

Optimal Rating and Position of Distributed Generators under Variable Loading Conditions using Bacterial Foraging Algorithm

J. Belwin Edward*, K. Ravi, R. Sarjila, C. Sakthigokulrajan and Avagaddi Prasad

School of Electrical Engineering, VIT University, Vellore - 632014, Tamil Nadu, India;
jbelwinedward@vit.ac.in, k.ravi@vit.ac.in, r.sarjila@yahoo.com,
er.sakthigokul@gmail.com, prasadavagaddi@gmail.com

Abstract

The inclusion of Distributed Generation (DG) in the electric utility infrastructure has created opportunities for many technological innovations to achieve a variety of both utility and customer's benefits. The presence of DG in the power system network exhibits complex non-linear nature and can be solved by using optimization techniques. Bacterial Foraging Optimization Algorithm (BFOA) is best method to solve any nonlinear complex optimization problem. Hence in this paper, the non-linear Optimal Power Flow (OPF) problem including DG is framed as objective function and solved by using BFOA. The performance of the projected technique is verified for IEEE 14 and 30 bus test systems. The study outcomes shows, saving obtained due to reduced power loss contributes remarkable reduction in generation cost by using the optimal schedule of DG.

Keywords: Bacterial Foraging Optimization Algorithm (BFOA), DG Placement, Distributed Generation (DG), Heuristic Algorithms, Optimal Power Flow (OPF)

1. Introduction

DG schemes able to give energy solutions to consumers that are more cost-effective, deliver high power quality, reliability and environmental friendly compared to existing techniques. DG is nothing but small scale electric source which comprises of any form of renewable energy resources such as biomass, wind, solar, diesel generator, small hydro power and micro turbine etc. associated straightly to the utility's distribution network or on the consumer site rather than connecting to the central generating station¹. DG provides many amenities to the utilities and customers that include standby generation, peak saving ability, base-load generation. Further,

for industries, DG can decrease total energy usage and peak demand charges². For bulk power producers, DG can increase universal system reliability and avoid huge amount of investments for upgradation of transmission system and decrease losses in transmission. The range of DG varies from several KW to 50 MW. The aforementioned advantages of DG have attracted the attention of researchers and motivated research on implementation of DG in power system network.

However, in contrast, one has to understand that the installation of DG at non-optimal position might cause undesirable power system behavior, such as cost and losses of the system increases, voltage upswing and uncertainties, stability and reliability problems³. So, it is

*Author for correspondence

essential to apply a techniques based on optimization or heuristic approach to detect the optimal rating and position of DG for a specified system that can deliver economic performance of the device. An outstanding study of various approaches applied for bestrating and position of DG is presented^{3,4}. OPF⁵ is used as one of the technique for optimal position of DG in power systems. It has taken decades to improve effective procedures for the solution of OPF due to its highly non-linear nature. Various optimization approaches have been used to solve for the above objective and the summary of the techniques applied is presented below:

Harrison et al. has implemented a technique that combination of Genetic Algorithm and OPF (GA-OPF) could deliver the better combination of locations within a distribution network for connecting a predefined number of DGs⁶. A novel hybrid technique projected by Gomez-Gonzalez et al. which uses discrete Particle Swarm Optimization (PSO) and OPF to connect a predefined number of DG among a big amount of possible combinations within a distribution network⁷. Ignacio et al. has presented a novel model by employing Tabu-Fuzzy for the multi-objective optimal forecasting of power distribution networks⁸. Genetic-Fuzzy (GA-FZ) technique implemented for distribution systems to solve placement of DG⁹. Gondomar et al. has proposed a fresh execution of a Genetic-Tabu Search (GA-TS) procedure for the optimal sharing of DGs in the distribution network¹⁰. Most of the above methods have used GA to find the optimal placement but GA has the inherent drawback of slower convergence, convergence to near global optimum and problem of pre-mature convergence.

Recently in the year 2002, Passino proposed BFOA¹¹. It eliminates animals with poor foraging strategies based on natural selection. Over certain real-world optimization problems, BFOA can perform many optimization algorithms in terms of final accuracy and convergence speed¹²⁻¹⁴. OPF problem using BFOA has been presented¹⁵. However, the advantage of BFOA is reaching guaranteed global optimum for the given problem.

In this paper, the innovative algorithm named hybrid BFOA-OPF is proposed to solve OPF problem with DG. An IEEE 30 bus test system with DG devices is considered and solved using the Proposed Algorithm. The simulation outcomes represents that the BFOA based OPF algorithm has an improved behavior in terms of tracking ability and optimization accuracy compared to GA.

2. Problem Formulation of OPF with DG

The objective of this article is to minimize the overall cost function that includes the cost characteristics of DG and fuel cost of other conventional generators in addition to the determination of best position and rating of DG for IEEE 14 and IEEE 30 bus system. Various possible formulations of Objective Function (OF) for power system network with DG are presented. The quadratic function for conventional cost functions in US\$/Hour and is given by:

$$C_x(P_g) = a + b.P_g + c.P_g^2 \quad (1)$$

Where, P_g is generator active power output in (MW), a , b and c indicates cost coefficients of generator.

The presence of DG in a power system can be represented either as a lineal function or as a quadratic function. However, expressing DG cost function as quadratic is more appropriate. Hence, in this paper, a quadratic cost functions for DG is taken and is given below:

$$C_y(P_{dg}) = d + e.P_{dg} + f.P_{dg}^2 \quad (2)$$

Where, P_{dg} is distributed generator active power outputs in (MW), d , e and f are cost coefficients the distributed generator.

The overall cost function C_T formulated as a combination of conventional fuel cost function and DG cost function is represented by:

$$C_T = C_x(P_g) + C_y(P_{dg}) \quad (3)$$

The above cost function is reframed with the objective of minimization of the total cost C_T :

$$\text{Min}(C_T) = \text{Min}(C_x(P_g) + C_y(f)) \quad (4)$$

Subject to the following constraints:

2.1 Equality Constraints

g defines equality constraints representing typical load flow equations:

$$P_{Gi} - P_{Di} - V_i \sum_{j=1}^{NB} [V_j [G_{ij} \cos(\delta_i - \delta_j) + B_{ij} \sin(\delta_i - \delta_j)]] = 0 \quad (5)$$

$$Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{NB} [V_j [G_{ij} \sin(\delta_i - \delta_j) + B_{ij} \cos(\delta_i - \delta_j)]] = 0 \quad (6)$$

Where the voltages of i^{th} and j^{th} bus are denoted with V_i and V_j respectively, P_{Gi} and P_{Di} are indicates active power of i^{th} generator and demand of active power of i^{th}

bus, Q_{Gi} and Q_{Di} indicates reactive power of i^{th} generator and demand of reactive power of i^{th} bus B_{ij} , G_i , and δ_{ij} are the susceptance, conductance and phase difference of voltages between i^{th} and j^{th} bus and total number of buses denoted with NB .

2.2 Inequality Constraints

h defines inequality constraints that consists:

2.2.1 Generator Constraints

Generator voltage, active output and reactive output are controlled by their minimum and maximum limits as follows:

$$V_{Gi}^{min} \leq V_{Gi} \leq V_{Gi}^{max}, i = 1, 2, \dots, NPV \quad (7)$$

$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max}, i = 1, 2, \dots, NPV \quad (8)$$

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max}, i = 1, 2, \dots, NPV \quad (9)$$

Where, at i^{th} generating unit minimum generator voltage, minimum active power output and minimum reactive power output are denoted with, V_{Gi}^{min} , P_{Gi}^{min} and Q_{Gi}^{min} respectively. Similarly maximum generator voltage, maximum active power output and maximum reactive power output at i^{th} generating unit are denoted with V_{Gi}^{max} , P_{Gi}^{max} and Q_{Gi}^{max} respectively. NPV is the number of PV bus including slack bus.

2.2.2 Transformer Constraints

Tap settings of the transformer are controlled by their minimum and maximum limits as follows:

$$T_i^{min} \leq T_i \leq T_i^{max}, i = 1, 2, \dots, NT \quad (10)$$

Where T_i^{min} indicates minimum tap setting limit and T_i^{max} indicates maximum tap setting limit of i^{th} transformer. NT indicates number of tap regulating transformers.

2.2.3 Shunt VAR Compensator Constraints

Shunt VAR compensators can be controlled by their minimum and maximum limits as follows:

$$Q_{Ci}^{min} \leq Q_{Ci} \leq Q_{Ci}^{max}, i = 1, 2, \dots, NC \quad (11)$$

Where Q_{Ci}^{min} indicates are the minimum VAR injection limit and Q_{Ci}^{max} indicates maximum VAR injection limit of i^{th} shunt capacitor. NC indicates number of shunt VAR compensators.

3. Bacterial Foraging Optimization Algorithm with OPF (BFOA-OPF)

Implementation of the proposed method (BFOA-OPF) for the above formulated OPF problem is explained in the subsequent section. The superiority of BFOA makes it an efficient tool for solving OPF problem with DG compared to other optimization techniques. The basic BFOA contains 3 basic steps; named as chemotaxis, reproduction and elimination-dispersal¹³. The below Figure 1 shows the flowchart for the proposed BFOA-OPF technique. The Figure 2 shows the flowchart for finding the optimal rating and position of the DG using BFOA.

3.1 Pseudo Code for Optimal Rating and Position of DG using BFOA

- Step 1:** Initialize DG rating P_{DG} , P_{Gi}^{max} .
- Step 2:** Evaluate Objective function using BFOA and update optimal DG Position.
- Step 3:** Increase DG rating in all Load buses.
- Step 4:** Check $P_{DG} > P_{Gi}^{max}$, if yes goto step 5 else go to step 2.
- Step 5:** Increase DG rating in optimal position.
- Step 6:** Evaluate Objective function using BFOA and update optimal DG rating,
- Step 7:** Check $P_{DG} > P_{Gi}^{max}$, if yes go to step 8 else go to step 5.
- Step 8:** Print: Optimal DG rating and position.
- Step 9:** Terminate.

4. Results and Discussions

4.1 Optimal Location of DG

In this work, internal combustion engine is considered as DG and it is inserted in all PQ buses of the test systems (IEEE14 bus and IEEE 30 bus systems). The value of DG connected in a particular PQ bus is varied between the limits (1 MW to 40 MW) and the corresponding total generation cost including the generation cost of DG is computed. The variation of total generation cost with respect to the DG size in each PQ bus for IEEE14 and IEEE 30 bus test systems are shown in Figure 3 and Figure 4 respectively. From Figure 3, it is evident that the reduction in cost is remarkable when DG is added at bus number 13.

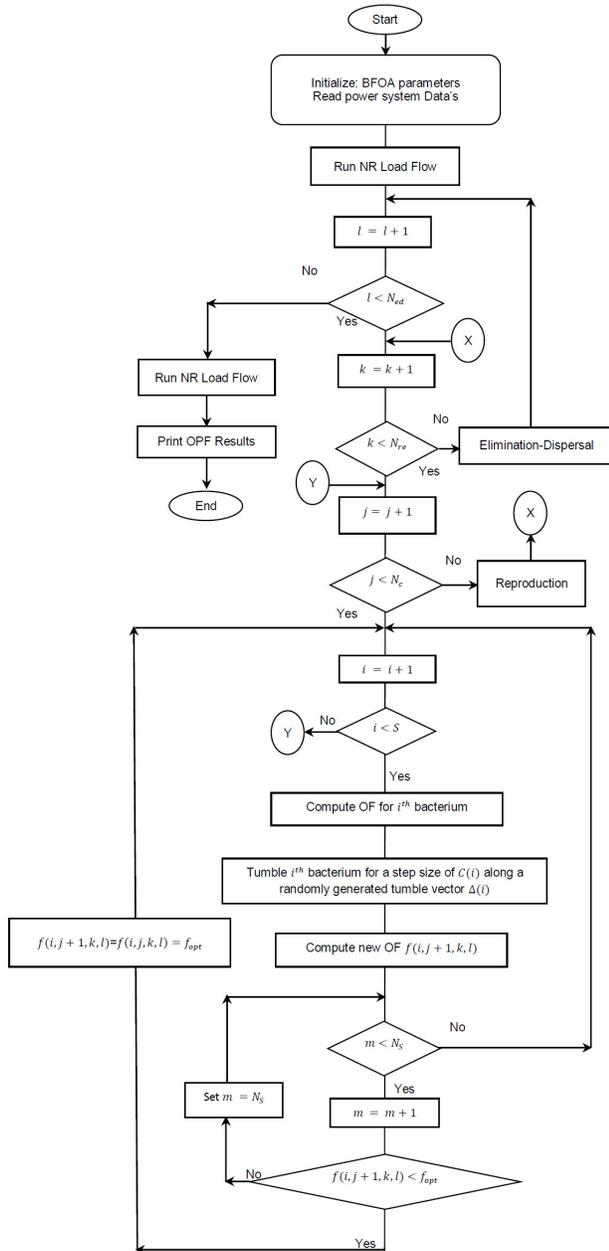


Figure 1. Flowchart for Optimal Power Flow using Bacterial Foraging Optimization Algorithm (BFOA-OPF).

In the same way it is found that bus number 7 is the optimum location for placing DG in IEEE 30 bus test system with increased loading of 30 MW at bus number 2 and is shown in Figure 4.

4.2 Optimal Rating of DG

Once the optimal location of DG is identified as explained in the previous section, the optimal rating of

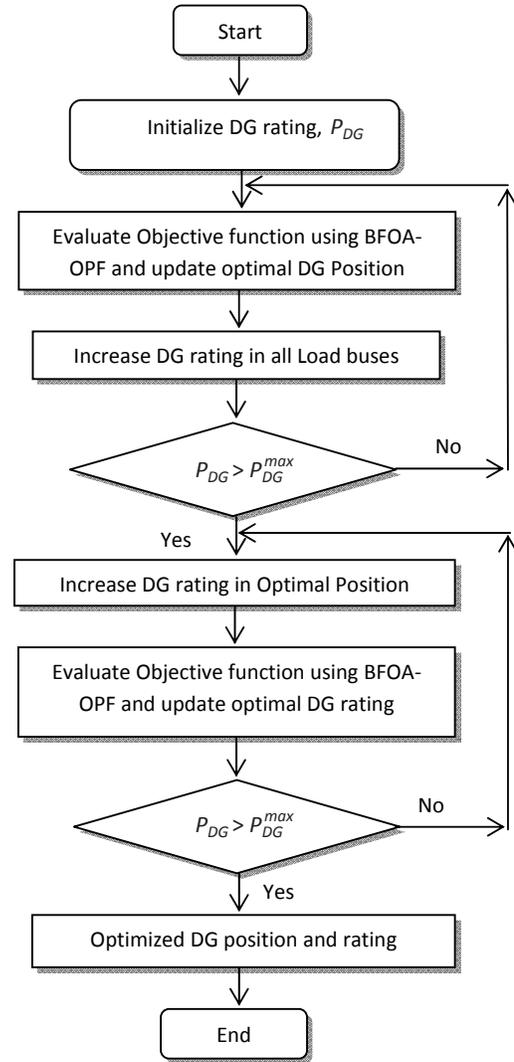


Figure 2. Flowchart for optimal rating and position of DG using BFOA

DG is computed by varying the rating of DG between the limits. The variation of total generation cost with respect to variation of DG in the identified optimal location i.e. at bus number 7 for IEEE 14 bus test system is shown in Figure 5. Similarly, the variation of total generation cost with respect to variation of DG in the identified optimal location i.e. at bus number 2 for IEEE 30 bus test system with addition of 30 MW loading and is shown in Figure 6. The optimal value of DG is found to be 15 MW and 23 MW and is presented in Figure 5 and Figure 6 respectively.

With increased loading of 10, 15, 20 and 30 MW in randomly selected load buses the optimal position and rating of DG are computed to check the effectiveness of

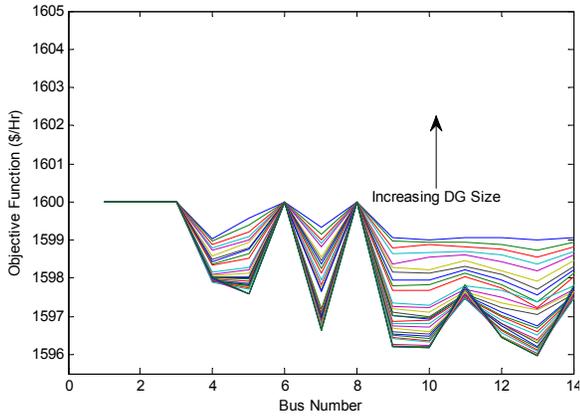


Figure 3. Variation of objective function with DG location for IEEE 14 bus system.

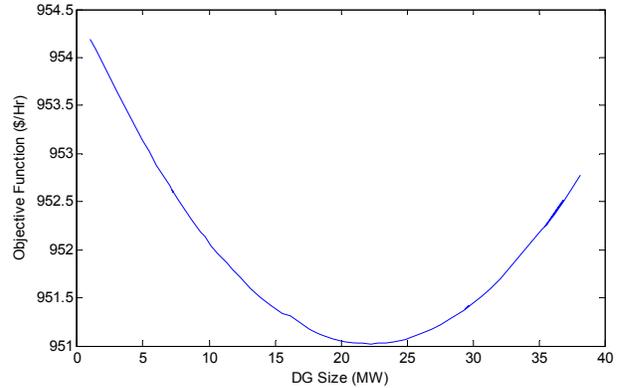


Figure 6. Variation of objective function with DG size for IEEE 30 bus system at optimal location (bus no. 7).

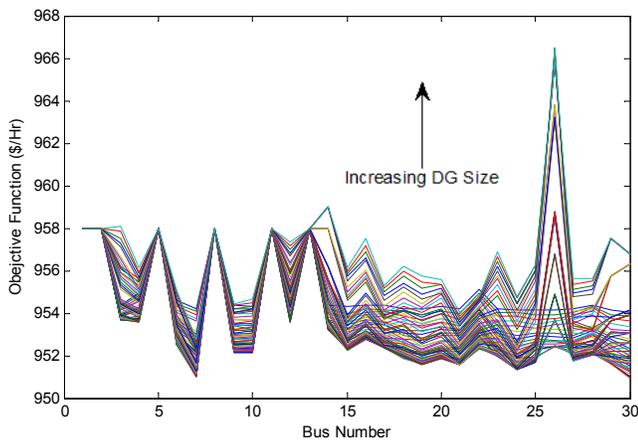


Figure 4. Variation of objective function with DG location for IEEE 30 bus system.

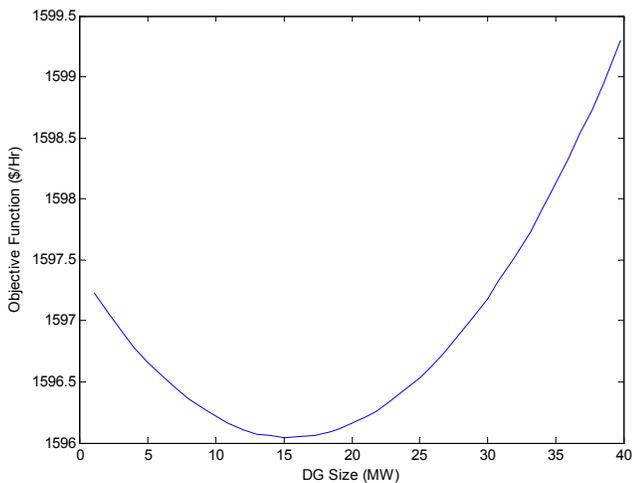


Figure 5. Variation of objective function with DG size for IEEE 14 bus system at optimal location (bus no. 13).

the proposed procedure. From the Table 1, it is evident that when 30 MW additional loading is done at buses 2, 4, 14, 17 and 10, the corresponding optimal DG positions are found to be bus numbers 21, 7, 24, 9 and 22 respectively.

Further, it may be noted that the rating of DG added to meet the additional load is always less than that of the load increased. DGs are located closer to the demand point so that it meets the required amount of additional load. However, the addition of DG to the existing IEEE 14 and IEEE 30 bus system will contribute to increase in total generation cost. This loss reduction compensates this increase in generator cost. It is also seen from the Table 1 in most of the cases, bus number above 20 is found to be the optimal position.

5. Conclusion

In this article, BFOA is suggested to detect the optimal rating and position of DG for IEEE 14 and IEEE 30 bus system. Minimization of total cost, in addition to optimal rating and position of DG, is framed as objective function and solved using the proposed method. Further, the proposed method is tested under varying load conditions and the results are presented. The proposed algorithm is found to be effective in detecting the optimal rating and position of DG and the suitable DG ratings are 15 MW for IEEE 14 with increased loading of 30 MW in bus number 4 and 23 MW for IEEE 30 bus system with increased loading of 30 MW in bus number 2. In conclusion, the results found in this work, proved that DG is a viable monetary alternative relative to enhancement of substations and feeder amenities, if the incremental cost of serving added load is considered.

Table 1. Optimal rating and position of DG devices under variable loading conditions

Bus No.	Normal Loading	New Loading	Optimal DG rating	Optimal DG position	Total loss	Total Cost	Total Load
	MW	MW	MW	Bus No.	MW	\$/Hr	MW
30 MW loading							
02	21.7	51.7	22.00	21	7.964	951.1	313.4
04	07.6	37.6	23.87	07	8.272	953.2	313.4
14	06.2	36.2	23.98	24	9.615	956.9	313.4
17	09.0	39.0	28.16	09	8.94	955.8	313.4
10	05.8	35.8	26.00	22	8.879	955.0	313.4
20 MW loading							
15	08.2	28.2	18.18	19	8.575	919.7	303.4
15 MW loading							
18	03.2	18.2	12.54	10	9.119	903.8	298.4
10 MW loading							
20	02.2	12.2	8.188	27	8.755	885.3	293.4
23	03.2	13.2	7.733	06	9.021	886.0	293.4

6. References

- Panwar NL, Kaushik SC, Kothari S. Role of renewable energy sources in environmental protection: A review. *Renewable and Sustainable Energy Reviews*. 2011 Apr; 15(3):1513–24.
- Pepermans G, Driesen J, Haeseldonckx D, Belmans R, D'haeseleer W. Distributed generation: Definition, benefits and issues. *Energy Policy*. 2005 Apr; 33(6):787–98.
- Tan WS, Hassan MY, Majid MDS, Rahman HA. Optimal distributed renewable generation planning: A review of different approaches. *Renewable and Sustainable Energy Reviews*. 2013 Feb; 18:626–45.
- Elavarasi R, Saravanan P. Impact of distributed generation on distribution systems and its protection. *Indian Journal of Science and Technology*. 2014 Nov; 7(S7):85–90.
- Hariharan T, Sundaram MK. Optimal power flow using hybrid intelligent algorithm. *Indian Journal of Science and Technology*. 2015 Sep; 8(23):1–9.
- Harrison GP, Piccolo A, Siano P, Wallace AR. Hybrid GA and OPF evaluation of network capacity for distributed generation connections. *Electric Power Systems Research*. 2008 Mar; 78(3):392–8.
- Gonzalez GM, Lopez A, Jurado F. Optimization of distributed generation systems using a new discrete PSO and OPF. *Electric Power Systems Research*. 2012 Mar; 84(1):174–80.
- Rosado RRIJ, Navarro DA. Possibilistic model based on fuzzy sets for the multi-objective optimal planning of electric power distribution networks. *IEEE Transactions on Power Systems*. 2004 Nov; 19(4):1801–10.
- Kim KH, Lee YJ, Rhee SB, Lee SK, You SK. Dispersed generator placement using Fuzzy-GA in distribution systems. *IEEE Power Engineering Society Summer Meeting*; Chicago, IL, USA. 2002 Jul 25. 3. p. 1148–53.
- Gandomkar M, Vakilian M, Ehsan MA. Genetic-based tabu search algorithm for optimal DG allocation in distribution networks. *Electric Power Components and Systems*. 2007 Feb; 33(12):1351–62.
- Passino KM. Biomimicry of bacterial foraging for distributed optimization and control. *IEEE Control Systems Magazine*. 2002 Jun; 22(3):52–67.
- Mishra S, Bhende CN. Bacterial foraging technique-based optimized active power filter for load compensation. *IEEE Transactions on Power Delivery*. 2007 Jan; 22(1):457–65.
- Edward BJ, Rajasekar N, Sathiyasekar K, Senthilnathan N, Sarjila R. An enhanced bacterial foraging algorithm approach for optimal power flow problem including FACTS devices considering system loadability. *ISA Transactions*. 2013 Sep; 52(5):622–8.
- Biswas A, Dasgupta S, Das S, Abraham A. A synergy of differential evolution and bacterial foraging optimization for faster global search. *International Journal on Neural and Mass-Parallel Computing and Information Systems*. 2007 Dec; 17(6):607–26.
- Tang WJ, Li MS, Wu QH, Saunders JR. Bacterial foraging algorithm for optimal power flow in dynamic environments. *IEEE Transactions on Circuits and Systems I*. 2008 Sep; 55(8):2433–42.