INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
(Volume3, Issue2)
Available online at www.ijariit.com

Intelligent Methods used for Placement of Distributed Generation Units in Distribution Networks

A. Arulvizhi
CK College Of Engineering & Technology, Cuddalore, Tamil Nadu

B. Balaji
CK College Of Engineering & Technology, Cuddalore, Tamil Nadu

G. Balambigai
CK College Of Engineering & Technology, Cuddalore, Tamil Nadu

---

Abstract: Distributed generation (DG) plays a significant role in reducing real power loss, lowering the operating cost and improving the voltage profile. This paper formulates the DG placement problem a combined objectives as individual objectives and presents a solution method for optimally determining the bus locations and sizing of multiple DG units in distribution networks using biogeography-based optimization (BBO). BBO, inspired from the geographical distribution of biological species, searches for an optimal solution through the migration and mutation operators. Test results on a 33-node distribution network reveal the superiority of the developed method.

Keywords: Radial distribution Networks; DG Units; Biogeography-Based Optimization.

NOMENCLATURE

BBO - biogeography based optimization, $[C]$ - branch-to-node matrix that describes the topological structure of the distribution network, c_1 & c_2 - cost coefficients of real power supplied by substation and DG units respectively, DG - Distributed Generation, f_j - j^{th} objective function, f_j^0 - value of f_j evaluated prior to placement of DG units, HSI - habitat suitability index, h_i - i^{th} habitat, $[I_L]$ - vector of load currents, $[i_b]$ - vector of branch currents, $i^{\max}_j$ - maximum permissible current through j^{th} branch, $I_{L,m}$ - equivalent load current at node- m , $Iter^{\max}$ - maximum number of iterations, LVM- lowest voltage magnitude, L_j - node location for installation of j^{th} DG unit, NVD - net voltage deviations, NOC - net operating cost, nn - number of bus, nb - number of branches, ndg - number of DG units for placement, neh - number of elite habitats, P^{mod} - habitat modification probability, P_m - mutation probability, P_{loss} - RPL in the network, $P_{DG,j}$ - real power rating of j^{th} DG unit, $P_{L-m} + jQ_{L-m}$ - real and reactive power load at node-m, $r_l + jx_l$ - resistance and reactance of branch- l , RPL – real power loss, $S^{\max}$ - maximum species count, SIV - suitability index variable, $V_m\angle\delta_m$ - voltage at node-m, $V_o\angle\delta_o$ - voltage at source node, VP - voltage profile, $[v_b]$ - vector of branch voltage drops, w_1 , w_2 & w_3 - weight factors, whose sum is equal to 1, w_b and w_g - penalty factors, $[z]$ - diagonal matrix containing the self-impedances of all the branches, $\mathbf{\Phi}$ - cost function, $\mathbf{\Psi}$ - augmented cost function combining objective and constraint functions, $\mathfrak{R}$ - a set of branches, whose current flow exceed the respective thermal limit, $\boldsymbol{\lambda}$ - immigration rate, μ - emigration rate

I. INTRODUCTION

Distribution networks provide the final link between the high voltage transmission network and the consumers. They are radial in nature and deliver power to a variety of loads in the residential, industrial and **commercial sectors with a view of satisfying the customers' demand in a more economical and reliable** manner. The high r/x ratio and the radial or weakly meshed nature cause progressive voltage drop and lead to significant power loss of around 13% of overall power loss of the entire power system [1].

Distributed Generation (DG), unlike conventional generation, aims to generate part of required electrical energy on small scale (typically 1 KW–50 MW) closer to the places of consumption and interchanges the electrical power with the network. The DG, also termed as embedded generation or dispersed generation or decentralized generation, has been defined as electric power source connected directly to the distribution network [2]. DGs include synchronous generators, induction generators, reciprocating engines, micro turbines, combustion gas turbines, fuel cells, solar photovoltaic, wind turbines and other small power sources. They are cost effective and environmental friendly as they eliminate the need for expensive construction of distribution and transmission lines. Besides they provide high power quality and more reliable energy than conventional generations. The number of DG units installed in the distribution system has been increasing significantly with a view of achieving the technical, economical and environmental benefits, which could be maximized by proper planning, that is, placement of DG at optimum location with optimum size and suitable type. The majority of the DG planning objective has been to minimize the real power loss (RPL) in the network and improve voltage profile (VP) [3].

Several methods for determining the optimal location and size of DG units have been proposed in the recent decades. An analytical method for determining optimal location of DG units in radial and meshed networks with a view of minimizing the RPL has been suggested in [4]. An improved method involving analytical expressions for finding optimal locations and sizing of multiple DGs for reducing RPL in distribution systems has been outlined in [5]. A hybrid algorithm combining genetic algorithm and particle swarm optimization for optimal placement of DGs with a view to minimize RPL, improve voltage profile and enhance voltage stability, has been presented in [6]. A simulated annealing based approach for optimal sizing of DGs at locations determined by loss sensitivity factors for RPL minimization and voltage profile improvement in distribution networks has been notified in [7]. A bacterial foraging optimization based method for solving multi-objective DG placement problem has been presented in [8]. It uses loss sensitivity factors for determining the optimal locations while the bacterial foraging finds out the optimal size of DGs. A mixed integer nonlinear programming based method for optimal placement of multiple DG units in distribution system for RPL minimization has been explained in [9]. A hybrid algorithm involving ant colony and artificial bee colony optimization has been described for determining optimal location and sizing of DGs in distribution networks with a view of minimizing RPL, reducing the emissions of DGs, lowering the energy cost and improving the voltage stability in [10]. An invasive weed optimization based algorithm for optimal sizing of multiple DGs to be placed at locations determined using loss sensitivity factor technique has been outlined in [11]. Recently, a Biogeography-Based Optimization (BBO), a population based meta-heuristic optimization technique sharing information between candidate solutions based on their fitness values, has been suggested for solving optimization problems by Simon [12]. It has been applied to a variety of power system optimization problems [13-16] and found to yield satisfactory results.

This paper attempts to apply BBO in solving the DG placement problem with a view of minimizing the RPL and reducing the operating cost besides obtaining better VP. The method is tested on 33-node radial network and the results are presented.

II. BIOGRAPHY BASED OPTIMIZATION

BBO, based on the concept of biogeography, is a stochastic optimization technique for solving multimodal optimization problems [14]. In BBO, a solution is represented by a habitat- i consisting of solution features named Suitability Index Variables (SIV), which are represented by real numbers. It is represented for a problem with nd decision variables as

$$h_i = [SIV_{i,1}, SIV_{i,2}, SIV_{i,3}, \quad , SIV_{i,nd}] \tag{1}$$

The suitability of sustaining larger number of species of a habitat- i can be modeled as a fitness measure referred to Habitat Suitability Index (HSI) as

$$HSI_i = f(h_i) = f(SIV_{i,1}, SIV_{i,2}, SIV_{i,3}, \quad , SIV_{i,nd}) \tag{2}$$

High HSI represents a better quality solution and low HSI denotes an inferior solution. The aim is to find optimal solution in terms of SIV that maximizes the HSI .

Each habitat is characterized by its own immigration rate λ and emigration rate μ . A good solution enjoys a higher μ and lower λ and vice-versa. The immigration and emigration rates are the functions of the number of species in the habitat and defined for a habitat containing k -species as

$$\mu_k = E^{\max}\left(\frac{k}{n}\right) \tag{3}$$

$$\lambda_k = I^{\max}\left(1 - \frac{k}{n}\right) \tag{4}$$

When $E^{\max} = I^{\max}$, the immigration and emigration rates can be related as

$$\lambda_k + \mu_k = E^{\max} \tag{5}$$

A population of candidate solutions is represented as a vector of habitats similar to any other evolutionary algorithm. The features between the habitats are shared through migration operation, which is probabilistically controlled through habitat modification probability, P^{mod} . If a habitat h_i in the population is selected for modification, then its λ is used to probabilistically decide whether or not to modify each SIV in that habitat. The μ of other solutions are thereafter used to select which of the habitats in the population shall migrate

randomly chosen *SIVs* to the selected solution h_i . The cataclysmic events that drastically change the *HSI* of a habitat is represented by mutation of *SIVs* **. The mutation operation modifies a habitat's** *SIV* randomly based on mutation rate P_m and tends to increase diversity among the population, avoids the dominance of highly probable solutions and provides a chance of improving the low *HSI* solutions. Mutation rate of each solution set can be calculated in terms of species count probability using the following equation:

$$P_m = m_{\max}\left(\frac{1-P^{k}}{P_{\max}}\right) \tag{6}$$

PROBLEM FORMULATION

Distribution Power Flow

The equivalent load current at node- m ($I_{L,m}$) of the distribution network can be computed from the specified real and reactive power loads $(P_{L-m} + jQ_{L-m})$ as

$$I_{L,m} = \left(\frac{\left(P_{L-m} - P_{DG,m}\right) + jQ_{L-m}}{V_m \angle \delta_m}\right)^{*} \quad ; \quad m = 1, 2, nn \tag{7}$$

The branch currents in terms of equivalent load currents of all the bus can be written as [17]

$$\left[i_b\right] = \left[C\right]\left[I_L\right] \tag{8}$$

The voltage drop across all branches can be computed from the relation

$$\left[v_b\right] = \left[z\right]\left[i_b\right] \tag{9}$$

Similar to (8), the node voltages can be written in terms of branch voltages by the relation

$$V_i \angle \delta_i = V_o \angle \delta_o - \sum_{j=1}^{nb} C_{ji}\, v_{b,j}\ ,\ i = 1, 2, , nn \tag{10}$$

Objective Functions

The objective of the DG placement problem is to minimize the RPL, net voltage deviations (NVD) and net operating cost (NOC). These objectives can be formulated as

The siting and rating of DGs should be optimally chosen in such a way to minimize the RPL and improve the VP besides reducing the operating cost. The first objective is thus built to indicate the RPL as

$$f_1 = RPL = \sum_{j=1}^{nb} \left|i_j\right|^2 r_j \tag{11}$$

The VP can be improved by minimizing the NVD between the node voltages and the nominal voltage value. The second objective is chosen to signify the NVD and tailored as

$$f_2 = NVD = \sum_{j=1}^{nn} \left|V_j - 1.0\right| \tag{12}$$

The NOC represents the cost associated with the real power supplied by the substation and the cost of real power supplied by DG units. As the real power supplied by the substation can be minimized by reducing the RPL, the NOC can be formulated as the third objective:

$$f_3 = NOC = c_1 P_{loss} + c_2 \sum_{j=1}^{ndg} P_{DG,j} \tag{13}$$

The above objectives can be calculated from the branch currents and bus voltages, obtained through iteratively solving the distribution power flow algorithm of (7), (8), (9) and (10) for a given load, location and rating of DGs. They can be blended into a single objective through suitable weight factors with a view of optimizing all the objectives simultaneously. As the range of above three objective function values are different, the significance given to individual objectives can be easily adjusted through weight factors, if they are brought to a same range by dividing each objective by its respective base case or maximum possible value. The resulting objective function can thus be formulated as

$$\text{Minimize } \Phi = w_1\left(\frac{f_1}{f_1^0}\right) + w_2\left(\frac{f_2}{f_2^0}\right) + w_3\left(\frac{f_3}{f_3^0}\right) \tag{14}$$

Where $f_3^0 = c_2 \sum_{j=1}^{ndg} P_{DG,j}^{\max}$ represents the maximum possible NOC of DG units.

Constraint Functions:

The substation and DG power should satisfy the power demand in the network, which is realized by the load flow problem of (7), (8), (9) and (10). Besides the locations and sizing of DG units should not cause violations, which are dealt as inequality constraints.

The net DG power should not exceed the net power demand in the network. It is imposed by

$$\sum_{j=1}^{ndg} P_{DG,j} \leq \sum_{k=1}^{nn} P_{load,j} \qquad (15)$$

The resulting flows in the lines should not exceed their respective thermal limits. It is represented by a constraint

$$\left| i_j \right| \leq i_j^{\max} \qquad (16)$$

III. PROPOSED METHOD

The placement of DG units in distribution networks not only supply real power but also minimizes the RPL and improves the VP. This section explains the BBO based DG placement method (BDGM), which involves representation of problem variables and formation of a HSI function.

The decision variables in BDGM are the node locations for installation of DGs and their ratings. Each habitat in BBO is therefore represented in vector form to denote the decision variables as

$$h = \left[L_1, L_2, \quad L_{ndg}, P_{DG,1}, P_{DG,2}, \quad P_{DG,ndg} \right] \qquad (17)$$

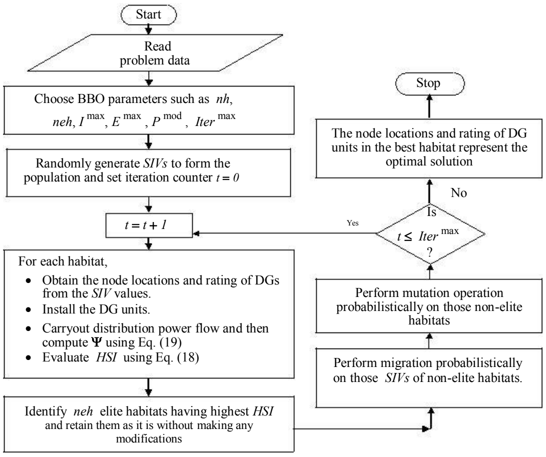

Fig. 1 Flow chart of BDGM

The BBO generates real numbers and hence to obtain integer values rounded off to the nearest integer values. The HSI function can be built and constraint as for locations, the real numbers are from the problem objective function

$$\text{Maximize} \qquad HSI = \frac{1}{1+\Psi} \qquad (18)$$

Where

$$\Psi = \begin{cases} \Phi + w_b \sum_{i \in \Re} \left(\left| i_j \right| - i_j^{\max} \right)^2 & \leftarrow \text{ if } \sum_{j=1}^{ndg} P_{DG,j} \leq \sum_{k=1}^{nn} P_{load,j} \\ \Phi + w_b \sum_{i \in \Re} \left(\left| i_j \right| - i_j^{\max} \right)^2 + w_g \left| \sum_{j=1}^{ndg} P_{DG,j} - \sum_{k=1}^{nn} P_{load,j} \right| & \leftarrow \text{otherwise} \end{cases} \qquad (19)$$

IV. SIMULATION

The BDGM is tested on a 12.66 kV, 33 node network, whose line and load data are taken from [18]. The total real and reactive power loads on the network are 3715 kW and 2300 kVar, respectively. The initial RPL of this network are 210.97 kW. The software package is developed in Matlab platform and executed in a 2.67 GHz Intel core-i5 personal computer. There is no guarantee that different executions of the developed method converge to the same solution due to the stochastic nature of the BBO and hence the algorithm is run 20 times and the best one is presented. The cost coefficients and weight parameters used in the cost function are given

Table I.

Parameter	Chosen Value
c_1	4
c_2	5
w_1	0.5
w_2	0.4
w_3	0.1

TABLE. I. CHOSEN PARAMETERS

The results of 33 node network, containing node locations, DG ratings, RPL, NOC and the lowest voltage magnitude (LVM) seen in the network are compared with those of the existing methods published in [6,7,8 and 11] in Table II. The %RPL savings (%RPLS) and the net DG required by all the methods are graphically displayed in Fig. 2 and 3 respectively. It is very clear from the results that the proposed BDGM offers the RPL of 85.43 kW, which is lower than those of the existing methods except SA. Though the SA seems to be better in respect of RPL savings, it leads to huge NOCs. Compared with that of BDGM, the RPL savings of SA is 1.61%, which is offset by the 38% rise in NOC. The VP before and after DG placement is pictorially depicted in Fig. 4. It is seen from the figure that there is significant improvement in the VP after DG placement. It increases the LVM seen in the network from 0.9038 to 0.9624 per unit.

It is very clear from these results that the proposed BDGM offers a better solution that simultaneously reduces network RPL and lowers the NOC. Besides it offers a reasonably good VP.

	DG Location	DG rating (MW)	RPL (kW)	NOC ($)	LVM (per unit)
Base-Case	---	---	210.97	---	0.9038
BDGM	31,15, 8	0.7434 0.5662 0.4645	85.43	9212.427	0.9624
GA[6]	11,29, 30	1.5000 0.4228 1.0714	106.30	15396.2	0.9809
PSO[6]	13, 32, 8	0.9816 0.8297 1.1768	105.35	15361.9	0.9806
GAPSO[6]	32, 16, 11	1.2000 0.8630 0.9250	103.40	15353.6	0.9808
SA[7]	6, 18, 30	1.1124 0.4874 0.8679	82.03	12666.6	0.9676
BFOA[8]	14, 18, 32	0.6521 0.1984 1.0672	89.90	9948.1	0.9705
IWO [11]	14, 18, 32	0.6247 0.1049 1.0560	85.86	9271.44	0.9716

TABLE. II. SUMMARY OF RESULTS

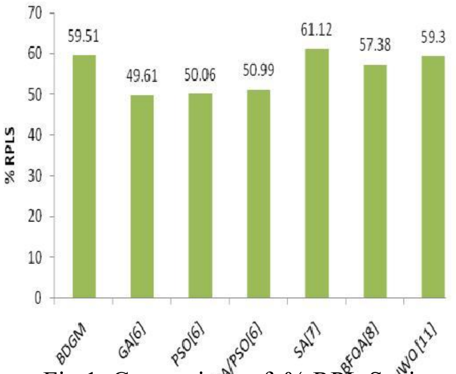

Fig.1. Comparison of % RPL Savings

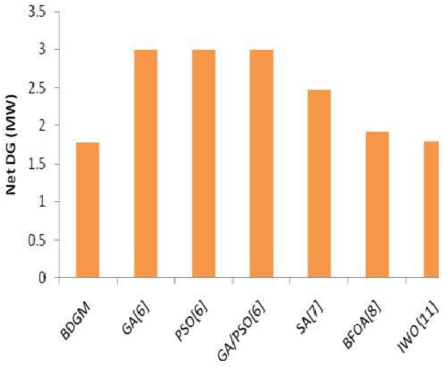

Fig.2. Net rating of DG units for placement

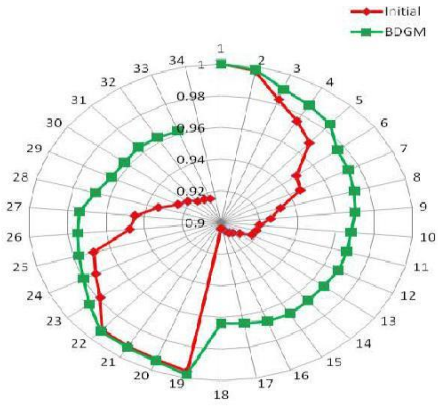

Fig.3. VP of 33 node network

CONCLUSION

A simple BBO based DG placement scheme for RPL minimization and operating cost reduction of radial distribution networks has been suggested. This method uses a simple distribution power flow involving branch-to-node matrix. The simulation results on 33-node system clearly indicate that the method is able to simultaneously reduce network RPL and lower the NOC, besides offering a reasonably good VP. The algorithm is suitable for practical implementation on networks of any size.

REFERENCES

[1] Ng, H. N., M. M. A. Salama, and A. Y. Chikhani. (2000). Classification of capacitor allocation techniques, Power Delivery, IEEE Transactions on 15(1): 387-392.

[2] Ackermann T, Andersson G and Soder L. (2001). Distributed generation: a definition, Electric Power Systems Research, 57(3): 195–204.

[3] Chiradejaand P., and Ramakumar R . (2004). An approach to quantify the technical benefits of distributed generation, IEEE Trans. Energy Conver., 19(4): 764-73.

[4] Wang, Caisheng, and M. Hashem Nehrir. (2004). Analytical approaches for optimal placement of distributed generation sources in power systems, IEEE Transactions on Power Systems, 19(4): 2068-76.

[5] Hung, Duong Quoc, and Nadarajah Mithulananthan. (2013). Multiple distributed generator placement in primary distribution networks for loss reduction, IEEE Transactions on Industrial Electronics, 60(4): 1700-08.

[6] Moradi, M. H., and M. Abedini. (2012). A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems, Electrical Power and Energy Systems, 34(1): 66-74.

[7] Injeti, Satish Kumar, and N. Prema Kumar. (2013). A novel approach to identify optimal access point and capacity of multiple DGs in a small, medium and large scale radial distribution systems, Electrical Power and Energy Systems, 45(1): 142-151.

[8] Kowsalya, M. (2014). Optimal size and siting of multiple distributed generators in distribution system using bacterial foraging optimization." Swarm and Evolutionary Computation, 15: 58-65.

[9] Kaur, Sandeep, Ganesh Kumbhar, and Jaydev Sharma. (2014). A MINLP technique for optimal placement of multiple DG units in distribution systems, Electrical Power and Energy Systems, 63: 609-17.

[10] Kefayat, M., A. Lashkar Ara, and SA NabaviNiaki. (2015). A hybrid of ant colony optimization and artificial bee colony algorithm for probabilistic optimal placement and sizing of distributed energy resources, Energy Conversion and Management, 92: 149-61.

[11] Rama Prabha. D and Jayabarathi. T. (2015). Optimal placement and sizing of multiple distributed generating units in distribution networks by invasive weed optimization algorithm, Ain Shams Engineering Journal, http://dx.doi.org/10.1016/j.asej.2015.05.014.

[12] D Simon. (2008). Biogeography-based optimization, IEEE Trans on Evolutionary Computation, 12(6): 702–713.

[13] R Rarick, D Simon, F Villaseca and B Vyakaranam. (2009). Biogeography-based optimization and the solution of the power flow problem, IEEE International Conference on Systems, Man, and Cybernetics, San Antonio, SMC: 1003–1008.

[14] A Bhattacharya and K.P Chattopadhyay. (2010). Solution of optimal reactive power flow using biogeography-based optimization, Int Journal of Electrical and Electronics Engineering, 4(8): 568-576.

[15] A.Bhattacharya and K.P Chattopadhyay. (2011). Application of biogeography-based optimization to solve different optimal power flow problems, IET Proc Gener., Transm & Distrib, 5(1): 70-80.

[16] S.Rajasomashekar and P Aravindhababu. (2012). Biogeography-based optimization technique for best compromise solution of economic emission dispatch, Swarm and Evolutionary Computations, dx.doi.org/10.1016/j.swevo.2012.06.001.

[17] P.Aravindhababu, S.Ganapathy and K.R.Nayar. (2001). A novel technique for the analysis of radial distribution systems, Electric Power and Energy Systems, ISSN:0142-0615, 23(3): 167-171.

[18] Baran M and Wu F. (1989). Network reconfiguration in distribution systems for loss reduction and load balancing, IEEE Trans on Power Delivery, 4(2): 1401–1407.