The Journal of CPRI,
Vol. 12, No. 2, June 2016 pp. 219-226

A novel Grey Wolf optimization algorithm for optimal DG units capacity and location in microgrids

Dinakara Prasad Reddy P*, Veera Reddy V C** , Gowri Manohar T*** and Chandra Sekhar B****

Distributed Generator (DG) resources are small electric generating plants that can provide power to homes, businesses or industrial facilities in distribution feeders. By optimal placement of DG we can reduce power loss and improve the voltage profile. However, the values of DGs are largely dependent on their types, sizes and locations as they were installed in distribution feeders. The main contribution of the paper is to find the optimal locations of DG units and sizes. Index vector method is used for optimal DG locations. In this paper new optimization algorithm i.e. Grey wolf optimization algorithm is proposed to determine the optimal DG size. This paper uses three different types of DG units for compensation. The proposed methods have been tested on 15-bus, 34-bus, and 69-bus radial distribution systems. MATLAB™, Version 8.3 software is used for simulation.

Keywords: *Grey Wolf optimization algorithm, index vector method, distributed generation placement, radial distribution system.*

1.0 INTRODUCTION

Distribution system is that part of the power system which connects the high voltage transmission system to low voltage consumers. 70% of the total losses are occurring in the primary and secondary distribution system, while the remaining 30% in transmission and sub transmission lines. Distribution losses are 15.5% of the generation capacity whereas the target level is 7.5%. Therefore the primary and secondary distribution system must be properly planned to ensure losses within the tolerable limits.

Distribution systems have more losses and poor voltage regulation. Almost 13% of the generated power is wasted as I^2 R losses. Loss reduction in distribution systems by applying the optimization methods is the current potential area of research. The basic requirements of a good distribution system are good voltage profile, availability of power on demand and reliability. The efficiency of the distribution system can be improved by adopting reactive power compensation, network reconfiguration, distributed generation and hybrid methods. Each method has its own advantages and disadvantages.

Distributed generators are commonly used to provide the real and reactive power compensation in distribution systems. However, DG unit installation in distribution networks requires an appropriate location and size. Thus, optimal placement plays an important role in minimizing the losses through proper installation and sizing which can be achieved by using optimization techniques.

*Research Scholar(JNTUK), Department of EEE, S V University College of Engineering, S V University, Tirupati-517502, India.
E-mail id : pdinakarprasad@gmail.com, Mobile : 09395112112
**Professor, EEE Department, AITS, Tirupati-517502, India.
***Professor, S V University College of Engineering, S V University, Tirupati-517502, India.
****Senior Research Fellow, Energy Efficiency & Renewable Engineering Division, Central Power Research Institute, Bangalore-560080, India.

The authors [1] paper presented a methodology for the integration of dispatchable and non dispatchable renewable Distributed Generation (DG) units for minimizing annual energy losses. The authors [2] presented a new multi-stage model, based on the Mixed Integer Nonlinear Programming (MINLP) approach, to determine the optimal Sub-transmission System Expansion Planning (SSEP). This model considers the placement of Distributed Generation (DG) units in distribution networks over the planning periods. The authors in paper [3] proposed sensitivity based simultaneous optimal placement of capacitors and DG. In this paper analytical approach is used for sizing. The authors in [4] developed simulating algorithm for optimal placement of DG units. The authors in paper [5] uses particle swarm optimization algorithm is used for DG allocation. The results obtained are promising when capered to analytical method. The authors in [6] proposed a new constrained multi-objective Particle Swarm Optimization (PSO) based Wind Turbine Generation Unit (WTGU) and photovoltaic (PV) array placement approach for power loss reduction and voltage stability improvement of radial distribution system.

The authors in paper [7] proposed a generalized optimization formulation is introduced to determine the optimal location of distributed generators to offer reactive power capability. The authors in paper [8] proposed a dynamic model of distributed generation in the smart grid, based on environmental compensation costs, traditional DG capacity cost, DG operation and maintenance costs, purchased power cost and network loss cost. The authors in [9] proposed a Golden Section Search (GSS) algorithm for Distributed Generator (DG) placement and sizing for distribution systems based on a novel index. A novel combined genetic algorithm (GA)/ particle swarm optimization (PSO) is presented in [10] for optimal location and sizing of DG on distribution systems. Improved group search optimizer (iGSO) is proposed in this paper [11] by incorporating Particle Swarm Optimization (PSO) into Group Search Optimizer (GSO) for optimal setting of DGs.

The authors in [12] presented new methodology based on nodal pricing for optimally allocating distributed generation for profit, loss reduction, and voltage improvement including voltage rise phenomenon. A value-based method is proposed in [13] to enhance the reliability and obtain the benefits for DG placement. An analytical approach based on exact loss formula has been presented in [14] to find the optimal size and location of DG however voltage constraint has not been considered.

Different types of the DG's can be characterized as

Type I: DG capable of injecting real power only, like photovoltaic, fuel cells etc. is the good examples of type-I DG.

Type II: DG capable of injecting reactive power only to improve the voltage profile fall in type-II DG, e.g. kvar compensator, synchronous compensator, capacitors etc.

Type III: DG capable of injecting both real and reactive power, e.g. synchronous machines.

Type IV: DG capable of injecting real but consuming reactive power, e.g. induction generators used in the wind farms.

Most of the approaches presented so far to formulate the optimal placement problem of DG are considering only the type-I DGs. In this paper type-I, type-II and type-III DG's are considered for optimal placement. Optimal placement problem has been solved using Grey Wolf optimization (GWO) algorithm approach by taking the exact loss formula as objective function. As the GWO technique is a heuristic global optimization method which is based on Grey wolf hunting process.

The algorithm is new and rapidly developed for its easy implementation and few particles required to be tuned as compared to other heuristic approaches. The proposed technique has been tested on 15 bus, 34-bus and 69- bus systems.

The results obtained from the technique have also been compared on the basis of different types of DG units.

2.0 PROBLEM FORMULATION

The objective of the optimal placement and sizing of DG is to minimize the active power loss in the distribution network and to improve the voltage profile.

The objective function:

$$\text{Min } f = \min(TLP) \quad ....(1)$$

Where TLP is the total power loss of the radial distribution system.

Constraints:

Equality constraints:

Power constraints:

$$P_{Loss} + \sum P_{Di} = \sum P_{DGi} \quad ....(2)$$

Inequality constraints:

Voltage constraints:

$$|V_{i\,min}| \leq V_i \leq |V_{i\,max}| \quad ....(3)$$

$$i = 1, 2, \ldots\ldots N$$

Where P_{DGi} is the real power generation using DG at bus i, P_{Di} is the power demand at bus i. V_{imin} and V_{imax} are the minimum and maximum voltages of the ith bus. In order to minimize the total power loss subjected to the constraints given in Eqs. (2) and (3), Grey wolf optimization algorithm is proposed.

3.0 OPTIMAL LOCATION OF DG BASED ON INDEX VECTOR METHOD

Index Vector method has been used for optimal allocation of DG in radial distribution system[15]. Real and Reactive components of currents are obtained by using base case load flow. In this paper, the index vector method has been used for optimal location problem. Based on the elements of the index vector, this method identifies a sequence of nodes to be connected with DG.

The index vector for bus n is given by

$$\text{index}[n] = \frac{1}{V(n)^2} + \frac{Iq(k)}{Ip(k)} + \frac{Qeff(n)}{totalQ} \quad ....(4)$$

Index[n] = "Index" for n^{th} bus.

V[n] = voltage at n^{th} bus.

Iq[k] = imaginary component of current in k^{th} branch.

Ip[k] = real component of current in k^{th} branch.

Qeff[n] = effective load at n^{th} bus.

Total Q = total reactive load of the given distribution system.

Arrange the index vector in descending order so that highest priority bus will come first and the lowest priority bus will come at the end. normalized voltage magnitudes are calculated for all the buses by the following formula: V(i)= V(i)/0.95. Buses, whose normalized values are less than 1.01 are considered as candidate nodes for DG locations.

The location of compensating device is at bus 6, 26 and bus 61 for 15, 34 and 69-bus systems respectively since at these buses, index vector value is maximum and normalized voltage is below 1.01.

4.0 GREY WOLF OPTIMIZATION ALGORITHM

In this paper new meta heuristic called Grey wolf optimization algorithm [16] is used for optimal sizing of DGs. The algorithm is inspired by leadership hierarchy and hunting mechanism of grey wolves in nature. There are basically four types of grey wolves such as alpha, beta, delta and omega.

Alpha grey wolf are leaders in the group. The leaders may be male and female. Alpha grey wolfs are mostly responsible to take decisions about hunting. The beta grey wolfs are subordinate wolfs which are helping in decisions or activities for alpha grey wolves. The omega grey wolfs play the role of victim. Scouts, hunter, caretakers etc came to delta grey wolf category. The grey wolf hierarchy is shown in Figure 1.

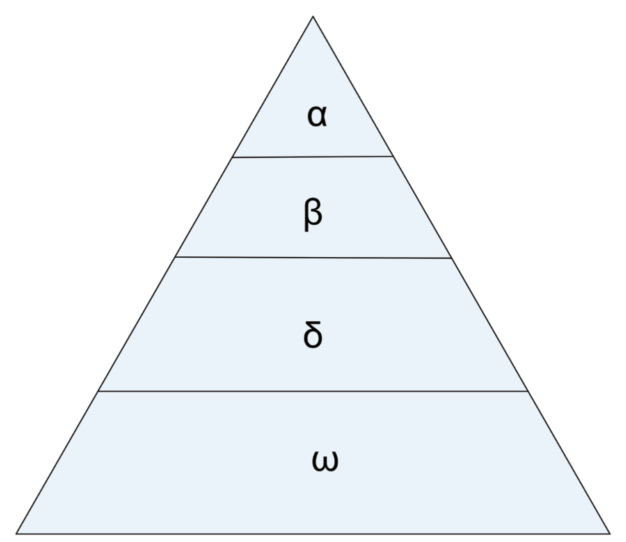

FIG. 1 HIERARCHY OF GREY WOLFS

According to hierarchy the wolfs have to submit to the all other wolfs. The main steps of grey wolf hunting are as follows

1. Social hierarchy
2. Tracking
3. Hunting
4. Attaching prey

4.1 Social hierarchy

Consider the fittest solution as the alpha. Next second and third best solutions are beta and delta grey wolfs respectively. Left over assumed to be omega. Omega grey follow the other three wolfs.

4.2 Tracking

Grey wolfs encircle prey during the hunt. The mathematical equations representing encircling behavior are

$$X(t+1)=X_p(t)-AD$$
$$D=CX_p(t)-X(t)$$
$$A=2ar_1-a$$
$$C=2r_2 \quad ....(5)$$

Where t indicates the current iterations. A, C are coefficient vectors. X_p is the position vector of the prey. X denotes the position vector of grey wolf. a is linearly decreased from 2 to 0. r1, r2 are the random vectors in [0,1].

4.3 Hunting

Hunting is usually guided by alpha grey wolfs. First three best solutions are saved for alpha, beta and delta. Alpha, beta and delta have better knowledge about the potential location of prey. The position update represented by following equations.

$$D_\alpha = |C_1X_\alpha - X|,\ D_\beta = |C_2X_\beta - X|,\ D_\delta = |C_3X_\delta - X|$$

$$X_1=X_\alpha - A_1(D_\alpha), X_2=X_\beta - A_1(D_\beta), X_3=X_\delta - A_1(D_\delta)$$

$$X(t+1) = \frac{X_1+X_2+X_3}{3} \quad ....(6)$$

4.4 Attacking Prey

When the prey is stop moving then the grey wolf finishes its hunting. A is the random value in the interval [-a,a]. Candidate solutions tend to diverge from the prey when A>1 and converge towards the prey when A<1.

The detailed GWO algorithm for optimal DG size is as follows

Step 1: Read line and load data of the system and solve the feeder line flow for the system using load flow method. In this paper branch current load flow method is used.

Step 2: Find the best DG locations of the buses using the index vector based method.

Step 3: Initialize the grey wolf population and itmax, Number of DG locations d=1, DG min=60, DG max=3000.

Step 4: Initialize a, A and C

Step 5: Determine fitness (active power loss) for each search agent by performing load flow. X_α is the best search agent, X_β is the second best and X_δ is the third best search agent.

Step 6: Select the DG value for minimum fitness as current best solution.

Step 7: Update the positions of the search agents by equation 3.

Step 8: Determine the losses for updated positions by performing load flow.

Step 9: Replace the current best solution with the updated values if obtained losses are less than the current best solution. Otherwise go back to step 7

Step 10: If maximum number of iterations is reached then print the results.

5.0 IMPLEMENTATION OF ALGORITHM

The complete structure of the work to solve the optimal DG placement and sizing of the three test systems using GWO algorithm is shown in Figure 1. At first the power loss is calculated from Load Flow method. After placing the DG and vary the size in steps using GWO algorithm. For different DG sizes compute the losses. The DG size corresponding to minimum loss is treated as the current best DG size. The procedure is repeated until no further minimum losses from the DG placement are achieved.

6.0 CASE STUDIES

6.1 Simulations results and analysis

In order to evaluate the proposed algorithm, three different test systems are taken from the[17] and [18]. The optimum size and place of DGs for the test systems 15, 34, and 69 buses are determined by GWO. The simulated results are tabulated and analyzed using MATLAB, version 8.3. In this work the parameters for GWO has been taken as pop=30, DGmin=60, DGmax=3000.

6.2 Test System 1: 15 Bus system

For 15 bus system without installation of DG real, reactive power losses are 61.7933 kW and 57.2977 kVAR respectively. This test system consists of 15 buses and 14 branches. Table 1 shows the real power losses after the placement of different types of DGs. From table it is inferred that using DG type III the losses are reduced more when compared to other type of DGs. The losses after the placement of DG type I, II and III are 45.8035 kW, 45.3228 kW and 29.9108 kW respectively. Also from Figure 2 it is inferred that the voltage profile of the system is improved more when DG type III is used.

6.3 Test System 3: 34 Bus system

For 34 bus system without installation of DG real, reactive power losses are 168.3 kW and 48.0083 kVAR respectively. This test system consists of 34 buses and 33 branches. Table 2 shows the real power losses after the placement of different types of DGs. From table it is inferred that using DG type III the losses are reduced more when compared to other type of DGs. The losses after the placement of DG type I, II and III are 82.4297 kW, 132.9023 kW and 58.8298 kW respectively. Also from Figure 3 it is inferred that the voltage profile of the system is improved more when DG type III is used.

6.4 Test System 4: 69 Bus system

For 69 bus system without installation of DG real, reactive power losses are 225.0446 kW and 102.2059 kVAR respectively. This test system consists of 69 buses and 68 branches. Table 3 shows the real power losses after the placement of different types of DGs. From table it is inferred that using DG type III the losses are reduced more when compared to other type of DGs. The losses after the placement of DG type I, II and III are 83.2279 kW, 160.0838 kW and 48.1969 kW respectively. Also from Figure 4 it is inferred that the voltage profile of the system is improved more when DG type III is used.

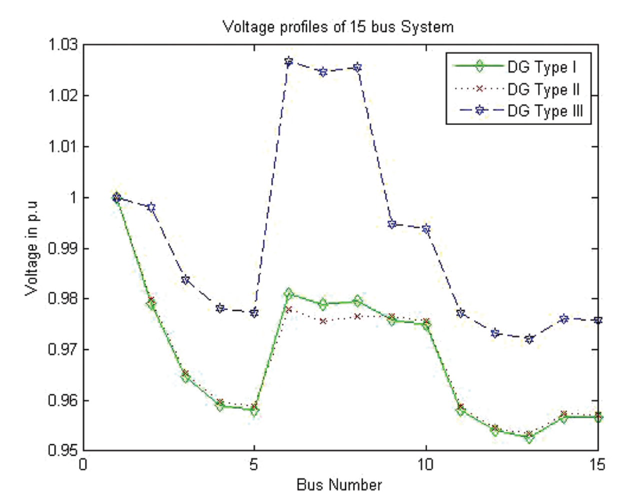

FIG. 2 VOLTAGE PROFILES OF 15 BUS SYSTEM USING DIFFERENT DG UNITS

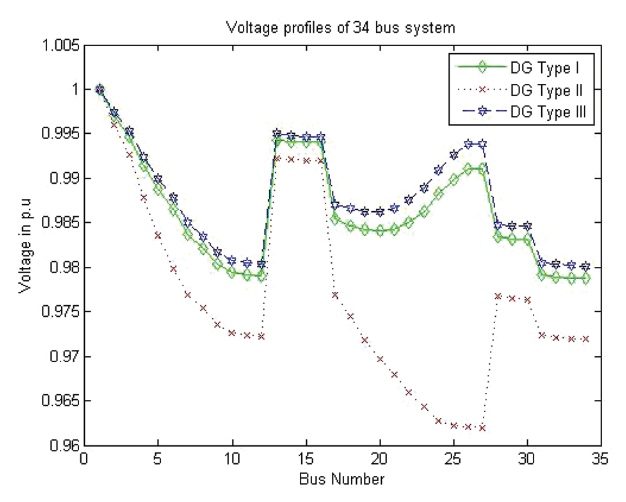

FIG. 3 VOLTAGE PROFILES OF 34 BUS SYSTEM USING DIFFERENT DG UNITS

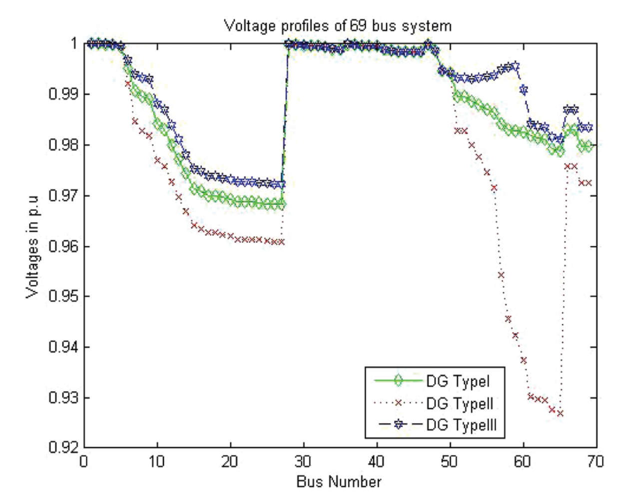

FIG. 4 VOLTAGE PROFILES OF 69 BUS SYSTEM USING DIFFERENT DG UNITS

TABLE 1				
RESULTS FOR 15 BUS SYSTEM				
Active Power losses Without DG (kW) = 61.7933				
Optimal DG location = 6				
DG type	Optimal Size of DG			Active Power losses
	kW	kVAR	kVA	With DG (kW)
I	675	-	-	45.8035
II	-	682	-	45.3228
III	-	-	681	29.9108

TABLE 2				
RESULTS FOR 34 BUS SYSTEM				
Active Power losses Without DG (kW) = 163.8				
Optimal DG location=26				
DG type	Optimal Size of DG			Active Power losses
	kW	kVAR	kVA	With DG (kW)
I	2086	-	-	82.4297
II	-	1250	-	160.838
III	-	-	1675	58.8298

TABLE 3				
RESULTS FOR 69 BUS SYSTEM				
Active Power losses Without DG (kW) = 225				
Optimal DG location=61				
DG type	Optimal Size of DG			Active Power losses
	kW	kVAR	kVA	With DG (kW)
I	1873	-	-	83.2279
II	-	1384	-	160.838
III	-	-	1640	48.1969

7.0 CONCLUSION

In this paper the optimum DG location and size for loss reduction and to improve voltage profile is determined through the index vector method and Grey wolf optimization algorithm. Here index vector method is used to find the DG locations in order to minimize the search space. The optimum DG size is evaluated based on the objective function which minimizes the total active power loss using Grey wolf optimization algorithm. Grey wolf optimization algorithm is new optimization technique which is used to find the optimum DG size. It has better convergence characteristics when compared to other algorithms. The simulation results shows that the overall impact of the DG units on voltage profile is positive and proportionate reduction in power losses is achieved. It can be interfered that best results can be achieved with type III DG.

REFERENCES

[1] D Q Hung, N Mithulananthan, K Y Lee,Optimal placement of dispatchable and non dispatchable renewable DG units in distribution networks for minimizing energy loss, International Journal of Electrical Power & Energy Systems, Vol. 55, pp.179–186,2014.

[2] M Jalali, K Zare, M T Hagh, A multi-stage MINLP-based model for sub-transmission system expansion planning considering the placement of DG units, International Journal of Electrical Power & Energy Systems. Vol. 63, pp. 8–16, 2013.

[3] S Gopiya Naik, D K Khatod, M P Sharma, Optimal allocation of combined DG and capacitor for real power loss minimization in distribution networks, International Journal of Electrical Power & Energy Systems. Vol. 53, pp. 967–973, 2013

[4] S K Injeti, N Prema Kumar, A novel approach to identify optimal access point and capacity of multiple DGs in a small, medium and large scale radial distribution systems, International Journal of Electrical Power & Energy Systems. Vol. 45, pp.142–151, 2013. doi:10.1016/j.ijepes.2012.08.043.

[5] S Kansal, V Kumar, B Tyagi, Optimal placement of different type of DG sources in distribution networks, International Journal of Electrical Power & Energy Systems. Vol. 53, pp. 752–760, 2013.

[6] Partha Kayal, C K Chanda, Placement of wind and solar based DGs in distribution system for power loss minimization and voltage stability improvement, International Journal of Electrical Power & Energy Systems, Vol. 53, pp. 795-809, ISSN 0142-0615, December 2013.

[7] Monica Alonso, Hortensia Amaris, Carlos Alvarez-Ortega, Integration of renewable energy sources in smart grids by means of evolutionary optimization algorithms, Expert Systems with Applications, Vol. 39, No. 5, April 2012, pp. 5513-5522, ISSN 0957-4174.

[8] D D Wu, M Junjie, W Yulong, L Yang, Information Engineering and Complexity Science - Part IISize and Location of Distributed Generation in Distribution System Based on Immune Algorithm, Systems Engineering Procedia, Vol. 4, pp. 124-132, ISSN 2211-3819, 2012.

[9] M M Aman, G B Jasmon, H Mokhlis, A H Bakar, Optimal placement and sizing of a DG based on a new power stability index and line losses, International Journal of Electrical Power & Energy Systems. Vol. 43, pp. 1296-1304, 2012.

[10] M H Moradi, M Abedini, A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems, International Journal of Electrical Power & Energy Systems, Vol. 34, pp. 66-74, 2012.

[11] Q Kang, T Lan, Y Yasn, L Wang, Q Wu, Group search optimizer based optimal location and capacity of distributed generations, Neuro computing, Vol. 78, pp. 55–63, 2012.

[12] R K Singh, S K Goswami, Optimum allocation of distributed generations based on nodal pricing for profit, loss reduction, and voltage improvement including voltage rise issue, International Journal of Electrical Power & Energy Systems, Vol. 32, pp. 637–644, 2010.

[13] J H Teng, Y H Liu, C Y Chen, C F Chen, Value-based distributed generator placements for service quality improvements, International Journal of Electrical Power & Energy Systems, Vol. 29, pp. 268–274, 2007.

[14] N Acharya, P Mahat, N Mithulananthan, An analytical approach for DG allocation in primary distribution network, International Journal of Electrical Power & Energy Systems, Vol. 28, pp. 669–678, 2008.

[15] V V S N Murthy, A Kumar, Comparison of optimal DG allocation methods in radial distribution systems based on sensitivity approaches, International Journal of Electrical Power & Energy Systems, Vol. 53, pp. 450–467, 2013.

[16] S Mirjalili, S M Mirjalili, A Lewis, G W Optimizer, S Mirjalili, S M Mirjalili, et al., Grey Wolf Optimizer, Vol. 1, issue 1, pp. 46–61, 2014.

[17] S Devi, M Geethanjali, Application of Modified Bacterial Foraging Optimization algorithm for optimal placement and sizing of Distributed Generation, Expert Systems with Applications. Vol. 41, pp. 2772–2781, 2014.

[18] D P R P, C H Prasad, M C V Suresh, Capacitor Placement Using Bat Algorithm for Maximum Annual Savings in Radial Distribution systems, Vol. 4, pp. 105–109, 2014.