ENDING NODES VOLTAGE BASED DG PLACEMENT IN DISTRIBUTION NETWORKS

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ABSTRACT

one of the main tools to reduce power loss of distribution networks and compensate the voltage drop along the feeding line to the ending loads is to implement Dispersed Generation (DG). The proper allocation of DGs in the distribution networks is a complex combinatorial optimization problem. in this paper a method based on equilibration of ending nodes voltage magnitude is presented which is simple and applicable to any distribution networks. The validity of the proposed method is verified through the application in 33 nodes distribution network.

INTRODUCTION

Traditionally, distribution systems are operated in centralized and vertical manner due to the simplicity of control and protection operations. These networks mainly include radial topologies or weakly-meshed structures having high value of R/X ratio which results in improper voltage profile and high power losses [1-2]. A prevalent action taken by the network operators to settle this problem is the feeder reconfiguration techniques [3-4]. By development of distributed generation (DG) in the power system, there has been another alternative to tackle with the poor voltage regulation and high power losses in distribution systems [5]. DG units, with several technological types, have potential advantages such as, power loss reduction, voltage profile improvement, reliability enhancement, and investment deferral of the system equipment. If the DG units' location and size are appropriately determined, they can play a key role in minimizing power loss and improving voltage profile of distribution networks [6]. The problem of DG placement and sizing is, in principal, a complex non-linear optimization problem. The implemented researches in this field fall into several categories in terms of the considered objectives, constraints, and solution algorithms. The objective functions intended by the researchers include power loss minimization, voltage profile improvement, network reinforcement cost minimization, reliability enhancement, and reduction of environmental emissions [7-9].

A wide range of solution methodologies have been proposed in literature for the DG siting and sizing problem. The solution techniques are mainly classified as mathematical programming algorithms, heuristics, meta-heuristic methods, and the analytical ones. The methods of first category use mathematical formulations like mixed-integer linear and non-linear programming. The heuristic methods are based on engineering experience such as researches done in. The meta-heuristic techniques, known also as population-based optimization methods, include the algorithms such as genetic algorithm (GA), particle swarm optimization (PSO), hybrid PSO (HPSO), harmony search (HS), artificial bee colony (ABC), Big Bang-Big crunch (BBBC) algorithm, grey wolf optimizer (GWO), and hybrid algorithms such as GA-PSO, genetic algorithm-tabu search (GA-TS), PSO and shuffled frog leaping algorithms (PSO-SFL) etc. [10-13]. The above-mentioned population-based techniques have been widely applied to optimize both the planning and operational studies, and they have obtained satisfactory results.

PROBLEM FORMULATION

The optimal configuration of a distribution network is the one in which all the ending nodes have exactly the same voltage magnitude [14]. Although, it may be impractical to design a network with the ending nodes having the same voltage in the real distribution networks, however, the theory indicates a precious clue to design a network with the least power loss. In [14-15], we used this principle to develop UVDA method for the network reconfiguration. However, this theory can also be employed for the DG placement problem. With a careful attention to the theory, it can be concluded that it is also possible to keep the configuration of network intact and change the characteristics of the network components such as location and size of DG units in a way that the theory's requirements are met. Therefore, based on the theory, it can be inferred that:

''*If a non-optimally configured purely resistive network is equipped with DG units in a way that all of the ending nodes are supplied with exactly the same voltage, the configuration of the network after DG placement becomes optimal*".

Hence, not only changing the status of the specific switches of network (reconfiguration) can lead to optimal configuration, but also the design of the network components such as the location and size of DG units may change the configuration of the network from the non-optimal state to optimal one [15].

This paper uses the above explanation in the process of DG placement and sizing. The real distribution networks are not purely resistive and the loads are combination of inductance and resistances. Considering the negligible effect of reactive parts of the loads in the process of active power allocation (DG placement and sizing process) and in order to fulfil the requirements of the abovementioned theory, the reactive parts of the loads are removed and not considered during the process of DG sizing and siting. It is evident that any loss reduction of this incomplete network with only pure active loads, will lead to the loss reduction of the original network. (note that implementing DG mostly effects the flow of active power of original network and the reactive power of the apparent power flowing in the branches remains almost intact). For this network with only active parts of the loads, there are two ways for the enhancement and equilibration of the ending nodes voltage magnitude.

I. *to locate DGs at the ending nodes themselves and enhance and regulate their voltage magnitude to the desired value by the means of tuning the amount of active power injection*
II. *to locate DGs at the upstream nodes of the ending nodes and enhance their voltage up to the value at which the ending nodes voltage magnitude become equal.*

Both of the methods satisfy the condition of having optimal configuration yet only the second method has the probability of further power loss reduction. Therefore, the nodes at the upstream branches of the ending nodes are considered as candidate nodes for DG placement. Finding the best location amongst the candidate nodes for loss reduction is an optimization problem. To solve this problem Particle Swarm Optimization (PSO) algorithm is used. It is noteworthy to mention that by the use of this method, the number of PSO variables for each DG placement is reduced from two variables (DG location and size) to only one variable (DG location) since the size of DG will be calculated in load flow program.

A BREIF REVIEW OF PSO

In order to optimally determine the location of DGs, the well-known PSO artificial algorithm has been implemented. PSO is an optimization technique formulated by Kennedy and Eberhart inspired by the natural behaviour of a population of birds or insects [16]. It has been applied successfully to various search and optimization problems. In PSO algorithm, each particle keeps track of its own position and velocity in the problem space. Let the position and the velocity of the ith particle of M population's individuals in the n dimensional search space be represented as $P_i = [p_{i,1}, p_{i,2}, \dots, p_{i,n}]$ and, $V_i[v_{i,1}, v_{i,2}, \dots, v_{i,n}]$ respectively. Similarly, according to a specific fitness function, the best solution of each particle (local best) and the best solution of the group (global best) are denoted as $P_i^l = [p_{i,1}^l, p_{i,2}^l, \dots, p_{i,n}^l]$ and $P^g = [p_1^g, p_2^g, \dots, p_n^g]$ respectively. The velocity and position are updated at each iteration by the following equations:

$$V_i^{it+1} = w.V_i^{it} + C_1.r_1.(P_i^l - P_i^{it}) + C_2.r_2.(P^g - P_i^{it}) \quad (1)$$

$$P_i^{it+1} = P_i^{it} + V_i^{it+1} \quad (2)$$

$$w = w_{max} - \frac{w_{max} - w_{min}}{it_{max}}.it \quad (3)$$

Where V_i^{it+1} is the velocity of ith particle at (it+1) iteration; r_1 and r_2 are the random numbers selected between 0 and 1, C_1 and C_2 are positive constants having values between 1 and 4. and it is the index of iteration number. w is a linearly decreasing inertia weight which increases as a function of iteration index.
Where w_{max} and w_{min} are the initial and final values of w and it_{max} is the maximum number of iteration. According to (2) each particle's velocity is updated and by (3) the position of the particle is modified.

DG MODELLING IN LOAD FLOW PROGRAM

Consider a part of distribution network (As Fig. 1 (a)) including buses i and j having the voltages of V_i and V_j. Before any compensation, due to the current flow (I_L) in series impedance of lines, bus j is subjected to high voltage drop. It is aimed to improve the voltage of bus j form V_j to V_{jnew} (ideally to 1p.u) by injecting adequate value of active power P_0 with the active current of I_A. The line's current flow after the injection of active power will be $I_L' = I_L - I_A$. The phasor diagram of voltages and currents is illustrated in Fig. 1 (b), which is the vector representation of Kirchhoff's Voltage Law (KVL) as (4). The phase angle of old and new voltages of bus j before and after compensation are α_{old} and α_{new}, respectively

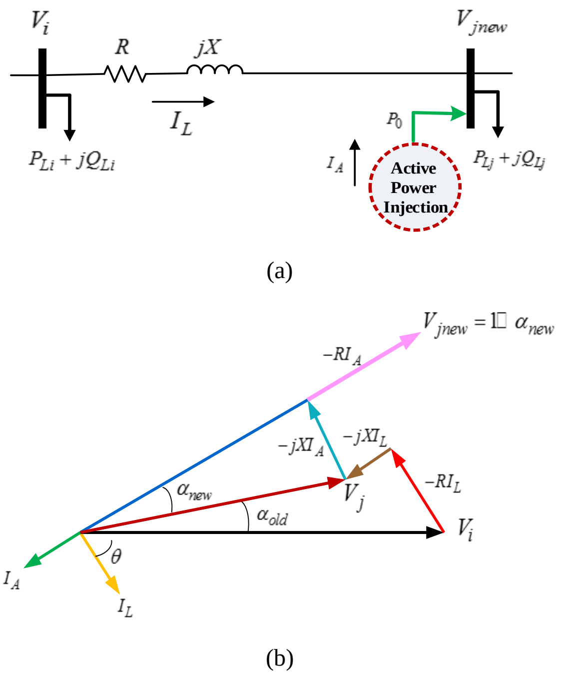

Fig. 1. (a): Single-line diagram of two buses of distribution network and (b): phasor diagram of voltages and current of the system

By considering $\alpha = \alpha_{old} + \alpha_{new}$, $x = XI_A$, and $y = RI_A$, we can say that:

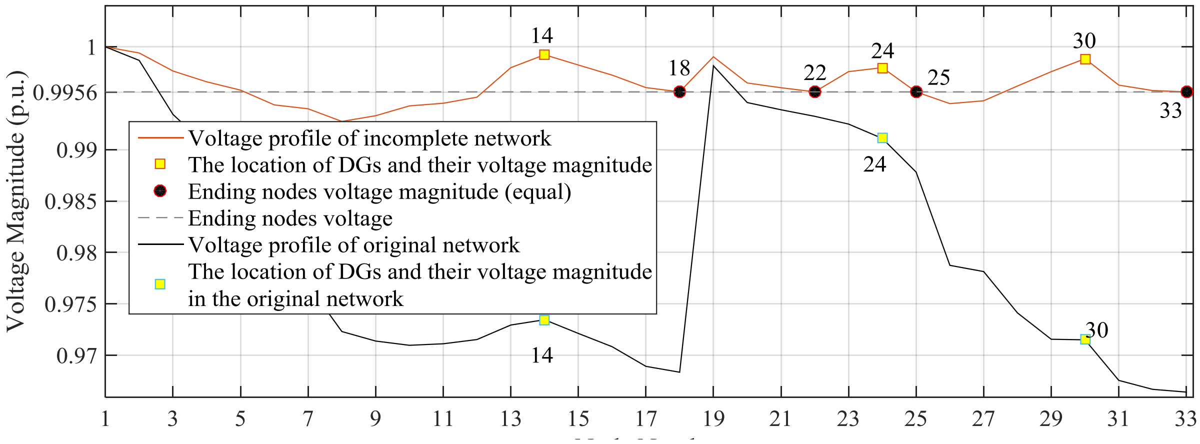

Fig. 2. Voltage profile of original and incomplete network with three DG units

Table. 1. Comparison of the obtained results of the proposed approach with the existing methods on 33-bus network

Number Of DGs	Techniques		Details				Total Capacity (kW)	Power Loss (kW)
Three DG units	IA		Bus	6	12	31	2520	81.1
			Size	900	900	720		
	Hybrid		Bus	13	24	30	2870	**72.9**
			Size	790	1070	1010		
	Proposed Method	I	Bus	18	25	33	**2094**	82.6
			Size	597	651	846		
		II	Bus	_14_	_24_	_30_	_2696_	_73.4_
			Size	_765_	_1020_	_911_		

$$V_{jnew}\angle\alpha_{new} = V_i\angle 0 - (R+jX)I_L\angle-\theta \\ -(R+jX)I_A\angle(180-\alpha_{new}) \quad (4)$$

$$V_j sin\alpha_{new} = x \quad (5)$$

$$V_j cos\alpha_{new} + y = V_{jnew} \quad (6)$$

$$\frac{x}{y} = \frac{XI_D}{RI_D} = \frac{X}{R} = k \quad (7)$$

$$V_j{}^2 cos^2\alpha_{new} = (V_{jnew} - y)^2 \quad (8)$$

$$V_j{}^2 - V_j{}^2 sin^2\alpha_{new} = y^2 - 2.V_{jnew}.y + V_{jnew}^2 \quad (9)$$

$$V_j{}^2 - k^2y^2 = y^2 - 2.V_{jnew}.y + V_{jnew}^2 \quad (10)$$

$$\underbrace{(1+k^2)}_{A}y^2 \underbrace{-2.V_{jnew}}_{B}y + \underbrace{(V_{jnew}^2 - V_j{}^2)}_{C} = 0 \\ \xrightarrow{yields} Ay^2 + By + C = 0 \quad (11)$$

By solving the quadratic equation of (11), the proper value of active current (I_A) and the corresponding active power (P_0) is determined as (12):

$$P_0 = -V_{jnew}I_A{}^* \quad (12)$$

At each iterative process of AC load flow program, Eq. (12) should be used to update the active power injection of the nodes where DGs are connected until the convergence condition is satisfied. In this paper, due to the advantages of backward-forward load-flow method, it has been employed in this paper [17].

SIMULATION RESULTS

To verify the effectiveness of the developed approach, it is applied to 33-bus distribution network. Both of the proposed methods (I and II in the problem formulation section) are implemented to site and size three DG units on the system under study. The results are compared with the results of improved analytical (IA) method [18] and the hybrid approach proposed in [19]. Comparing method II versus I, the method II suggests better operation plan with more power loss reduction. Nevertheless, the results of method I is also acceptable since its results are better than IA method in view of negligible difference in power loss and a considerable reduction in the total capacity of DGs. The amount of power loss of method II is almost the same as Hybrid method (only 0.5 kW higher than Hybrid method) which is the least among all the other methods. Still, the method II utilizes 2696 kW DG capacity instead of 2870 kW of Hybrid method (174 kW less than Hybrid method). It is worth to mention that the location of DGs in both methods are almost the same. Figure 2 shows the voltage profile of complete (original) and incomplete (only active parts of the loads) network having DGs. As it can be seen the voltages of DGs are adjusted in a way that all of the ending nodes have exactly the same voltage. Voltage of ending nodes is 0.9956 p.u.

CONCLUSION

A new way of analysis is done for distribution networks in this paper. For active power injection (DG allocation), the negligible effect of reactive loads on the process of DG allocation is ignored and reactive parts of the loads of the network are removed. for the resulted network a method is derived based on the theory of optimal configuration. The theory indicates that optimal configuration for the resulted network is the one in which all of the ending nodes have exactly the same voltage. Two methods were proposed to satisfy the theory of optimal configuration based on equilibration of ending nodes voltage magnitude by the use of DG allocation. the necessary amount of active power or the optimal size of DGs (to enhance the voltage magnitude of the nodes they are connected up to the desired value) are calculated using the proposed formulation and solving a quadratic equation. As it is seen, the proposed approach obtains lower power loss with the sizes much less than the other methods.

REFERENCES

[1] H. L. Willis, Power Distribution Planning Reference Book, 2nd Edition, MarcelDekker, New York, 2004, pp. 1217.

[2] W. H Kersting, "Distribution System Modeling and Analysis", CRC Press, 2000.

[3] D. Shirmohammadi, H. W. "Reconfiguration of electric distribution networks for resistive line losses reduction", IEEE Trans. Power Deliv., vol. 4, no. 2, pp. 671-679, Apr. 1989.

[4] G. K. Viswanadha, P. R. Bijwe, "Efficient reconfiguration of balanced and unbalanced distribution systems for loss minimization'", IET Gener. Transm. Distrib., vol. 2, no., pp. 7-12, Jan. 2008.

[5] J. A. Pecas Lopes, N. Hatziargyrou, J. Mutale, P. Djapic, N. Jenkins, "Integrating Distributed Generation into Electric Power Systems: a Review of Drivers, Challenges and Opportunities", Electr. Power Syst. Res., vol. 77, no. 9, pp. 1189-1203, Jul. 2007

[6] H. L. Willis, G. S. Walter, "Distributed power generation: planning and evaluation", CRC Press, 2000.

[7] H. Hedayati, S. A. Nabaviniaki, A. Akbarimajd, "A method for placement of DG units in distribution networks", IEEE Trans. Power Deliv., vol. 23, no. 3, pp.1620-16288, May 2008.

[8] F. S. Abu-Mouti, M. E. El-Hawary, "Optimal distributed generation allocation and sizing in distribution systems via artificial bee colony algorithm", IEEE Trans. Power Deliv., vol. 26, no. 4, pp. 2090-2101, Oct. 2011.

[9] DQ. Hung, N. Mithulananthan N, K. Y. Lee, "Optimal placement of dispatchable and nondispatchable renewable DG units in distribution networks for minimizing energy loss", Electr. Power Energ. Syst. vol. 55, pp. 179-86.

[10] K. Nekooei, M. M. Farsangi, H. Nezamabadi-Pour, K. Y. Lee, "An improved multiobjective harmony search for optimal placement of DGs in distribution systems", IEEE Trans. Smart Grid, vol. 4, no. 1, pp. 557-567, Mar. 2013.

[11] M. Esmaeili, M. Sedighizadeh, M. Esmaili, Multi-objective optimal reconfiguration and DG (Distributed Generation) power allocation in distribution networks using Big Bang-Big Crunch algorithm considering load uncertainty, vol. 103, pp. 86-99, May 2016.

[12] U. Sultana, A. B. Khairuddin, A. S. Mokhtar, N. Zareen, B. Sultana "Grey wolf optimizer based placement and sizing of multiple distributed generation in the distribution system", Energy, vol. 11, pp. 525-536, Sep. 2016.

[13] M. H. Moradi, M. Abedini, "A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems", Electr. Power Energy Syst., vol. 34, no. 1, pp. 66-74, Jan. 2012.

[14] Akbar Bayat, "Uniform voltage distribution based constructive algorithm for optimal reconfiguration of electric distribution networks" Electric Power Systems Research vol. 104, pp. 146– 155, 2013.

[15] Akbar Bayat, A. Bagheri, R. Norouzian, Optimal Sizing and Placement of Dispersed Generation Accompanied by Reconfiguration of Distribution Networks for Maximum Loss Reduction, International Journal of Electrical Power and Energy Systems, Volume 77, January 2016, Pages 360-371

[16] J. Kennedy and R. Eberhart. 1995, "Particle swarm optimization", In Proceedings of IEEE International Conference on Neural Networks, IEEE Press, Piscataway, NJ. pages 1942-1948,

[17] L.R. Araujo, D.R.R. Penido, S. Carneiro Jr., J.L.R. Pereira, P.A.N. Garcia, A comparative study on the performance of TCIM full Newton versus backward–forward power flow methods for large distribution systems,

[18] T. Gozel, M. H. Hocaoglu, "An analytical method for the sizing and siting of distributed generators in radial system", Electr. Power Syst. Res., vol. 79, no. 6, pp. 912-918, Jun. 2009.

[19] M. A. Kashem, V. Ganapathy, G. B. Jasmon, and M. I. Buhari, "A novel method for loss minimization in distribution networks," in Proc. IEEE Int. Conf. Elect. Utility Deregulation Restruct. Power Technol., 2000, pp. 251-256.