IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 13, Issue 1 Ver. II (Jan. – Feb. 2018), PP 54-65
www.iosrjournals.org

Heuristic Approach to DG Sizing and Siting in Distribution System for Voltage Drop Reduction

Gopiya Naik. S[1,*], D. K. Khatod[2], M. P. Sharma[3]
[1]*Associate Professor, Dept. of E and EE, PESCE, Mandya, Karnataka (India).*
[2]*Associate Professor, Dept. of EEE,* [3]*Professor, Alternate Hydro Energy Centre, IIT Roorkee, Roorkee-247667, India.*
Corresponding Author: Gopiya Naik. S

Abstract: *This paper presents the impact of penetration level and power factor of DG on the voltage drop in a distribution system. For this purpose, suitable expressions have been developed to estimate the squared voltage drop reduction caused by the DG. A method is also suggested to determine the optimal location and size of DG. This method requires only base case load flow solution. The proposed method is implemented under MATLAB environment and applied on a 33-bus test distribution system with two different values of DG power factor. The voltage drop reduction by proposed method is compared with that by the repeated load flow method. The comparison shows that the results by proposed method is in close agreement to that of repeated load flow method and both are following similar trends.*

Keywords: *Distribution System, Distributed Generation, Penetration Level, Voltage Drop.*

Date of Submission: 15-01-2018 Date of acceptance: 30-01-2018

I. Introduction

Appropriate size and location of DG offers several technical, economical and environmental benefits to distribution networks. For optimal allocation of DG in distribution networks, different objectives such as power loss minimization [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 34], improvement of voltage profile [5, 14, 34] or voltage stability of the network [3], network investment cost minimization [15, 16, 17], reduction of environmental impact [18] etc. were touched by the researchers using single or multi objective problem formulation. Different optimization techniques like Analytical approaches [1, 8, 9, 10, 14, 13], Particle Swarm Optimization [2, 3], Evolutionary Programming [11], hybrid GA and Tabu search [7], heuristic methods [5, 8] have been applied to solve the above DG allocation issues.

Despite of optimal allocation of DG, its penetration level is also an important aspect in context of distribution system planning in presence of DG. The penetration level of DG is a ratio of the power injected by DG to the total power demand of a given distribution network. The impact of DG penetration level on distribution system has been presented by many authors. In references [19, 20, 21, 12, 22], the effect of DG penetration level on distribution losses has been presented. Impact of DG penetration on voltage profile was presented in [23, 20, 24]. The authors in [20, 22, 24, 25] presented the impact of DG penetration on investment cost. Quezeda *et al.* [12] developed an approach to compute the annual energy losses at different penetration and concentration level of DGs connected to the distribution network. Many regulatory committees and utilities have recommended DG interconnection procedures to guarantee a reasonable penetration level of DGs in distribution systems [26, 27, 28, 29, 30]. In practice, many DG interconnection procedures adopt different % rules for simplified DG interconnection. However, they unfortunately cannot provide any suitable documentation on technical studies or background information to determine these rules. Therefore, determination of suitable penetration level of DG in distribution network and its impact on system performance needs further attention of the researchers. Further, the available indices for checking the voltage profile improvement due to DG placement require a number of load flow solutions which depends on the system size (number of buses in the system) and incremental step-size for DG. Hence, a suitable method is required to check the voltage profile improvement after DG placement in the radial distribution network requiring only base case load flow solution.

This paper therefore, presents a heuristic approach based method to find the DG penetration level and power factor and their impact on the squared voltage drop in a given distribution system. By varying the DG size in a pre-specified range at a bus at a time, the squared voltage drop reduction is calculated by developed expression and then the DG size corresponding to maximum squared voltage drop reduction is selected as optimal DG penetration level for the bus under consideration. This method requires only base case load flow solution. The proposed method is implemented under MATLAB environment and applied on a 33-bus test system with two different values of DG power factors.

II. Forward-Backward Sweep Load Flow Method

The distribution system operation and planning studies requires information about steady state operation of the system at various load levels, which can be obtained from the load flow analysis. For load flow analysis of transmission network, well established methods are Gauss-Seidel (GS) method and Newton-Raphson (NR) method. The distribution system is mainly of radial structure, fed at one point and has higher R/X ratio of lines as compared to the transmission lines. This makes a distribution system ill-conditioned [31]. Therefore, existing methods for load flow analysis of transmission network may either become inefficient in the load flow analysis of distribution network or not converge [31, 32].

Various methods available for load flow analysis of distribution systems can be divided into two categories. The first type of method is based on proper modification of existing methods such as NR and GS methods. On the other hand, the second type of method is based on backward and forward sweep process using Kirchhoff's laws. Due to its low memory requirement, computational efficiency and robust convergence characteristic, backward and forward sweep based algorithm has gained significant popularity for load flow analysis of distribution systems. In this study, backward and forward sweep method [31] is used to find out the load flow solution of the distribution systems and is being described in following sub-sections.

2.1 Branch Numbering Scheme

The branch numbering process of a network divides the network in several layers and constructs a tree of the network. The first layer contains all the branches that are connected to the root or substation bus where the source is connected. The next (second) layer consists of all branches that are connected to the receiving end bus of the branches in the previous (first) layer and so on. All branches of the network should be considered in the tree and they should appear only once. After dividing all the branches in different layers, the branch numbering process starts at the first layer sequentially. The numbering of branches in any layer starts only after numbering all the branches in the previous layer. This process of branch numbering is continued till all branches of the network are considered [31].

2.2 Load Flow Equations

Consider the π-circuit model of a branch connected between buses/nodes p and q of a radial distribution network as shown in Fig. 1. Buses p and q are sending end and receiving end nodes, respectively, of the branch under consideration.

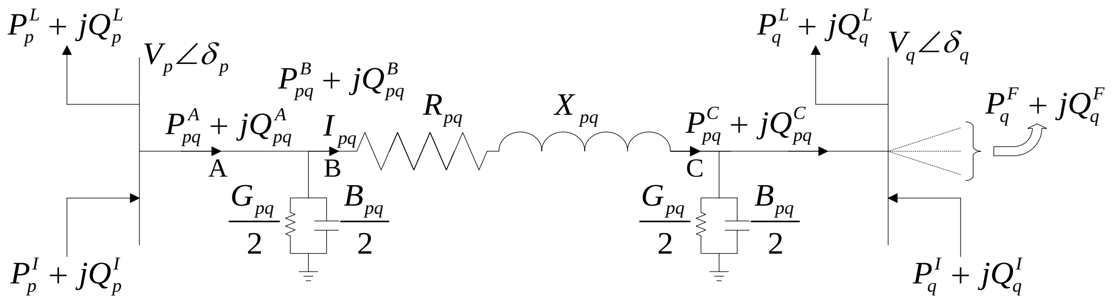

Fig. 1: π-circuit model of a branch connected between buses p and q

The active and reactive power flows at point C of the branch as shown in Fig. 1 can be given as [11, 31, 33,]:

$$P_{pq}^C = P_q^L + P_q^F - P_q^I + V_q^2 \frac{G_{pq}}{2} \tag{1}$$

$$Q_{pq}^C = Q_q^L + Q_q^F - Q_q^I - V_q^2 \frac{B_{pq}}{2} \tag{2}$$

where,

P_{pq}^C and Q_{pq}^C = Total active and reactive power, respectively, at point C of the branch under consideration,

P_q^L and Q_q^L = Total active and reactive loads, respectively, at receiving end bus q,

P_q^I and Q_q^I = Active and reactive power injections, respectively, at receiving end bus q,

P_q^F and Q_q^F = Sum of active and reactive power flows, respectively, through all the downstream branches connected to receiving end bus q.

V_q = Voltage magnitude of receiving end bus q,

G_{pq} and B_{pq} = Charging shunt conductance and susceptance, respectively, of branch connected between buses *p* and *q*.

The active and reactive power flows at points B and C of the branch as shown in Fig. 1 can be related as [11, 31, 33]:

$$P_{pq}^B = P_{pq}^C + I_{pq}^2 R_{pq} \tag{3}$$

$$Q_{pq}^B = Q_{pq}^C + I_{pq}^2 X_{pq} \tag{4}$$

where,

P_{pq}^B and Q_{pq}^B = Total active and reactive power, respectively, at point B of the branch under consideration,

I_{pq} = Magnitude of current flowing through the series impedance of branch connected between buses *p* and *q*.

R_{pq} and X_{pq} = Series resistance and reactance, respectively, of branch connected between buses *p* and *q*.

The phasor current, $\boldsymbol{I}_{pq}$ flowing through the series impedance of branch connected between buses *p* and *q* as shown in Fig. 1 is given as:

$$\boldsymbol{I}_{pq} = \frac{P_{pq}^B - jQ_{pq}^B}{\boldsymbol{V}_p^*} = \frac{P_{pq}^C - jQ_{pq}^C}{\boldsymbol{V}_q^*} \tag{5}$$

where,

$\boldsymbol{V}_p$ and $\boldsymbol{V}_q$ = Phasor voltages of buses p and q, respectively,

$\boldsymbol{V}_p^*$ = Conjugate of phasor quantity $\boldsymbol{V}_p$.

Using eq. (5), the active and reactive power flows at point B as given by eqs. (3) and (4), respectively, can be written as:

$$P_{pq}^B = P_{pq}^C + \frac{\left(P_{pq}^C\right)^2 + \left(Q_{pq}^C\right)^2}{V_q^2} R_{pq} \tag{6}$$

$$Q_{pq}^B = Q_{pq}^C + \frac{\left(P_{pq}^C\right)^2 + \left(Q_{pq}^C\right)^2}{V_q^2} X_{pq} \tag{7}$$

Further, the active and reactive power flows at points A and B of the branch as shown in Fig. 1 can be related as:

$$P_{pq}^A = P_{pq}^B + V_p^2 \frac{G_{pq}}{2} \tag{8}$$

$$Q_{pq}^A = Q_{pq}^B - V_p^2 \frac{B_{pq}}{2} \tag{9}$$

where,

P_{pq}^A and Q_{pq}^A = Total active and reactive power, respectively, at point A of the branch under consideration,

V_p = Voltage magnitude of sending end bus p,

Now the phasor voltages at buses p and q can be related as [11, 31, 33]:

$$\boldsymbol{V}_q = \boldsymbol{V}_p - \boldsymbol{I}_{pq}\left(R_{pq} + jX_{pq}\right) = \boldsymbol{V}_p - \frac{P_{pq}^B - jQ_{pq}^B}{\boldsymbol{V}_p^*}\left(R_{pq} + jX_{pq}\right) \tag{10}$$

Representing different voltages in polar form and multiplying both the sides by $1\angle -\delta_p$ yields

$$V_q\angle\left(\delta_q-\delta_p\right)=V_p-\frac{P_{pq}^B-jQ_{pq}^B}{V_p}\left(R_{pq}+jX_{pq}\right) \tag{11}$$

Further, simplifying the above equation results

$$V_q\angle\left(\delta_q-\delta_p\right)=\left(V_p-\frac{P_{pq}^B R_{pq}+Q_{pq}^B X_{pq}}{V_p}\right)-j\left(\frac{P_{pq}^B X_{pq}-Q_{pq}^B R_{pq}}{V_p}\right) \tag{12}$$

Using above equation, the voltage magnitude and angle at bus q can be written as:

$$V_q=\sqrt{V_p^2-2\left(P_{pq}^B R_{pq}+Q_{pq}^B X_{pq}\right)+\frac{\left(P_{pq}^B\right)^2+\left(Q_{pq}^B\right)^2}{V_p^2}\left(R_{pq}^2+X_{pq}^2\right)} \tag{13}$$

$$\delta_q=\delta_p-\tan^{-1}\left(\frac{P_{pq}^B X_{pq}-Q_{pq}^B R_{pq}}{V_p^2-P_{pq}^B R_{pq}-Q_{pq}^B X_{pq}}\right) \tag{14}$$

2.3 Algorithm for Load Flow

Various computational steps involved in solving the load flow problem of a single source radial distribution network are as below:

Step 1: Read the line data (series impedances and shunt admittances for all the branches) and bus data (power demand and injection at different buses) of the radial distribution network under consideration.

Step 2: Divide the network in several layers and constructs a tree of the network. Number different branches and buses as discussed in Section 2.1.

Step 3: Initialize the voltage magnitudes and their angles at different buses except root bus. The voltage magnitudes and their angles at different buses are taken as equal to corresponding values at root bus.

Step 4: Compute the active and reactive power flows at point A of each branch of the given network using eqs. (8) and (9), respectively. The power flow should be calculated in a backward direction. The backward direction means eqs. (8) and (9) are first applied to the branches of last layer and proceed in reverse direction until the first layer is reached.

Step 5: Compute the voltage magnitude and its angle at the receiving end bus of each branch using eqs. (13) and (14), respectively. The voltage should be calculated in a forward direction. The forward direction means eqs. (13) and (14) are first applied to the branches of first layer and proceed in forward direction until the last layer is reached.

Step 6: Compute the mismatch in voltage magnitudes at different buses by subtracting the previously known voltage magnitudes from those updated in Step 5. Find the maximum mismatch in voltage magnitude.

Step 7: Check whether maximum mismatch in voltage magnitude is within an acceptable tolerance? If yes, go to Step 8, otherwise repeat Steps 4 to 6.

Step 8: Stop the calculation. Print voltage magnitudes and their angles at different buses and the active and reactive power flows at different branches.

III. Proposed Methodology

In this section, the mathematical formulation of the proposed method is presented, which begins with the following assumptions:

1. The radial distribution network under consideration is balanced and fed by a single source.
2. The power factor of DG is known.

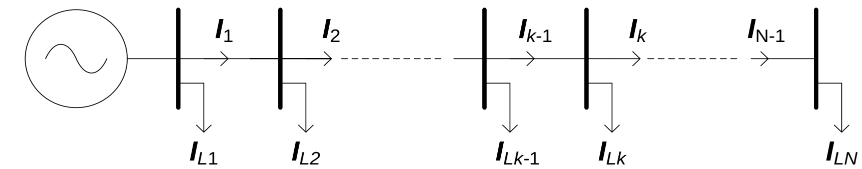

Fig. 2: A typical *N*-bus radial distribution system

Consider a typical N-bus radial distribution system as shown in Fig. 2. In this figure, $\boldsymbol{I}_k$ is the phasor current in branch k while $\boldsymbol{I}_{Lk}$ is the phasor current of load connected at node k. The square of voltage drop in a branch *i* can be given as:

$$VD_i = \left| \boldsymbol{I}_i \boldsymbol{Z}_i \right|^2 = \left| \left(I_{ai} + jI_{ri} \right)\left(R_i + jX_i \right) \right|^2 \tag{15}$$

where, $\boldsymbol{I}_i$ is the phasor current in branch *i* with I_{ai} and I_{ri} being its real and imaginary components, respectively and $\boldsymbol{Z}_i$ is the complex impedance of the branch *i* with R_i and X_i being its real and imaginary components, respectively.

Further, the square of voltage drop in branch *i* asgiven by eq. (15) can be simplified as:

$$VD_i = \left(R_i I_{ai} - X_i I_{ri} \right)^2 + \left(X_i I_{ai} + R_i I_{ri} \right)^2 = \left(I_{ai}^2 + I_{ri}^2 \right)\left(R_i^2 + X_i^2 \right) = \left(I_{ai}^2 + I_{ri}^2 \right) Z_i^2 \tag{16}$$

where, Z_i is the magnitute of $\boldsymbol{Z}_i$.

Now the total squared voltage drop in the entire system can be given as:

$$VD = \sum_{i=1}^{N-1} VD_i = \sum_{i=1}^{N-1} \left(I_{ai}^2 + I_{ri}^2 \right) Z_i^2 \tag{17}$$

When a DG is placed at a bus (say bus *k*) as shown in Fig. 3, it injects a current $\boldsymbol{I}_{DG}$ into the network and thereby alters the currents in all the branches connected between sub-station (bus 1) to bus *k*. However, the currents in the remaining branches are unaffected by the DG placed at bus *k*. The injected current by DG placed at bus *k* can be written as:

$$\boldsymbol{I}_{DG} = I_{aDG} + jI_{rDG} = I_{aDG}\left(1 + j\tan\phi\right) \tag{18}$$

where, I_{aDG} and I_{rDG} are the real and reactive components, respectively, of $\boldsymbol{I}_{DG}$ and ϕ is the phase angle of $\boldsymbol{I}_{DG}$.

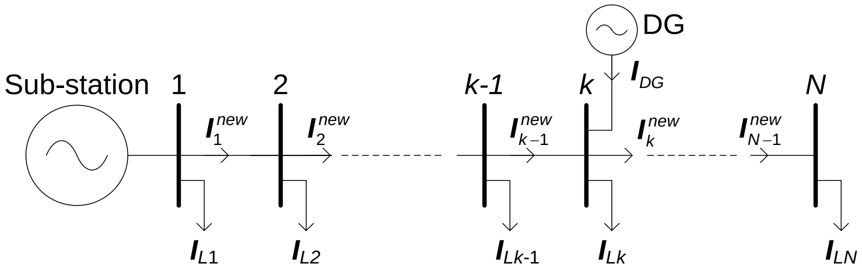

Fig. 3: A typical *N*-bus radial distribution system with DG placed at bus *k*

Now, the modified current in branch *i* due to DGat bus *k* can be given as:

$$\boldsymbol{I}_i^{new} = \boldsymbol{I}_i - D_i \boldsymbol{I}_{DG} = \left(I_{ai} - D_i I_{aDG} \right) + j\left(I_{ri} - D_i I_{aDG} \tan\phi \right) \tag{19}$$

where, $\boldsymbol{I}_i$ is the phasor current in branch *i* before DG placement and $\boldsymbol{I}_i^{new}$ is the modified phasor current in branch *i* after DG placement. The value of D_i is given by following relation:

$$D_i = \begin{cases} 1, & \text{if branch } i \text{ is between bus 1 and bus } k \\ 0, & \text{otherwise.} \end{cases}$$

The total squared voltage drop in a radial distribution network depends on the current and impedance of different branches as given in eq. (17). Since placement of DG at bus *k* in the network alters the currents in all the branches connected between sub-station (bus 1) to bus *k*, it also causes the change in voltage drop. Now, the total modified squared voltage drop, VD_{new} after DG placement can be given as:

$$VD_{new} = \sum_{i=1}^{N-1} \left[\left(I_{ai} - D_i I_{aDG} \right)^2 + \left(I_{ri} - D_i I_{aDG} \tan\phi \right)^2 \right] Z_i^2 \tag{20}$$

Then the percentage squared voltage drop reduction, ΔVD associated with placement of DG is given as:

$$\Delta VD = \frac{VD - VD_{new}}{VD} \times 100\% \tag{21}$$

Substituting the values of *VD* and VD_{new} from eqs. (17) and (20), respectively, in eq. (21); and simplifying the expression yields the following:

$$\Delta VD = \frac{\sum_{i=1}^{N-1}\left[2D_i I_{aDG}\left(I_{ai} + I_{ri}\tan\phi\right) - \left(D_i I_{aDG}\sec\phi\right)^2\right]Z_i^2}{VD} \times 100\% \qquad (22)$$

Equation (22) can be used to compute the squared voltage drop reduction associated with single DG placement of a given size and power factor. The developed expression for squared voltage drop reduction requires the active component and angle of injected current by DG. However, the DG capacity is generally expressed in terms of VA rating and power factor. Hence, the following expressions can be used to compute the active component and angle of injected current by DG:

$$I_{aDG} = \frac{V\sec\phi}{S_{DG}} \qquad (23)$$

$$\phi = \theta - \cos^{-1}(PF_{DG}) \qquad (24)$$

where, V and θ are the magnitude and angle, respectively, of bus voltage at which DG is connected, S_{DG} is the VA rating of DG and PF_{DG} is the power factor of DG.

3.1 SOLUTION ALGORITHM OF PROPOSED METHOD

The computational procedure of proposed algorithm can be given in the following steps:

1. Read the data regarding number of buses (N), configuration/connectivity, resistance and reactance of different branches, real and reactive power demand at different buses of distribution network under consideration.
2. Perform the load flow to calculate the branch currents, bus voltages and active power losses as discussed in Section 2.2.
3. Assume the power factor of DG and initialize bus counter, i = 2 (the source bus is numbered as 1 and not considered for DG placement.
4. Initialize DG size, j = 5% of total system load.
5. Compute the the active component and angle of injected current by DG using eqs. (23) and (24), respectively. Also, calculate squared voltage drop reduction using eq. (22) and store the results.
6. Check whether j = 100% of total system load ? If yes, go to Step 7, otherwise $j = j$ + 5% of total system load and go to Step 5.
7. Check whether $i = N$? If yes, go to Step 8, otherwise $i = i + 1$ and go to Step 4.
8. Identify the values of i and j corresponding to maximum squared voltage drop reduction. The value of i gives the optimal bus for DG placement and the value of j gives the near optimal DG capacity at bus i. The optimal DG capacity lies in between j-1 and j+1, which can further be optimized.
9. Initialize DG size at bus i, $k = j - 1$.
10. Compute the the active component and angle of injected current by DG using eqs. (23) and (24), respectively. Also, calculate squared voltage drop reduction using eq. (22) and store the results.
11. Check whether $k = j + 1$? If yes, go to Step 12, otherwise $k = k$ + 1% of total system load and go to Step 10.
12. Compare the squared voltage drop reduction at bus i and find out the overall maximum value of squared voltage drop reduction. Also, identify the value of k corresponding to maximum squared voltage drop reduction. The value of k gives the optimal DG capacity at bus i.

IV. Results And Discussion

The developed algorithm for the optimal placement and sizing of DG to reduce squared voltage drop is implemented under MATLAB environment and applied on 33-bus test distribution system. For the test system, two different values of DG power factors are considered as [9]:

a) DG is operated at a power factor equal to the power factor of total load of the system,
b) DG is operated at unity power factor.

1.1 33-Bus Radial Distribution System

The single line diagram of a 12.66 kV, 33-bus radial distribution system and the relevant data for this test system are acquired from reference [35]. This test system has a total demand of (3715 + *j*2300) kVA with the power factor of total load as 0.85 lagging. The base case losses in the system are 202.68 kW and 135.14 kVAR.

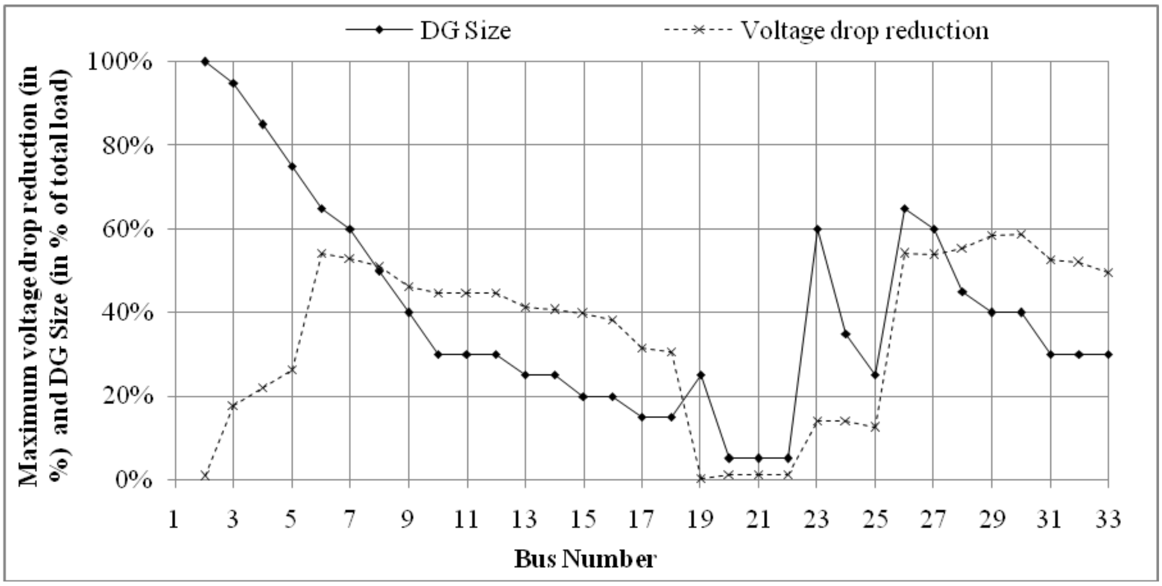

Fig. 4: Maximum voltage drop reduction and corresponding size of LPF DG at different buses of 33-bus system

First, at each bus (except root bus) of 33-bus network, the size of load power factor (LPF) DG is varied from 0 to 100% of total load in a step of 5% and for each possible size of LPF DG, the voltage drop reduction is calculated with the help of developed expression. Then, the maximum voltage drop reduction and corresponding DG size is recorded at each bus. A bus-wise plot of the maximum voltage drop reduction and corresponding DG size is shown in Fig. 4. From this figure, it is clear that both the maximum voltage drop reduction as well as corresponding DG size vary from bus to bus. Among different buses, DG placement at bus 30 offers maximum voltage drop reduction of about 59% with DG capacity of 40% of total load. The results shown in Fig. 4 can also be used to define maximum permissible size/penetration level of DG at different buses. For example, if anyone wishes to connect DG at bus 10 due to some location constraint, then DG size at 0.85 lagging power factor cannot exceed 30% of total system load.

In order to validate the results obtained by the developed expression, the squared voltage drop reduction obtained by the developed expression is compared with that obtained by performing the repeated load flow by varying the DG size at a bus. For this purpose, bus number 30 of 33-bus system is selected because this bus is resulting maximum squared voltage drop reduction as shown in Fig. 4. Fig. 5 shows the variation ofsquared voltage drop reduction by proposed method as well as repeated load flow method with DG capacity, when a DG is placed at bus number 30 and operated at LPF, which is 0.85 lagging. The squared voltage drop reduction with respect to the DG size at a bus follows an inverted U shape curve.

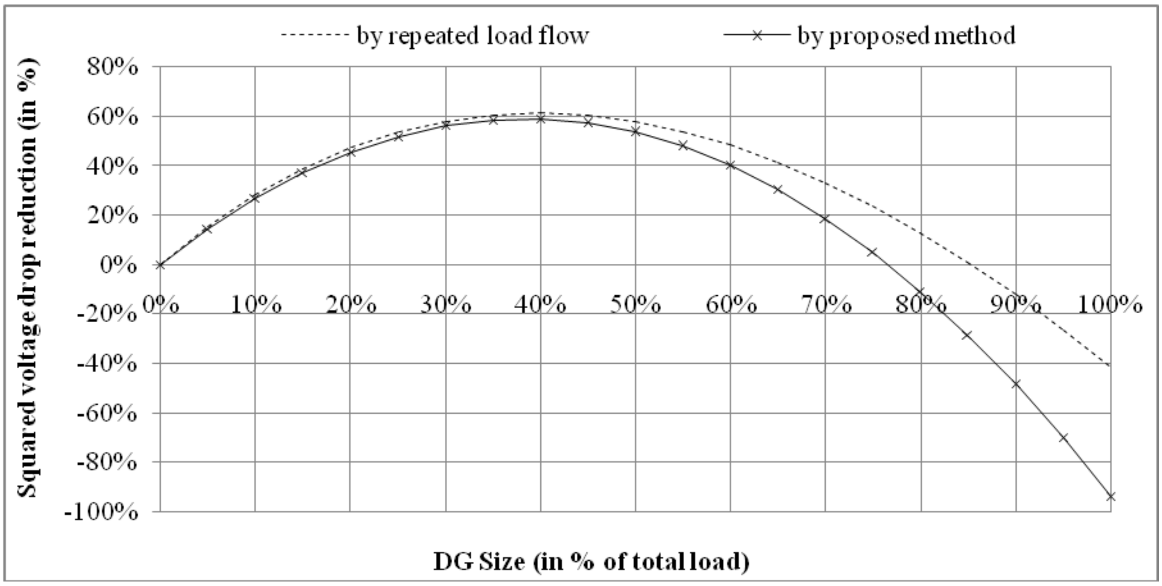

Fig. 5: Comparison of voltage drop reduction with LPF DG connected at bus 30 of 33-bus system

From Fig. 5, it can be observed that the squared voltage drop reduction computed by proposed method is close to that computed by running load flow and both are following similar trends. However, there is always a small difference, because the proposed derivation computes the squared voltage drop reduction due to the change in current through only those branches which are lying between sub-station (or root) bus and bus at which DG is connected. In actual practice, DG placement reduces the current flowing through different branches in the radial distribution network. This reduction in branch current reduces the voltage drops not only in those branches which are lying between sub-station (or root) bus and DG connected bus but also in remaining branches. This phenomenon is well reflected by load flow solution. Thus the squared voltage drop reduction calculated by proposed method is slightly less as compared to that calculated by repeated load flow method. But, the proposed method requires only base case load flow solution, while repeated load flow method requires as many load flow solutions as the number of DG sizes under consideration.

The maximum squared voltage drop reduction is observed by proposed method as well as repeated load flow method, when DG size is 40% of total load. However, by proposed method, maximum squared voltage drop reduction is 58.92%, whereas, it is 61.38% in the case of repeated load flow method. Though the squared voltage drop reduction calculated by proposed method is slightly less as compared to that calculated by repeated load flow method, DG sizes corresponding to maximum squared voltage drop reductionidentified by proposed method as well as repeated load flow method are same.

Again from Fig. 5, it is observed that the optimal capacity of LPF DG at bus 30 lies in the range of 35-45% of total load. In order to determine the exact optimal size of LPF DG at bus 30, its size is varied from 35 to 45% of total load in a step of 1% and obtained results are shown in Fig 6. From this figure, it observed that the optimal size of LPF DG is 38% of total load at bus 30.

A similar exercise is also carried out with unity power factor (UPF) DG. The proposed method is applied to different buses of 33-bus network by varying the size of UPF DG from 0 to 100% of total load in a step of 5% and the maximum voltage drop reduction and corresponding DG size is recorded at each bus. The same is plotted in Fig 7. Among different buses, DG placement at bus 6 offers maximum voltage drop reduction of 36.37% with DG capacity of 55% of total load. By comparing the results shown in Figs. 5 and 7, it can be concluded that placement of LPF DG results more voltage drop reduction as compared to the placement of UPF DG. In addition, with power factor of DG, optimal DG capacity at a bus also varies. Hence, DG power factor plays an important role in deciding the voltage drop reduction and capacity of DG.

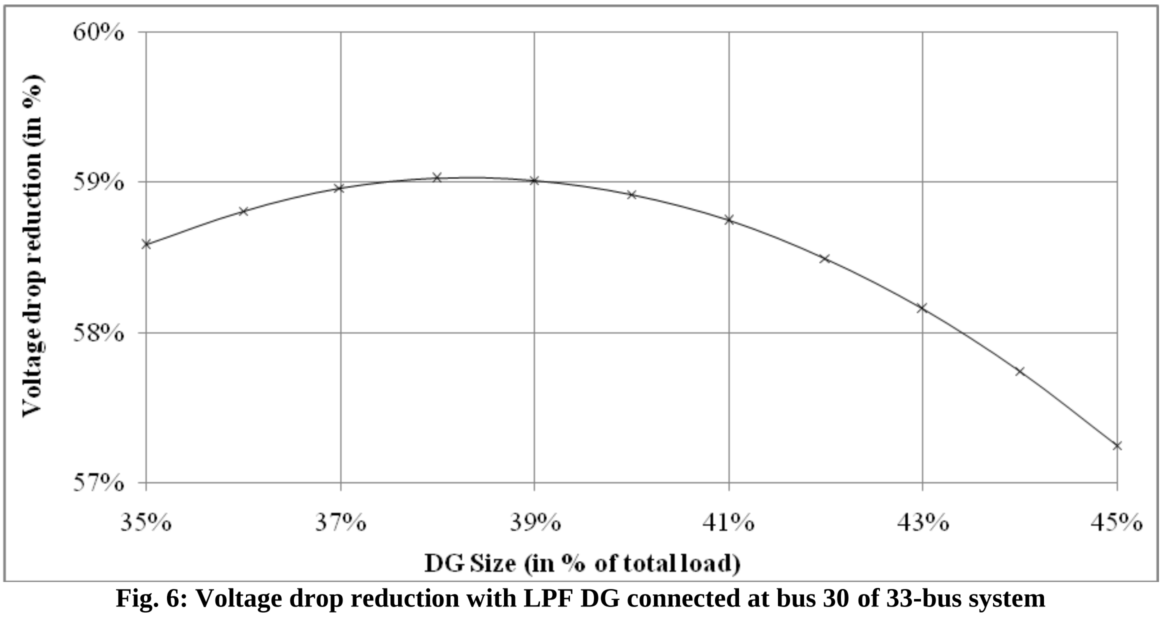

Fig. 6: Voltage drop reduction with LPF DG connected at bus 30 of 33-bus system

In order to validate the results obtained by the developed expression, bus number 6 of 33-bus system is selected because this bus is resulting maximum squared voltage drop reduction with UPF DG as shown in Fig. 7. The squared voltage drop reduction obtained by the developed expression is compared with that obtained by performing the repeated load flow by varying the UPF DG size at bus 6. Fig. 8 shows the variation in squared voltage drop reduction by proposed method as well as repeated load flow method with DG capacity.

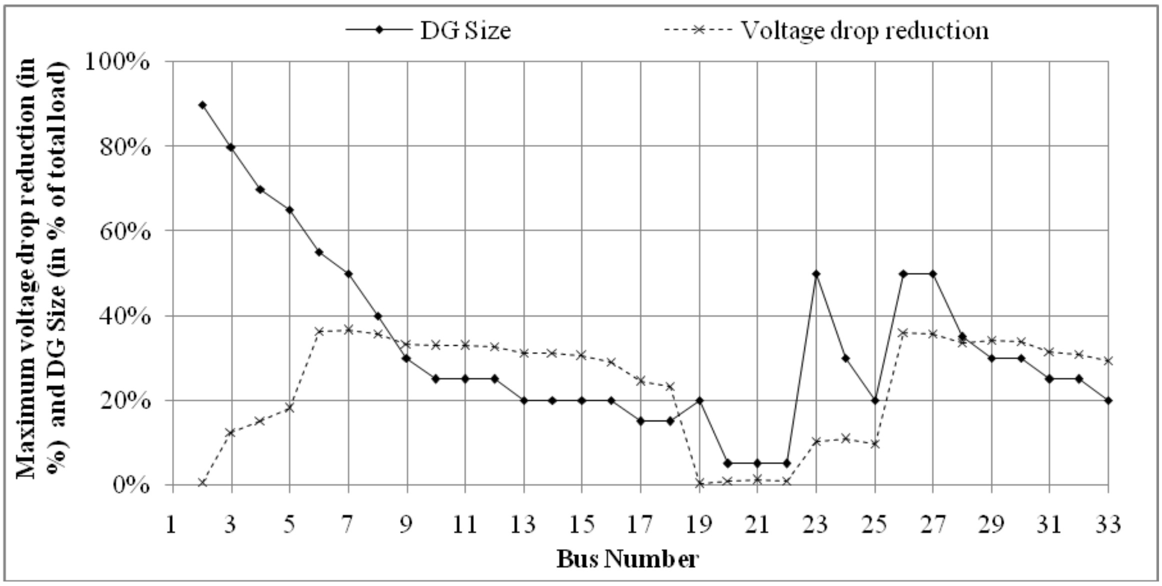

Fig. 7: Maximum voltage drop reduction and corresponding size of UPF DG at different buses of 33-bus system

By proposed method, maximum squared voltage drop reduction is 36.37%, whereas, it is 40.34% in the case of repeated load flow method. Though the squared voltage drop reduction calculated by proposed method is slightly less as compared to that calculated by repeated load flow method, DG sizes corresponding to maximum squared voltage drop reductionidentified by proposed method as well as repeated load flow method are same. The maximum squared voltage drop reduction is observed by proposed method as well as repeated load flow method, when DG size is 55% of total load.

Again from Fig. 8, it is observed that the optimal capacity of UPF DG at bus 30 lies between 50-60% of total load. In order to determine the exact optimal size of UPF DG at bus 30, Steps 9 to 12 of Section 3.1 is used and obtained results are shown in Fig. 9. From this figure, it observed that the optimal size of LPF DG is 38% of total load at bus 30, while optimal size of UPF DG is 53% of total load at bus 6.

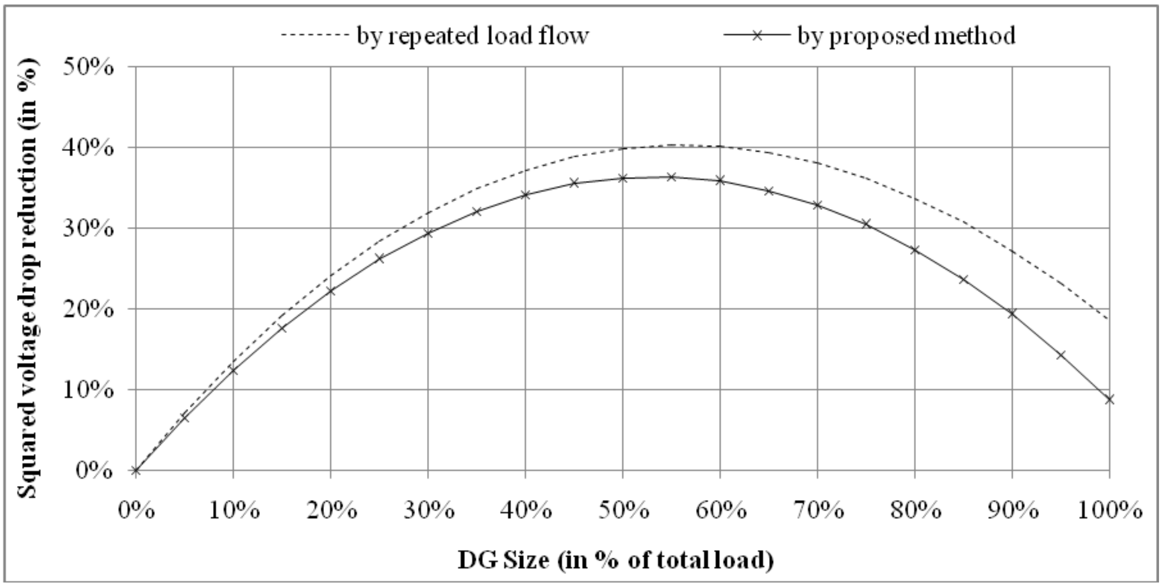

Fig. 8: Comparison of voltage drop reduction with UPF DG connected at bus 6of 33-bus system

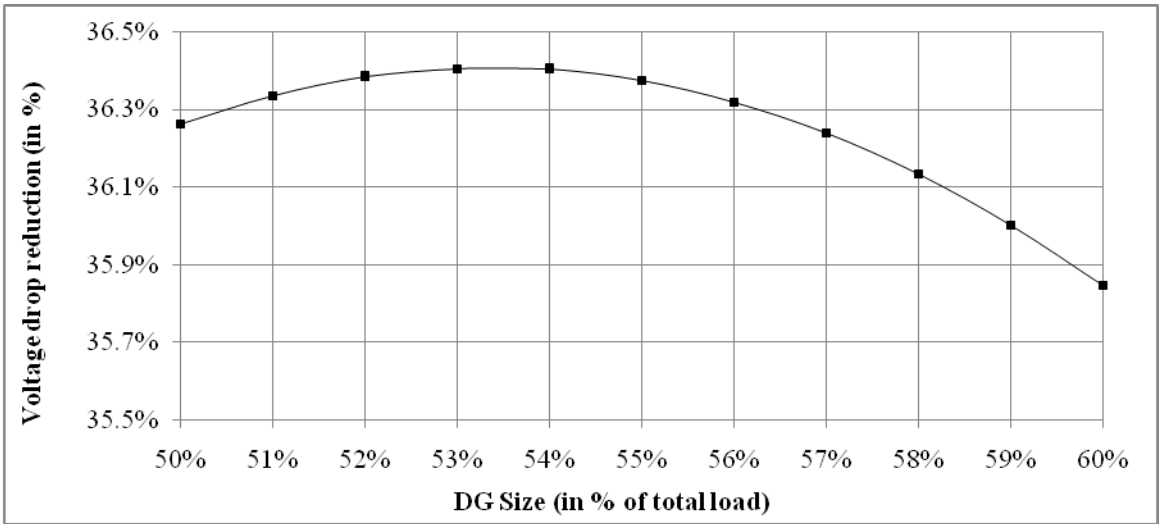

Fig. 9: Voltage drop reduction with UPF DG connected at bus 6 of 33-bus system

The voltage profiles of 33-bus system by placing LPF DG with capacity 38% of total load at bus 30 and UPF DG with capacity 53% of total load at bus 6 are shown in Fig. 10. In this figure, the base case voltage profile is also plotted for the sake of comparison. There is significant improvement in the voltage profile of system with DG placement in both the cases. However, in case of LPF DG, it is better as compared to the case with UPF DG. The obtained results are in line with those shown in Figs. 6 and 9. The voltage drop reduction of 59.02% is observed from Fig. 6 by placing LPF DG at bus 30, while the voltage drop reduction of 36.41% is observed from Fig. 9 by placing UPF DG at bus 6.

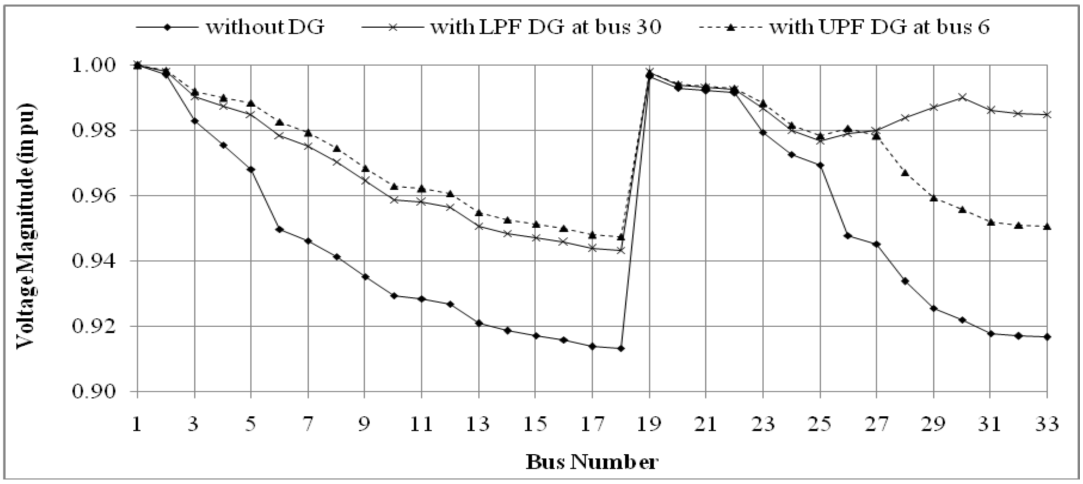

Fig. 10: Voltage profile of 33-bus system with LPF and UPF DG placement

Table 1: Summary of results for 33-bus test systems for voltage drop reduction

Particulars	33-bus test system	
DG size (in % of Total Load)	38%	53%
DG Power Factor	LPF	UPF
Location (Bus)	30	6
Voltage Drop Reduction (%)	59.02	36.41
Minimum Voltage (in pu) and corresponding Bus	0.943 pu at bus 18	0.947 pu at bus 18

Now, summarizing the analysis carried out for 33-bus test system, Table 1 shows the results for LPF and UPF DG placement in considered test systems. For the test system, the placement of LPF DG always results more voltage drop reduction. Depending on the power factor of DG, its size and optimal location may vary.

Further, an analysis has also been carried out for the computational burden involved in determining the optimal location and size of DG. The proposed method takes only base case load flow solution, while on the other hand the repeated load flow method requires a number of load flow solutions which depends on the system size (number of buses in the system) and incremental step-size for DG. The number of load flow solutions required is plotted in Fig. 18 as a function of system size with different values of incremental step-size for DG. The number of load flow solutions required varies linearly with the system size for a given value of incremental step-size for DG. The proposed method requires less computation burden in comparison to repeated load flow method. Since the trends of squared voltage drop reduction calculated by proposed method and repeated load flow method are same, the results obtained by proposed method can also be used to reduce the search space, if proposed method is used with an optimization technique.

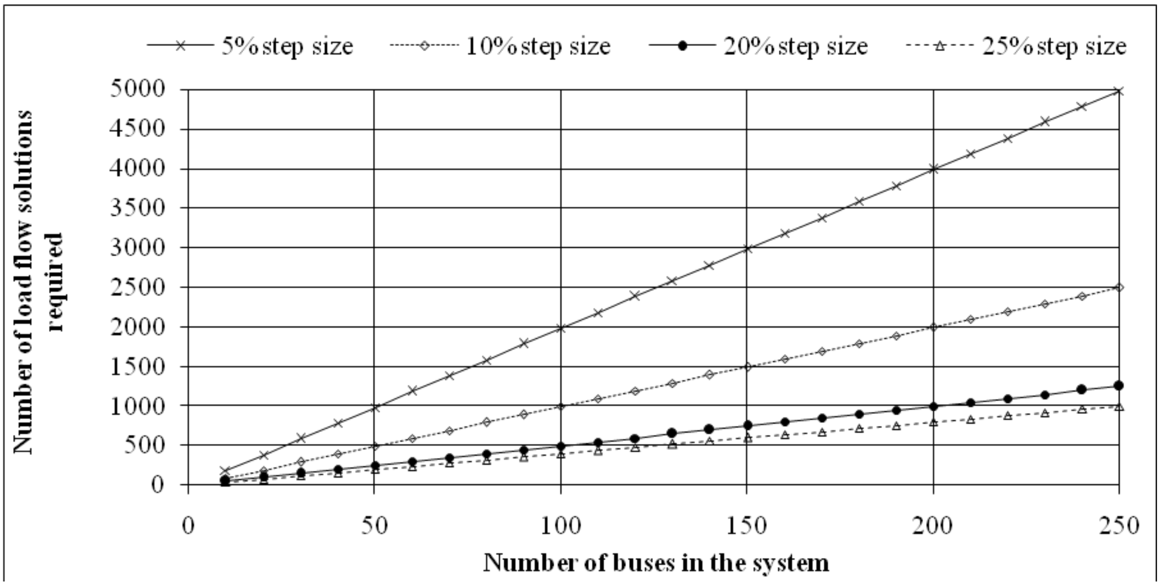

Fig. 18: Variation in number of load flow solutions required with system size and incremental step-size for DG

V. Conclusion

This paper presents a method to analyze the impact of DG of a given size and power factor on the squared voltage drop in a distribution system. On the basis of developed expression, an algorithm has been presented to determine the optimal location and size of DG in a distribution system for reduction of the squared voltage drop. This method requires only base case load flow solution. The proposed method has been implemented under MATLAB environment. The squared voltage drop reduction by proposed method has been compared with that by the repeated load flow method which shows that the results by proposed method is in close agreement to that by repeated load flow and both are following similar trends. The proposed algorithm has been applied to 33-bus radial distribution test system considering DG operation at two different power factors, one at unity power factor and another at load power factor. The obtained results show that there is significant improvement in the voltage profile of system with DG placement by proposed method. However, in case of load power factor DG, it is better as compared to the case with unity power factor DG.

Acknowledgements

The first author would like express thanks to Principal, PES College of engineering, Mandya, and the Management, PET®, Mandya, Karnataka, for their support and encouragement in carrying out this research work.

References

[1] Acharya N., Mahat P., and Mithulananthan N., An analytical approach for DG allocation in primary distribution network, *International Journal of Electrical Power and Energy Systems*, 28(10), 669-678, 2006.

[2] Al-Rashidi M.R., and Al-Hajri M.F.,Optimal planning of multiple distributed generation sources in distribution networks: A new approach, *Energy Conversion and Management*, 52(11), 3301-3308, 2011.

[3] Aman M.M., Jasmon G.B., Bakar A.H.A., and Mokhlis H., A new approach for optimum DG placement and sizing based on voltage stability maximization and minimization of power losses, *Energy Conversion and Management*, 70, 202-210, 2013.

[4] Atwa Y.M,, EI-Saadany E.F,, Salama M.M.A., and Seethapathy R.,Optimal renewable resource mix for distribution system energy loss minimization, *IEEE Transactions on Power Systems*, 25(1), 360-370, 2010.

[5] Chiradeja P., and Ramkumar R., An approach to quantify the technical benefits of distributed generation, *IEEE Transactions on Energy Conversion*, 19(4), 764-773, 2004.

[6] Elsaiah S., Benidris S., and Mitra J., Analytical approach for placement and sizing of distributed generation on distribution systems, *IET Generation, Transmission and Distribution*, 8(6), 1039-1049, 2014.

[7] Gandomkar M., Vakilian M., and Ehsan M., A Genetic based Tabu search algorithm for optimal DG allocation in distribution networks, *Electric Power Components and Systems*, 33(12), 1351-1362, 2007.

[8] Gozel T., and Hocaoglu M.H., An analytical method for the sizing and siting of distributed generators in radial systems, *Electric Power Systems Research*, 79, 912-918, 2009.

[9] Hung D.Q., Mithulananthan N., and Bansal R.C., Analytical expressions for DG allocation in primary distribution networks, *IEEE Transactions on Energy Conversion*, 25(3), 814-820, 2010.

[10] Hung D.Q., Mithulanathan N., and Bansal R.C., Analytical Strategies for renewable distributed generation integration considering energy loss minimization, *Applied Energy*, 105, 75-85, 2013.

[11] Khatod D.K., Pant V., Sharma J.D., Evolutionary programming based optimal placement of renewable distributed generators, *IEEE Transactions on Power Systems*, 28(2), 683-695, 2013.

[12] Quezeda V.H.M., Jua-Rivier Abbad., and T. Gomez., Assessment of energy distribution losses for increasing penetration of DG, *IEEE Transactions on Power Systems*, 21(2), 533-540, 2006.

[13] Wang C., and Nehir M.H., Analytical approaches for optimal placement of distributed generation sources in power system, *IEEE Transactions on Power Systems*, 19(4), 2068-2076, 2004.

[14] Khan H., and Choudhry M.A., Implementation of distributed generation algorithm for performance enhancement of distribution feeder under extreme load growth, *International Journal of Electrical Power and Energy Systems*, 32(9), 985-997, 2010.

[15] Celli G., Ghiani E., Mocci S., and Pilo F., A multi-objective evolutionary algorithm for siting and sizing of distributed generation, *IEEE Transactions on Power Systems*, 20(2), 750-757, 2005.

[16] El-Khattam W., Bhattacharya K., Hagazy Y.G., and Salama M.M.A., Optimal investment planning for distributed generation in a competitive electricity market, *IEEE Transactions on Power Systems*, 19(3), 1674-1684, 2004.

[17] Mendez V.H., Rivier J., De la Fuente J.I., Gomez T., Arceluz J., Marin J., and Madurga A., Impact of distributed generation on distribution investment deferral, *International Journal of Electrical Power and Energy Systems*, 28(4), 244-252, 2006.

[18] Chiradeja P., and Ramkumar R., An approach to quantify the technical benefits of distributed generation, *IEEE Transactions on Energy Conversion*, 19(4), 764-773, 2004.

[19] Bialek J., Tracing the flow of electricity, *IEE Proceedings on Generation, Transmission, Distribution*, 143, 313-320, 1996.

[20] Keane A., and Malley M.O., Optimal utilization of distribution networks for energy harvesting, *IEEE Transactions on Power Systems*, 22(1), 467-475, 2007.

[21] Lo K.L., Hassan M.Y., and Jovanonic S., Assessment of MW mile method for pricing transmission services: A negative flow-sharing approach, *IET Generation, Transmission and Distribution*, 1(6), 904-911, 2007.

[22] Singh D., Singh D., and Verma K.S., Comparative analysis for penetration of distributed generation in power systems, *IEEE International Conference on Sustainable Energy Technologies*, Singapore, 2008, 1271- 1276

[23] Chen P.C., Salcedo R., Zhu Q., de León F., Czarkowski D., Jiang Z.P., Spitsa V., Zabar Z., and Uosef R.E., Analysis of voltage profile problems due to the penetration of distributed generation in low-voltage secondary distribution networks, *IEEE Transactions on Power Delivery*, 27(4), 2020-2028, 2012.

[24] Maciel R.S., Padilha-Feltrin A., da Rosa M.A., and Miranda V., A multi-objective evaluation of the impact of the penetration of distributed generation, *2nd IEEE/PES International Conference and Exhibition on Innovative Smart Grid Technologies*, Manchester, 2011.

[25] Keane A., and Malley M.O., Optimal allocation of embedded generation on distribution networks, *IEEE Transactions on Power Systems*, 20(3), 1640-1646, August 2005.

[26] Ayres H.M., Freitas W., de Almeida M.C., and da Silva L.C.P., Method for determining the maximum allowable penetration level of distributed generation without steady-state voltage violations, *IET Generation, Transmission and Distribution*, 4(4), 495-508, 2010.

[27] Bhowmik A., Maitra A, Halpin S.M., and Schatz J.E., Determination of allowable penetration levels of distributed generation resources based on harmonic limit considerations, *IEEE Transactions on Power Delivery*, 18(2), 619-624, 2003.

[28] Kim T.E., and Kim J.E, A method for determining the introduction limit of distributed generation system in distribution system, *IEEE Power Engineering Society Summer Meeting*, Vancouver, BC, Canada, 2001.

[29] Morren, J., and de Hann, S.W.H., "Maximum penetration level of distributed generation without voltage limits, *20th international conference and exhibition on electricity distribution* (*CIRED 2009*), Prague, Czech Republic, June 8-11, 2009.

[30] Thong V.V., Dommelen D.V., and Belmans R., Penetration level of distributed energy resources with anti-islanding criteria and secure operation of power system, *IEEE Power Engineering Society General Meeting*, Montreal, QC, Canada, 2006.

[31] Haque M.H., Efficient load flow method for distribution systems with radial or mesh configuration, *IEE Proceedings on Generation, Transmission and Distribution*, 143(1), 33-38, 1996.

[32] Das D., Nagi H.S., and Khotari D.P., Novel method for solving radial distribution networks, *IEE Proceedings on Generation Transmission and Distribution*, 141(4), 291-298, 1994.

[33] Khatod D.K., Pant V., and Sharma J.D., A novel approach for sensitivity calculations in the radial distribution systems, *IEEE Transactions on Power Delivery*, 21(4), 2048-2057, 2006.

[34] Gopiya Naik S., Khatod D.K., and Sharma M.P., Optimal allocation of combined DG and capacitor for real power loss minimization in distribution networks, *International Journal of Electric Power and Energy Systems*, 53, 967-73, 2013.

[35] Baran M.E., and Wu F.F., Network reconfiguration in distribution systems for loss reduction and load balancing, *IEEE Transactions on Power Delivery*, 4(2), 1401-1407, 1989.

IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) is UGC approved Journal with Sl. No. 4198, Journal no. 45125.

Gopiya Naik. S "Heuristic Approach to DG Sizing and Siting in Distribution System for Voltage Drop Reduction." IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) 13.1 (2018): 54-65.