactive power injection limits at i^{th} compensator

- **Security constraints**

These are the constraints includes voltages at buses and transmission line loading

$$V_{k\min} \le V_k \le V_{k\max}; \qquad k = 1,2,.....,NB$$

$$S_{Lk} \le S_{Lk\max}; \qquad k = 1,2,.....,nl$$

The inequality constraints can be handled using penalty function, given as follows

$$A_{m,aug}(x,u) = A_m(x,u) + R_1\left(P_{g,slack} - P_{g,slack}^{\lim}\right)^2 +$$

$$R_2\sum_{i=1}^{NL}\left(V_i - V_i^{\lim}\right)^2 + R_3\sum_{i=1}^{NG}\left(Q_{G_i} - Q_{G_i}^{\lim}\right)^2 + R_4\sum_{i=1}^{nl}\left(S_{l_i} - S_{l_i}^{\max}\right)^2$$

Where $R_1, R_2, R_3,$ and R_4 are the penalty quotients having large positive value. The limit values are defined as

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

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

5. Implementation of proposed AALO algorithm

Pseudo code of proposed AALO algorithm is detailed below:

1. Read the input data which include bus data
2. Initialize the parameters of AALO search variables (N), dimension (D), maximum number of iterations (IT), lower and upper bounds.
3. Randomly initialize the population of ants and ant lions using below equation. Then evaluate their fitness.

$$A(r) = [0, cs(2w(r_1) - 1), cs(2w(r_2) - 1), ...cs(2w(r_{IT}) - 1)]$$

4. Allocate control variables of ants in to load flow data and solve the considered objectives
5. Set best ant lion obtained so far as elite.

while the end criteria is not achieved

for i= 1 to N

6. Apply roulette wheel for the selection of an ant lion and update j and k using Eqs. (13) and (14).

$$j^t = \frac{j^t}{Z} \qquad (13)$$

$$k^t = \frac{k^t}{Z} \qquad (14)$$

where, $Z = 10^K t/IT$,in which t and IT are current and maximum number of iteration respectively. K is a constant weight defined based on the basis of current iteration (K =2 when t> 0.1IT, K =3 when t> 0.5IT, K =4 when t> 0.75IT, K =5 when t> 0.9IT, K=6 when t > 0.95IT).

7. Create a random walk for thei^{th} and then the random walks can be normalized so that they are inside the search spaceusing Eq. (15).

$$A_i^t = \frac{(A_i^t - m_i)\times(k_i^t - j_i^t)}{n_i - m_i} + j_i^t \qquad (15)$$

8. Amend the position of ants using Eq. (16).

$$Ant_i^t = \frac{(Q_A^t + Q_E^t)}{2} \qquad (16)$$

where, Q_A^t and Q_E^t random walk around the ant lion and elite selected at t^{th} iteration.

9. Again update the obtained position of ants using levy operator using Eq. (17).
end for

$$Lévy(\alpha) = \left| \frac{\Gamma(1+\alpha)\times \sin(0.5\pi\alpha)}{\Gamma\left(\frac{1+\alpha}{2}\right)\times\alpha\times 2^{0.5(\alpha-1)}} \right|^{\frac{1}{\alpha}} \qquad (17)$$

where, α is a constant whose value considered to be equal to 1.5 [11] and Γ is a gamma distribution function

10. Evaluate the fitness of each and every ant and replace with ant lion if Eq. (18) is satisfied.

$$AntLion_j^t = Ant_i^t \text{ if } f(Ant_i^t) > f(AntLion_j^t) \qquad (18)$$

where, Ant_j^t is the position of selected i^{th} ant at t^{th} iteration.

11. If ant lions become fitter than the elite then update it.
end while
The global solution is obtained (elite).

6. Results and Analysis

Example-1: Sphere test function

In this section, two examples are preferred one is Sphere test function and IEEE 30 bus system to validate the proposed algorithm. Sphere test function is given below equation (18)

$$F = \sum_{i=1}^{n} x_i^2 \qquad -100 \le x \le 100 \qquad (18)$$

Convergence characteristics for the Sphere test function are shown in Fig.1. From Fig. 1 it can be observed that, initial iteration starts with lesser value in case of the proposed AALO algorithm in comparison with hybrid cuckoo search algorithm (HCSA) and basic ant line optimization (ALO) algorithm.. It can also be observed that convergence curve of proposed algorithm shows a smooth variation while for ALO algorithm curve has stepped variations.

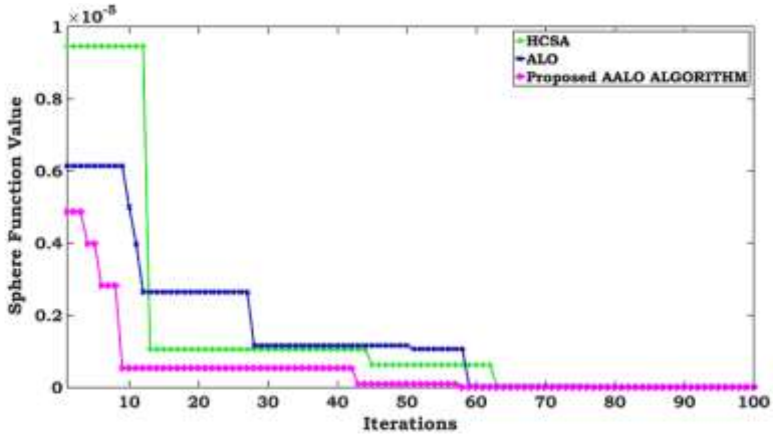

Fig. 1 Convergence curve for the Sphere test function with different algorithms

Example-2: IEEE 30 bus system

In order to justify the robustness and effectiveness of the proposed algorithm, IEEE-30 bus system is considered for solving the single objective OPF problem, in which 6 generators and remaining are the PQ buses. It consists of 41 transmission lines, 18 control variables, 4 transformers and two shunt devices. Required bus data, line data, load data, cost data and generation data has been considered from [12].

Optimal power flow results for generation fuel cost with implementation of proposed AALO algorithm is tabulated in Table 1, with its comparison from the existing algorithms. It can be seen that generation fuel cost is minimized to 789.46$/h which is by far the better solution obtained in comparison to other existing algorithms.

Table.1 Comparison of OPF solutions for generation fuel cost minimization for IEEE-30 bus system

Variables	**FFA [11]**	**ALO**	**Proposed AALO**
PG1, MW	177.72	176.65	175.97
PG2, MW	45.46	48.84	48.12
PG5, MW	22.24	21.53	25.19
PG8, MW	20.60	21.74	15.98
PG11, MW	14.71	12.17	18.62
PG13, MW	12.00	12.00	14.30
V1, p.u.	1.10	1.10	1.06
V2, p.u.	1.08	1.07	0.98
V5, p.u.	0.92	1.07	0.95
V8, p.u.	1.10	1.07	0.97
V11, p.u.	0.96	0.96	0.98
V13, p.u.	1.06	1.03	0.90
T 6-9, p.u.	1.01	1.00	0.98
T 6-10, p.u.	0.99	1.08	0.99
T 4-12, p.u.	0.99	1.10	0.94
T 28-27, p.u.	0.98	1.03	0.95
Q 10, p.u.	28.98	15.07	6.51
Q 24, p.u.	20.53	9.57	10.15
Generation fuel cost $/h	**802.38**	**802.20**	**798.46**

The convergences characteristic of generation cost is shown in Fig.2. From this figure it is clear that the proposed method is best when compared to existing methods

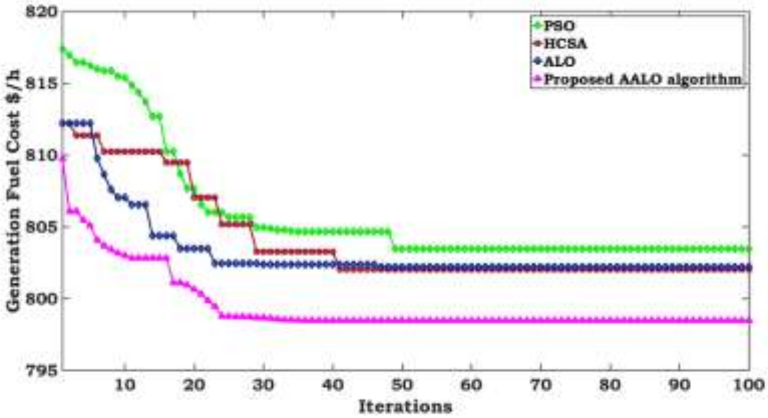

Fig. 2 Convergence characteristics of fuel cost for IEEE 30 bus system

7. Conclusions

In this paper, Ameliorated Ant Lion Optimization Algorithm had been proposed for minimizing the single objective problem of OPF including objectives such as generation fuel cost, emission and total power losses in power system. The proposed algorithm had been tested on Sphere test function, which in results proves that the addition of Lévy flight operator in existing Ant Lion Optimization Algorithm revamp the performance and yields better solutions with fast convergence rate. Thus the proposed algorithm had been validated on IEEE-30 bus system and hence it can be contemplated as a better alternative approach for solving OPF problems more effectively and efficiently.

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