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Bacterial Foraging Optimization for Dispersed Energy Resources Placement Considering Reliability Enhancement and Power Loss Reduction of Distribution Systems

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Abstract: Distributed generators are beneficial in reducing the losses effectively compared to other methods of loss reduction. On the other hand DGs can be implemented for improvement of reliability of system too. In this paper optimal DG sources placement using Bacterial Foraging Optimization (BFO) is discussed. The optimal size and location of the DG unit is calculated. Reliability and power loss reduction indices of distribution system nodes are modeled and with aiming to achieve to minimum power loss and the most reliability in a typical distribution system DG sizing and placement is addressed. The new idea of this paper is based on two subjects. At first, the issue of DG placement and sizing according to two various purposes including power loss reduction and reliability improvement as simultaneously is analyzed and disused. Another idea of this study is implantation of Bacterial Foraging Optimization (BFO) as optimization tool for this purpose. In the other word, this study at first has discussed the issue of DG sitting and sizing in distribution system based on both aims includes power loss reduction and reliability enhancement using Bacterial Foraging Optimization (BFO).

Key words: Distributed generation · Distribution system · BFO algorithm · Reliability · Power loss reduction

INTRODUCTION

Distributed generation (DG) plays an important role in the distribution system. They have many benefits such as economical, technical and environmental benefits. Technical benefits are including peak reduction, power quality and reliability improvement and increasing efficiency of distribution system. DG is usually defined as an electric power source connected directly to the distribution network. By [1-4], the optimum location of the DGs in distribution network has been analyzed. They have studies the optimal location of DGs from various points of view. The main criterion that they have researched about DG optimal location includes system reliability improvement, the voltage profile improvement; network losses reduction .In Refs [5-8], the authors directed their studies to optimize location and sizing of DGs in distribution system.

Up to now many optimization techniques includes genetic algorithm (GA), tabu search (TS), particle swarm optimization (PSO), simulated annealing (SA) have been utilized by [9-15] to find optimal location and sizing of DGs. In this paper the new idea based on BFO algorithm has been implemented to find optimal location and size of DG in distribution system. Also another main idea of this paper is considering simultaneously reliability improvement and loss reduction. The reliability index that has been used in this research is based total average energy not supplied (AENS) with combined by power loss redaction considered as power loss reduction index (PLRI).

Modeling

Power Loss Reduction: DG sources are normally placed close to load centers and are added mostly at the distribution level. They are relatively small in size (relative to the power capacity of the system in which they are placed) and modular in structure [16-19].

A common strategy for sizing and placement of DG is either to minimize system power loss or system energy loss of the power systems. The voltage at each bus is in the acceptablerange and the line flows are within the limits. These limits are important so that integration of DG into the system does not increase the cost for voltage

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control or replacement of existing lines. The formulation to determining the optimal size and location of DG in a system is as follows:

Loss Reduction Factor Index per node is defined as the ratio of percentage reduction in loss from base case when a DG having size DGS KW is installed at bus i, to the DG size at that bus. Power Loss Reduction Index (PLRI) is expressed as:

$$PLRI = \frac{Ploss_{Base} - Ploss_{DGi}}{Ploss_{Base}} \tag{1}$$

where

After the iterative solution of bus voltages, line flows and line losses can be calculated. The complex powers Sij from bus i to j and Sji from bus j to i are:

$$\begin{aligned} Sij &= V_i I^*_{ij} \\ Sji &= V_j I^*_{ji} \end{aligned} \tag{2}$$

The power loss in line i-j is the algebraic sum of the power flows determined from the above equations.

$$Ploss = \sum_{i=1}^{N\_bus} \sum_{j=1}^{N\_bus} \mathrm{Re}\left\{S_{ji} + S_{ij}\right\} \tag{3}$$

Reliability Improvement: In order to guaranty the reliability of system, the paper calculates the power not supplied after the three phases short-circuit. In Vietnam, the more detail rate values for calculating the reliability are not yet available. So we just consider the time after fault clearing assuming that all DG are in ready state. The momentary interruption due to DG ready state is neglected. Reliability Improvement Index (RII) is illustrated as:

$$RII = \left\{\frac{AENS_T - AENS_i}{AENS_T}\right\} \tag{4}$$

where

ENS_T : The total average energy not supplied when the fault happened in sequence in all the sections in the case of without DG.

ENS_i : The total average energy not supplied when the fault happened in sequence in all the sections with the i-combination of DG.

which

$$AENS = \frac{\sum L_a(i) u_i}{\sum N_i} \tag{5}$$

which

N_i Number of customer at ith load point,

u_i Interruption duration at ith load point,

$L_a(i)$ Average load at ith load point,

Multiobjective Based Problem Formulation: The multiobjective index for the performance calculation of distribution systems for DG size and location planning with load models considers all previous mentioned indices by giving a weight to each index. The PSO-based multiobjective function (MOF) is given by:

$$MOF = \omega_1 * PLRI + \omega_2 * RII \tag{6}$$

where

$$\omega_1 + \omega_2 = 1 \tag{7}$$

These weights are indicated to give the corresponding importance to each impact indices for the penetration of DG with load models and depend on the required analysis (e.g., planning, operation, etc.). The weighted normalized indices used as the components of the objective function are due to the fact that the indices get their weights by translating their impacts in terms of cost. It is desirable if the total cost is decreased. In this work, due to more important the reliability factor respect to power loss reduction pupose, these weights are assigned as w_1 = 0.60 and w_2 = 0.40. However, these values may vary according to engineer’s concerns, Subjected to various operational constraints to satisfy the electrical requirements for distribution network. These constraints are the following.

Bacterial Foraging Optimization: The BF algorithm was first presented by Pasino in 2002. The idea in this algorithm was adopted from biological and physical living behavior of *E. coli* bacteria existing in human intestine. This algorithm has three main processes namely Chemotaxis, Reproduction and Elimination-Dispersal.

These processes are introduced in this section [19].

Chemotaxis: An *E. coli* bacterium can decide to move in two different ways depending on its environment. A bacterium is subject to change during its lifetime between the two ways of swimming (swim for a short time) and tumbling. In BFO, one moving unit length with random directions represents tumbling and one moving unit length with the same direction relative to the final stage represents swimming. The mathematical equation for Chemotaxis is expressed as follows:

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}} \tag{8}$$

where:

θ^i : Location of i^{th} bacterium
$C(i)$: Movement length
$\Delta(i)$: Direction random vector
j : is representing j^{th} Chemotaxis
k : is representing k^{th} reproduction,
l : is representing l^{th} elimination and dispersal.

Also, the number of Chemotaxis is represented by N_C.

Reproduction: After the number of N_C Chemotaxis steps, reproduction step takes place. N_{re}, represents the number of reproduction steps.

Elimination-Dispersal: The swimming process prepares the conditions for local search and reproduction process speeds up the convergence. In a large space swimming and reproduction for searching global optimal point cannot be sufficient. In bacterial foraging, dispersion takes place after a definite number of reproduction processes. A bacterium is selected with regard to a prearranged probability of P_{ed} to be dispersed in the environment and moved to another position. These events can effectively prevent trapping in local optimal point. Ned is the number of elimination and dispersal phenomenon and P_{ed} is defined for every bacterium with the probability of elimination and dispersal. The flowchart of process is presented in Fig. 1.

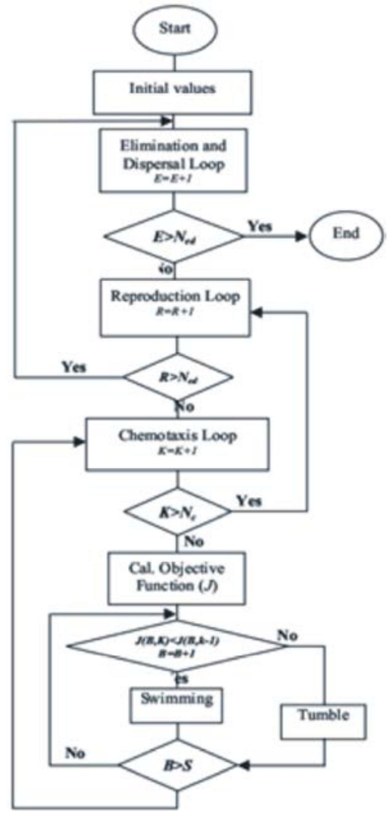

Fig. 1: B.F. Algorithm Flowchart

The Proposed BF Algorithm Application: In this section, the proposed method is used for determination the number, size and optimal location of DG devices in power systems. The objective functions and equality and inequality constraints employed in this paper are also discussed.

In order to use the BF process for the determining the size and optimal location of DG devices, it is required that each bacterium should have 2 variables. These variables are the size and optimal location of DG devices.

The optimization problem can be expressed as follows:

Minimize $J(x, u)$,
Subject to:

$g_j(x, u) = 0, j = 1,2,..., M$
$h_k(x, u) = 0, k = 1,2,... K$

where,

$J(x,u)$: Objective function
$g_j(x, u)$: Inequality constraints
$h_k(x, u)$: Equality constraints

Vector "x": consists of dependent variables
Vector "u": consists of control variables

And K and M are the number of equality and inequality constraints, respectively. It should be noted that each constraints can be expressed as linear or nonlinear ones.

In the proposed application the goal is to obtain the position of individual devices on the feeder, where these devices may be placed on a limited number of branches or buses. The locations where protective devices may be placed could be coded using discrete number between 1 and M, where M is the number of possible branches in the system where protective devices may be placed. Similarly, possible DGs may be coded using discrete numbers ranging from 1 to P for location and C_{min} and C_{max} for capacity, that R is the number of possible buses where DGs may be placed and C_{min} to C_{max}, that C_{min} and C_{max} are minimum and maximum possible capacity of DGs. So, a single solution can be defined as a specific allocation of individual DGs and protective devices on the feeder, i.e., the k^{th} solution in the population is an (2N)-dimensional row vector of discrete numbers:

$$X_k = \begin{Bmatrix} [x\,y\;z] \,|\, x_i \in \{1,...,P\}, i = 1,...,N, y_i \in \{C_{\min},...,C_{\max}\} \\ z_j \in \{1,...,R\}, j = 1,...,M \end{Bmatrix}$$

where:

X	Location list of each chromosomes
P	Number of buses
N	Number of Dgs
M	Number of lines
$C_{\min}$	Minimum Capacity of DGs
$C_{\max}$	Maximum Capacity of Dgs

with constraint

$$m \le M_{\max}$$
$$n \le N_{\max}$$
$$P_{\min} \le P_{DG}\,(i) \le P_{\max}$$
$$Q_{\min} \le Q_{DG}\,(i) \le Q_{\max}$$
$$\sum\nolimits_{i=1}^{m} P_{DG}(i) \le P_{DG,total}$$

where:

m	Number of DGs,
$M_{\max}$	Maximum number of DGs,
n	Number of MGs,
$N_{\max}$	Maximum number of MGs,
P_{DG}	Active power of DGs,
Q_{DG}	Reactive power of DGs,
$P_{\min}$, $P_{\max}$	Constraint of active power of DGs,
$Q_{\min}$, $Q_{\max}$	Constraint of reactive power of DGs
$P_{DG,total}$	Maximum capacity of DGs for Network,

The first part of constraint is related to DGs that is formed of number, possible location, active and reactive power for each source. The second part is related to permissible voltage of each load point in islanding mode and the last part is the number and possible location of MGs, so:

$$P_{DG-i,\min} \le P_{DG-i} \le P_{DG-i,\max}$$
$$Q_{DG-i,\min} \le Q_{DG-i} \le Q_{DG-i,\max}$$
$$V_{i-\min} \le V_i \le V_{i-\max}$$

which:

Q_{DG-i}	Reactive power of ith DG
V_i	Voltage at ith load point
$P_{DG-i,\min}$, $P_{DG-i\max}$	Constraint of active power of ith DG
$Q_{DG-i,\min}$, $Q_{DG-i\max}$	Constraint of reactive power of ith DG
$V_{\min}$, $V_{\max}$	Constraint of load point voltage

In this paper DGs have capability of voltage control and they are modeled as PV bus in power flow study. The Newton-Raphson method is applied in each island and if one of the constraints about DGs or load point voltage has been broken the island will be shut down. For each combination of switches and DGs, reliability areas are determined. Then, considering the islanding capability of the network, reliability index is calculated after the fault simulation on each line. In order to calculate the loss and voltage profile, a complete power flow is applied. Finally, for each chromosome, the amount of objective function is calculated.

Simulation and Results: The proposed methodology is tested on test systems to show that it can be implemented in distribution systems of various configuration and size. The test system is a 15 bus system with the 776.50 KVAR and base voltage 22KV. A single line diagram of the test system is shown in Figure 2. Also the real power request at each load point is listed by Table 1.

A computer program has been written in MATLAB 7.6 to calculate the optimum location and sizes of DG at various buses using BFO and reparative load flow method to identify the best location and size of DG. A complex Newton based load flow program is used to solve the load flow problem. The multiobjective function optimally minimized is shown in Figure 3.

By using the method described here, the best location in 15 bus system is in the order 5, 7, 11 and 15 and corresponding optimal sizes are 147.41 KW, 160.85 KW, 187.11 KW and 223.27 KW for reducing power loss and improvement reliability .The corresponding optimal size of DGs Table 2.

Table 1: The request power in each load point of test system

Load Point	Demand[kW]	Load Point	Demand[kW]
2	108	9	102
3	96	10	8
4	62	11	132
5	242	12	76
6	41	13	16
7	148	14	26
8	57	15	135

Table 2: Optimal DG unit sizes for 15-bus radial distribution system

Test System	Optimal Locations	Optimum DG Size in KW
15 bus	5	147.41
	7	160.85
	11	187.11
	15	223.27

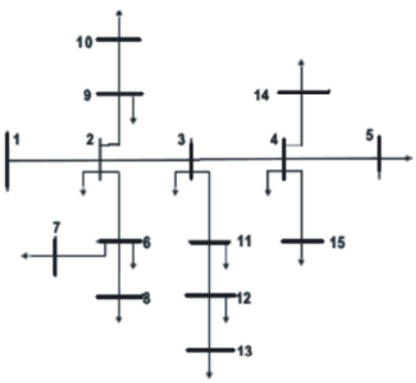

Fig. 2: Test distribution system

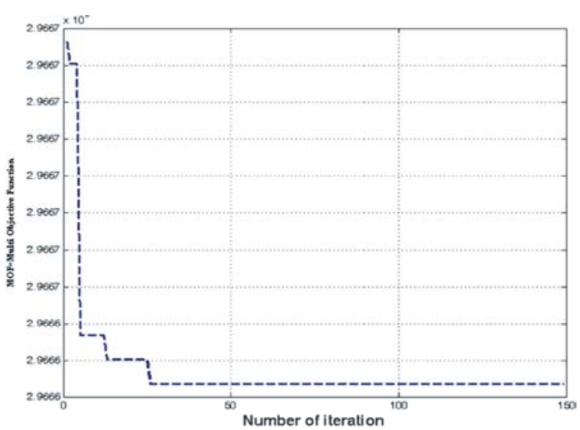

Fig. 3: Multiobjective function optimally minimized value versus iteration number

Results show that installing DG on system improve reliability indices and decrease power loss in system. Table 3 gives the total power loss in system before and after installing DG in optimal place with optimum result value. Also another index i.e. reliability index, show that average energy not supplied in system reduces when DGs are implemented in system at optimal locations.

Table 3: Results of power loss and average energy not supplied

Power Loss		AENS	
Without DG	With DG	Without DG	With DG
280.8 KW	110.5	75.7 kwh/yr	35.67
	120.6		48.34
	140.3		59.10
	150.2		64.30

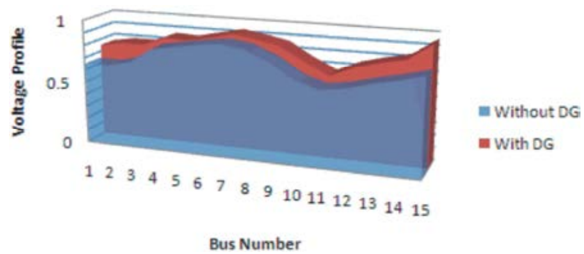

Fig. 4: Voltage profile before and after DG installation at each bus of system

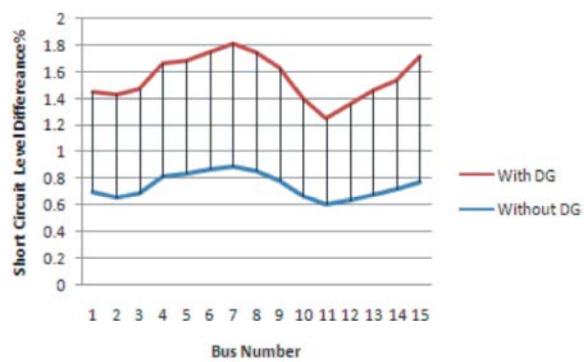

Fig. 5: The short circuit level difference of the system at each bus

By using the method described here, the best location in 15 bus system is in the order 5, 7, 11 and 15 and corresponding power loss are 110.5 KW, 120.6 KW, 140.3 KW and 150.2 KW, also corresponding average energy not supplied are 35.67 kwh/yr, 48.34 kwh/yr, 59.10 kwh/yr and 64.30 kwh/yr.

Figure 4 gives voltage profile of each bus in 15 bus radial system. The result shows the voltage level before and after installing DG. Before DG installation, voltage level from bus number 7-14 is lower than 0.95p.u. After DG installation, the voltage levels of these buses are improved with minimum of 0.96 p.u. for bus number 8. Further more if multiple DGs are installed, voltage level will be higher than the previous levels.

As a result of the placement of DG units in the system, the short circuit level at most of the system buses was increased. Figure 5 shows the difference between the short circuit level at each bus of the system with and without DG as a percent of the value of short circuit level before placement of DG units in the system. As shown in figure, the maximum increase is very low where a maxi-mum difference of 3.92% occurred at bus 4.

CONCLUSION

The DG placement in distribution must meet some objective functions in order to enhance the quality of network. The proposed objectives of the paper are met to Iran condition. These objective functions must be reflex not only the benefit of utility but also the private owner. In this study special type of DG as photovoltaic arrays (P.V), is introduced and that makes the solution more suitable. Beside, the expanding of objective and constraints are available in this work, so the paper's program is very convenient for users. In this paper an objective function with aim to reduce real power loss in all feeders of system and increase reliability of system, is considered and analyzed with BFO. In this investigation the effect of presence of DGs on voltage profile and short circuit level of each buses of test system are considered and analyzed.

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