# Self Adaptive Firefly Algorithm based Reducing fuel cost for location of DC link

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**Abstract** – Economic load dispatch (ELD) is an important operational problem is formulated as an optimization problem of minimizing the fuel cost while satisfying several equality and inequality constraints. This paper presents a Self Adaptive Firefly Algorithm (SFO) for the solution of the Optimal Power Flow (OPF) with DC Link Placement Problem. OPF problem is formulated as a nonlinear constrained multiobjective optimization problem where different objectives and different constraints have been considered. The recent developments in power electronics have enabled introduction of dc links in the AC power systems with a view of making the operation more flexible, secure and economical. This paper formulates a new OPF to embrace dc link equations and presents a heuristic optimization technique, inspired by the behavior of fireflies, for solving the problem. It presents simulation results of IEEE14 test systems with a view of demonstrating its effectiveness.

**Keywords**: Economic Load Dispatch, AC/DC power flow, firefly optimization, Valve point effect

## 1. Introduction

The Optimal Power flow (OPF) problem has been widely used in power system operation, control and planning since its introduction by Carpenter in 1962 [1]. The Optimal Power flow problem to determines for different optimal settings for certain power system control variables by optimization for selected objective functions while satisfying a set of equality and inequality constraints for given settings of loads and system parameters. The control variables include generator active powers, generator bus voltages, transformer tap ratios and the reactive power generation of shunt compensators. In general, the total fuel cost (FC) is commonly used as the main objective for OPF problems. The existing OPF problem can be modified to handle AC/DC systems [2-3]. The resulting optimization problem, designated as Optimal Power flow with location of DC links, is a large scale, non-linear non-convex and multimodal optimization problem with continuous and discrete control variables. The existence of nonlinear power flow constraints and the DC link equations make the problem non-convex even in the absence of discrete control variables [4]. Recently, Firefly Optimization (FO) has been suggested by Dr. Xin-She Yang for solving optimization problems [5]. It has been applied to a variety of engineering optimization problems and found to yield satisfactory results[6-9]. It has been applied to a variety of Economic Load Dispatch problems [10-14] and found to yield satisfactory results. However, the choice of FA parameters is important in obtaining good convergence and global optimal solution. This paper formulates the problem of OPFDC, [15-22] suggests a solution methodology involving a self adaptive FO (SFO) with a view of obtaining the global best solution and demonstrates its performance through simulation results on the modified IEEE 14 bus systems.

## 2. Problem Formulation

The OPFDC problem is formulated as a constrained nonlinear optimization problem through combining the standard OPF problem and the DC link equations as

Minimize $\Phi(x,u)$ (1)

Subject to

$b(x,u)=0$ (2)

$g(x,u)\le 0$ (3)

Where

$x=[V_i^L, Q_j^G, P_s^G]$

(4)

$u=[P_k^G, V_j^G, T_v, Q_q^C, I_p^{dc}]$

(5)

$$b(x,u)=\begin{cases} P_m^G - P_m^D - V_m \sum\limits_{n\in\{\Omega,\Pi\}} V_n (G_{mn}\cos\delta_{mn} + B_{mn}\sin\delta_{mn}) = 0 \\ Q_m^G - Q_m^D - V_m \sum\limits_{n\in\{\Omega,\Pi\}} V_n (G_{mn}\sin\delta_{mn} - B_{mn}\cos\delta_{mn}) = 0 \\ h(x,u)=0 \end{cases} \quad (6)$$

$$g(x,u)=\begin{Bmatrix} P_k^{G(\min)} \le P_k^G \le P_k^{G(\max)} \\ Q_j^{G(\min)} \le Q_j^G \le Q_j^{G(\max)} \\ Q_q^{C(\min)} \le Q_q^C \le Q_q^{C(\max)} \\ T_v^{\min} \le T_v \le T_v^{\max} \\ V_j^{G(\min)} \le V_j^G \le V_j^{G(\max)} \\ V_i^{L(\min)} \le V_i^L \le V_i^{L(\max)} \\ I_p^{dc(\min)} \le I_p^{dc} \le I_p^{dc(\max)} \\ |S_{Li}| \le S_{Li}^{\max} \end{Bmatrix}$$

(7)

$$h(x,u)=\begin{Bmatrix} V_m^{dc} - s_m\, c_2\, h_m\, V_w^{ac}\, cos\theta_m + s_m\, c_3\, X_m^c\, I_m^{dc} = 0 \\ V_m^{dc} - 0.995\, s_m\, c_2\, h_m\, V_w^{ac}\, cos\varphi_m = 0 \\ Q_w^{ac} - V_w^{ac}\, c_2\, h_m\, I_m^{dc}\, sin\varphi_m = 0 \\ P_w^{ac} - V_w^{ac}\, c_2\, h_m\, I_m^{dc}\, cos\varphi_m = 0 \\ P_m^{dc} - V_m^{dc}\, I_m^{dc} = 0 \\ I_m^{dc} - \left(V_m^{dc} - V_n^{dc}\right)/R_{mn}^{dc} = 0 \\ V_m^{dc} - V_n^{dc} - I_m^{dc}\, R_{mn}^{dc} = 0 \end{Bmatrix} \quad (8)$$

$s_m$ = 1 for rectifier and -1 for inverter

$c_2 = 3\sqrt{2}/\pi$ $\quad c_3 = 3/\pi$

$i \in \Omega$ $\quad j \in \Pi$

$k \in \Psi$ $\quad v \in \Re$

$p \in \Im$ $\quad q \in \aleph$

**Minimization of Fuel Cost**

$$\text{Minimize} \quad \Phi_1(x,u) = \sum_{j\in\Pi} a_j\, P_j^{G^2} + b_j\, P_j^G + c_j + \left| d_j \sin(e_j(P_j^G(\min) - P_j^G)) \right| \quad (9)$$

The multi-objective OPFDC problem is tailored by combining several objectives through weight factors so as to optimize all the objectives simultaneously.

$$\text{Minimize} \quad \Phi(x,u) = \sum_{i=1}^{nobj} w_i\, \Phi_i \quad (10)$$

### 3. Equations and Units

The proposed method (PM) involves representation of problem variables that include the control variables and self-adaptive parameters, $\alpha_i$ , $\beta_{oi}$ and $\gamma_i$ ; and the formation of a light intensity function, $LI$ .

### 3.1 Representation of decision variables

Each firefly in the PM is defined to denote these decision variables in vector form as

$$f = [P_k^G, V_j^G, T_v, I_p^{dc}, L_p, \alpha, \beta_o, \gamma];$$

$$j \in \Pi \quad k \in \Psi \quad v \in \Re \quad p \in \Im$$

(11)

### 3.2 Intensity Function

The SFO searches for optimal solution by maximizing a light intensity function, denoted by $LI$ , which is formulated from the objective function of Eq. (1) .The $LI$ can be built as

$$\text{Maximize} \quad LI = \frac{1}{1+\Phi^A} \quad (12)$$

Where

$$\Phi^A = \Phi(x,u) + \lambda_V \sum_{i\in\Omega}\left(V_i^L - V_i^{\text{limit}}\right)^2 + \lambda_Q \sum_{i\in\Pi}\left(Q_i^G - Q_i^{\text{limit}}\right)^2 + \lambda_P\left(P_S^G - P_S^{\text{limit}}\right)^2 + \lambda_S \sum_{i\in M}\left(S_{Li} - S_{Li}^{max}\right)^2 \quad (13)$$

The power system is altered through setting the control parameters of $\{P_k^G, V_j^G, T \text{ and } I_p^{dc}\}$ for each firefly.

### 3.3 Solution Process

The pseudo code of the PM is as follows.

**Read** the Power System Data

**Choose** the parameters, $nf$ and $Iter^{\max}$.

**Generate** the initial population of fireflies

**Set** the iteration counter $t = 0$

**while** (termination requirements are not met) do

**for** $i = 1:nf$

- Set the control parameters according to $i$ -th firefly values
- Obtain the values for $\alpha_i$ , $\beta_o$ and $\gamma$ from the firefly
- Run AC/DC power flow
- Evaluate the augmented objective function $\Phi^A$ and light intensity function $LI_i$ using Eqs. 13 and 12 respectively

**for** $j = 1 : nf$

- Set the control parameters according to $j$-th firefly values
- Obtain the values for $\alpha_i$, $\beta_o$ and $\gamma$ from the firefly
- Run AC/DC power flow
- Evaluate the augmented objective function $\Phi^A$ and light intensity function $LI_j$ using Eqs. 13 and 12 respectively

if $LI_i < LI_j$

Compute $r_{i,j} = \left\| f_i - f_j \right\| = \sqrt{\sum_{k=1}^{nd} \left( f_i^k - f_j^k \right)^2}$

Evaluate $\beta_{i,j} = \beta_{o,i} \exp\left( -\gamma_i \, r_{i,j}^2 \right)$

Move $i$-th firefly towards $j$-th firefly through

$$f_i(t) = f_i(t-1) + \beta_{i,j}\left( f_j(t-1) - f_i(t-1) \right) + \alpha\left( rand - 0.5 \right)$$

**end**-(if)

**end**-( $j$ )

**end**-( $i$ )

Rank the fireflies and find the current best.

**end**-(while)

**Choose** the best firefly possessing the largest $LI_i$ in the population as the optimal solution

## 4. Simulations

The PA is tested on IEEE 14 bus test system, whose data have been taken from Ref. [24]. The fuel cost coefficients, lower and upper limits for real power generations for IEEE 14 bus test system are given in Table 3 of the appendix. Programs are developed in Matlab 7.5 and executed on a Core i3 , 2.2 GHz personal computer. Newton Raphson technique [23] is used to carry out the load flow during the optimization process. The parameters chosen for the PA are given in Table A.2.

The optimal solution obtained by the PA for IEEE 14 bus test system are given along with the initial solution before optimization in Tables A.3 respectively. The objective in this case is the minimization of the FC. It is observed from Table A.3, In case of 14 bus system the initial FC of 834.6716 $/h is reduced to 826.1494, 825.2302,825.8675 and 826.0464$/h by the location of DC line number 12 ,5 ,11 and 16 respectively. It is very clear from these tables that the proposed algorithm is able to Fuel cost is decreased. The resulting Fuel cost after optimization IEEE 14 bus test system is decreased.

## 5. Summary

Indeed the FA is a powerful novel population based method for solving complex optimization problems. In this paper, SAFA solution technique for ELD problem of AC/DC systems is developed and tested on IEEE 14 bus test system. The algorithm uses NR load flow technique for computing the slack bus power that includes network loss and is able to offer the global best solution at lower computational burden.

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**APPENDIX –A**

Table A.1 Generator Data for IEEE 14 bus test system

| Bus | $a$ | $b$ | $c$ | $d$ | $e$ | $P_j^{G(\min)}$ | $P_j^{G(\max)}$ |
|---|---|---|---|---|---|---|---|
| 1 | 0.0016 | 2.00 | 150 | 0.063 | 50 | 50 | 300 |
| 2 | 0.0100 | 2.50 | 25 | 0.098 | 40 | 20 | 80 |
| 3 | 0.0625 | 1.00 | 0 | 0 | 0 | 15 | 50 |
| 6 | 0.00834 | 3.25 | 0 | 0 | 0 | 10 | 35 |
| 8 | 0.025 | 3.00 | 0 | 0 | 0 | 10 | 30 |

Table A.2 FA parameters

| Parameter | Value |
|---|---|
| $nf$ | 30 |
| $Iter^{\max}$ | 100 |

Table A.3 Results of IEEE 14 bus test system

| Control Variables (p.u) | Before Optimization | PM ( After Optimization with DC Link ) | | | |
|---|---|---|---|---|---|
| $P_{G1}$ | 188.974 | 213.488951 | 212.608932 | 213.234294 | 213.488648 |
| $P_{G2}$ | 35 | 20.000000 | 20.000000 | 20.000000 | 20.000000 |
| $P_{G3}$ | 20 | 15.803174 | 16.256370 | 15.929864 | 15.769082 |
| $P_{G6}$ | 12 | 10.000000 | 10.000000 | 10.004641 | 10.000000 |
| $P_{G8}$ | 12 | 10.000000 | 10.023054 | 10.000000 | 10.000047 |
| $V_1^G$ | 1.060 | 1.099604 | 1.098670 | 1.099337 | 1.099355 |
| $V_2^G$ | 1.045 | 1.073385 | 1.070445 | 1.072559 | 1.073201 |
| $V_3^G$ | 1.010 | 1.035194 | 1.031349 | 1.033780 | 1.035434 |
| $V_6^G$ | 1.070 | 1.044688 | 1.044505 | 1.044820 | 1.044514 |
| $V_8^G$ | 1-090 | 1.031624 | 1.029250 | 1.030246 | 1.031784 |
| $T_1$ | 0.978 | 0.963857 | 0.959380 | 0.962309 | 0.964185 |
| $T_2$ | 0.969 | 1.025585 | 1.027116 | 1.024010 | 1.025313 |
| $T_3$ | 0.932 | 0.986749 | 0.991637 | 0.988021 | 0.987272 |
| $\alpha$ | --- | 0.000952 | 0.000056 | 0.004427 | 0.000505 |
| $\beta_o$ | --- | 0.008196 | 0.006809 | 0.010849 | 0.006613 |
| $\gamma$ | --- | 0.608644 | 0.604241 | 0.614050 | 0.607513 |
| $L_p^{dc}$ | --- | 12 | 5 | 11 | 16 |
| $I_p^{dc}$ | --- | 0.130748 | 0.149296 | 0.137301 | 0.131202 |
| Loss | 8.9737 | 10.2921 | 9.8884 | 10.1688 | 10.2578 |
| Net Fuel Cost ($/h) | 834.6716 | 826.1494 | 825.2302 | 825.8675 | 826.0464 |

**References**

[1] Carpentier, J, "Contribution a l'Etude du Dispatching Economique," Bulletin de la Societe Francaise des Electriciens, vol. 3, pp.431-474, 1962.

[2] Cong Ji, Zhi-nong Wei, Guo-qiang Sun, Yong-hui Sun, "AC-DC Decoupling Algorithm of Optimal Power Flow with HVDC System," Applied Mechanics and Materials, vol.457, pp.1107-1112, 2014.

[3] Wang Feng , Le Anh Tuan, Lina Bertling Tjernberg, Anders Mannikoff and Anders Bergman, "A New Approach for Benefit Evaluation of Multiterminal VSC–HVDC Using a Proposed Mixed AC/DC Optimal Power Flow," IEEE Trans. on Power Delivery, vol.29, no.1, 432-443, 2014.

[4] J.Arrillaga, C.RArnold and B.J.Harker, "Computer Modeling of Electrical power systems," John Wiley & sons Ltd, pp.168-185, 1983.

[5] X. S. Yang, "Firefly algorithms for multimodal optimization," in Proceedings of the Stochastic Algorithms: Foundations and Applications of Lecture Notes in Computing Sciences, Springer, Sapporo, Japan, vol.5792, pp. 178-178, 2009.

[6] K. Mangoli, and K.Y. Lee, "Optimal real and reactive power control using linear programming, Electrical Power System Research," vol.26, no.1, pp.1-10, 1993.

[7] O.Alsac,and B. Scott, "Optimal load flow with steady state security, IEEE Transactions on power Apparatus and systems," vol.PAS, pp.745-751, 1974.

[8] Momoh JA and Zhu JZ, "Improved interior point method for OPF problems," IEEE Trans Power Syst., vol.14, no.3, pp.1114–20, 1999.

[9] Burchett RC, Happ HH and Vierath DR, "Quadratically convergent optimal power flow," IEEE Trans Power Apparatus Syst., vol.103, pp.3267–76, 1984.

[10] Abdel-Fattah Attia, Yusuf A.Al-Turki and Abdullah M.Abusorrah, "Optimal power flow using adapted genetic algorithm with adjusting population size," Electric Power Components and Systems, vol.40, pp.1285-99, 2012.

[11] Sood YR, "Evolutionary programming based optimal power flow and its validation for deregulated power system analysis," Int J Electr Power Energy Syst, vol.29, no. 1, pp.65-75, 2007.

[12] Mahmood Joorabian and Ehsan Afzalan, "Optimal power flow under both normal and contingent operation conditions using the hybrid fuzzy particle swarm optimisation and Nelder–Mead algorithm (HFPSO–NM)," Applied Soft Computing, vol.14, pp.623–633, 2014.

[13] A.V.Naresh babu, T. Ramana and S.Sivanagaraju, "Analysis of optimal power flow problem based on two stage initialization algorithm," Int J Electr Power Energy Syst., vol.55, pp.91-99, 2014.

[14] Niknam T, Narimani MR, Jabbari M and Malekpour AR, "A modified shuffle frog leaping algorithm for multi-objective optimal power flow," Energy, vol.36, pp.6420-32, 2011.

[15] Sivasubramani.S and Swarup.KS, "Multi-objective harmony search algorithm for optimal power flow problem," Int J Electr Power Energy Syst., vol.33, no.3, pp.745–52, 2011.

[16] Duman S, Güvenç U, Sönmez Y and Yörükeren N, "Optimal power flow using gravitational search algorithm," Energy Convers Manage, vol.59, pp.86-95, 2012.

[17] B.Srinivasa Rao and K. Vaisakh, "Multi-objective adaptive clonal selection algorithm for solving environmental/economic diaptch and OPF problems with load uncertainty," Electrical Power and Energy Systems, vol.53, pp.390-408, 2013.

[18] M. Rezaei Adaryani and A. Karami, "Artificial bee colony algorithm for solving multi-objective optimal power flow problem, Electrical Power and Energy Systems," vol.53, pp. 219-230, 2013.

[19] Mojtaba Ghasemi, Sahand Ghavidel, Mohsen Gitizadeh and Ebrahim Akbari, "An improved teaching-learning-based optimization algorithm using Levy mutation strategy for non-smooth optimal power flow," Electrical Power and Energy Systems, vol.65, pp.375-384, 2015.

[20] P. Kessel and H. Glavitsch, "Estimating the voltage stability of a power system," IEEE Trans. Power Deliver, vol.1, no.3, pp.346-54, 2000.

[21] Tahir Nadeem Malika, Azzam ul Asarb, Mudasser F. Wynec and Shakil Akhtar, "A new hybrid approach for the solution of nonconvex economic dispatch problem with valve-point effects," Electric Power Systems Research, vol.80, pp.1128-1136, 2010.

[22] Jason Yuryevich and Kit Po Wong, "Evolutionary programming based optimal power flow," IEEE Trans. on Power Systems, vol.14, no.4, pp.1245-1257, 1999.

[23] W.F. Tinney and C.E. Hart. (1967). Power flow solution by Newton's method, IEEE Trans. PAS-86: 1449-1460.

[24] Test Systems Archive, Available at http://www.ee.washington.edu/research/pstca/ (Accessed December 2012).