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Loss Minimization and Voltage Profile Improvement with Network Reconfiguration and Distributed Generation

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Abstract: A new method of reducing active power losses and voltage profile improvement in distribution networks by simultaneous placement of optimally sized Distributed Generation (DGs) is proposed in this paper. A loss sensitivity factor is mainly considered for DG placement in the distribution network for loss reduction and voltage profile improvement. This Loss Sensitivity Index method is tested in different cases with the combination of network reconfiguration and DGs. All cases are compared to identify the superiority of the proposed method. This method is tested to demonstrate the performance and effectiveness of the IEEE 33 Bus Radial Distributed System in ETAP software.

Keywords: Radial distribution System, Distributed Generation, Loss Sensitivity Factor, Network Reconfiguration, Loss Minimization, Voltage profile.

1. Introduction

The term "Distributed Generation" (DG) refers to the production of electricity near the consumption areas. With current initiatives on smart grid and sustainable energy, Distributed generations (DGs) are going to play the vital role in the emerging electric power systems. Nowadays, DGs are the part of distributed energy resources (DERs) which also include energy storage and responsive loads [1]. The major driving forces behind the increased penetration of DGs can be categorized into environmental, commercial and regulatory factors. Distribution systems, whether they are radial type systems found in rural or suburban areas, or network type systems located in urban areas are designed to operate without any generation on the distribution system or at customer loads. The introduction of generation sources on the distribution system can significantly impact the flow of power and voltage conditions at customers and utility equipment [2, 3]. One of the main advantages of DG is its proximity to the consumer loads. DG can play an important role in improving the reliability of the grid, reducing the transmission losses, providing better voltage support and improving power quality. The distributed generation also reduces greenhouse gas emission addressing the pollutant concerns by providing clean and efficient energy.

Network reconfiguration is widely used for optimizing distribution system operations [4, 5]. Distribution systems are normally operated as radial systems. However, the configuration of the system can be changed (reconfigured) by changing the state of some sectionalizing switches, strategically placed on the line sections of the system [6, 7]. Especially with the introduction of remote control capability to the switches, on-line network reconfiguration becomes an important part of distribution automation.

The network is reconfigured for two purposes: (i) to reduce the system power loss, (ii) to relieve the overloads in the network. The first problem is referred to as network reconfiguration for loss reduction and the second as load balancing.

However, due to dynamic nature of loads, total system load is more than its generation capacity that makes relieving of load on the feeders not possible and hence voltage profile of the system will not be improved to the required level [8]. To meet the required level of load demand, DG units are integrated into distribution network to improve voltage profile, to provide reliable and uninterrupted power supply and also to achieve economic benefits such as minimum power loss, energy efficiency, and load leveling. In the proposed method, network reconfiguration and DG installation are dealt simultaneously for improved loss minimization and voltage profile [9, 10].

2. Problem Formulation

Consider the main feeder in the distribution network with n buses as shown in Figure1

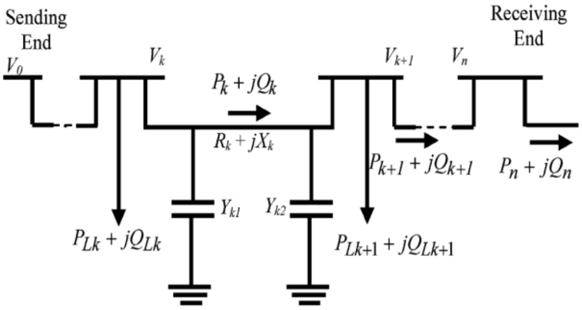

Figure 1. Single line diagram of the main feeder

A. Power Flow Equations

Power flows in a distribution system are computed by the following set of simplified recursive equations derived from single line diagram shown in Fig.1.

$$P_{k+1} = P_k - P_{Loss,k} - P_{Lk+1} = P_k - \frac{R_k}{|V_k|^2}\{P_k^2 + (Q_k + Y_k\,|V_k|^2)^2\} - P_{Lk+1} \qquad (1)$$

$$Q_{k+1} = Q_k - Q_{Loss,k} - Q_{Lk+1} = Q_k - \frac{X_k}{|V_k|^2}\{P_k^2 + (Q_k + Y_{k1}\,|V_k|^2)^2\} - Y_{k1}\,|V_k|^2 - Y_{k2}|V_{k+1}|^2 - Q_{Lk+1} \qquad (2)$$

$$|V_{k+1}|^2 = |V_k|^2 + \frac{R_k^2 + X_k^2}{|V_k|^2}(P_k^2 + {Q'_k}^2) - 2(R_kP_k + X_KQ_k) = |V_k|^2 + \frac{R_k^2 + X_k^2}{|V_k|^2}(P_k^2 + (Q_k + Y_k|V_k|^2)^2) - 2\big(R_kP_k + X_K(Q_k + Y_k|V_k|^2)\big) \qquad (3)$$

The power loss in the line section connecting buses k and $k+1$ may be computed as

$$P_{Loss}(k, k+1) = R_k \frac{(P_k^2+Q_k^2)}{|V_k|^2} \qquad (4)$$

The total power loss of the feeder $P_{T,Loss}$, may then be determined by summing up the losses of all line sections of the feeder, which is given as

$$P_{T,Loss} = \sum_{k=1}^{n} P_{Loss}(k, k+1) \qquad (5)$$

B. Power Loss using Network Reconfiguration

The network reconfiguration problem in a distribution system is to find the best configuration of the radial network that gives minimum power loss while the imposed operating constraints are satisfied, which are voltage profile of the system, the current capacity of the feeder and radial structure of distribution system. The power loss of a line section connecting buses k and $k+1$ between and after reconfiguration of network can be computed as

$$P'_{Loss}(k, k+1) = R_k \frac{(P_k^2+Q_k^2)}{|V'_k|^2} \qquad (6)$$

Total power loss in all the feeder sections, $P'_{T,Loss}$, may then be determined by summing up the losses in all line sections of network, which is written as

$$P'_{T,Loss} = \sum_{k=1}^{n} P'_{Loss}(k, k+1) \qquad (7)$$

C.Loss Reduction Using Network Reconfiguration

Net power loss reduction, ΔP_{Loss}^{R} , in the system is the difference of power loss before and after reconfiguration, that is (5)–(7) and is given by

$$\Delta P_{Loss}^{R} = \sum_{k=1}^{n} P_{T,Loss}(k, k+1) - \sum_{k=1}^{n} P'_{T,Loss}(k, k+1) \qquad (8)$$

D.Power Loss Reduction Using DG Installation

Installation of distribution generation units in optimal locations of a distribution system results in several benefits. These include reduction of line losses, improvement of voltage profile, peak demand shaving, relieving the overloading of distribution lines, reduced environmental impacts, increased overall energy efficiency, and deferred investments to upgrade existing generation, transmission, and distribution systems.

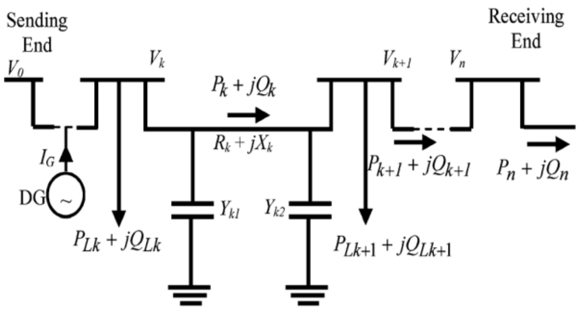

Figure 2. Distribution system with DG installation at an arbitrary location

The power loss when a DG is installed at an arbitrary location in the network as shown in Fig.2 is given by

$$P_{DG,Loss} = \frac{R_k}{V_k^2}(P_k^2 + Q_k^2) + \frac{R_k}{V_k^2}(P_G^2 + Q_G^2 - 2P_kP_G - 2Q_kQ_G)\left(\frac{G}{L}\right) \quad (9)$$

Net power loss reduction, ΔP_{Loss}^{DG}, in the system is the difference of power loss before and after installation of DG unit, that is (9)–(11) and is given by

$$\Delta P_{Loss}^{DG} = \frac{R_k}{V_k^2}(P_G^2 + Q_G^2 - 2P_kP_G - 2Q_kQ_G)\left(\frac{G}{L}\right) \quad (10)$$

The positive sign of ΔP_{Loss}^{DG} indicates that the system loss reduces with the installation of DG. In contrast, the negative sign of ΔP_{Loss}^{DG} implies that DG causes the higher system loss.

3. Optimal Location for DG Placement

Sensitivity analysis is used to compute sensitivity factors of candidate bus locations to install DG units in the system. Estimation of these candidate buses helps in reduction of the search space for the optimization procedure. Consider a line section consisting an impedance of $R_k + jX_k$ and a load of $P_{Lk,eff} + jQ_{Lk,eff}$ connected between $k-1$ and k buses as shown in Fig.3.

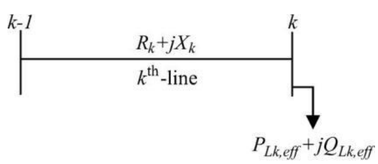

Figure 3. Line Section with an Impedance

Active power loss in the k th-line between $k-1$ and k buses is given by

$$P_{lineloss} = \frac{(P_{Lk,eff}^2 + Q_{Lk,eff}^2)R_k}{V_k^2} \quad (11)$$

Now, the loss sensitivity factor (LSF) can be obtained with the equation

$$\frac{\partial P_{lineloss}}{\partial P_{Lk,eff}} = \frac{2*P_{Lk,eff}*R_k}{V_k^2} \quad (12)$$

Using (12), LSFs are computed from load flows, and values are arranged in descending order for all buses of the given system. It is worth to note that LSFs decide the sequence in which uses are to be considered for DG unit installation.

4. Results and Discussions

To demonstrate the effectiveness of the proposed method, it is applied to IEEE 33 Bus Radial distribution system. This network consists of 33 Buses, 32 Branches, and 5 tie lines as shown in Fig.4.

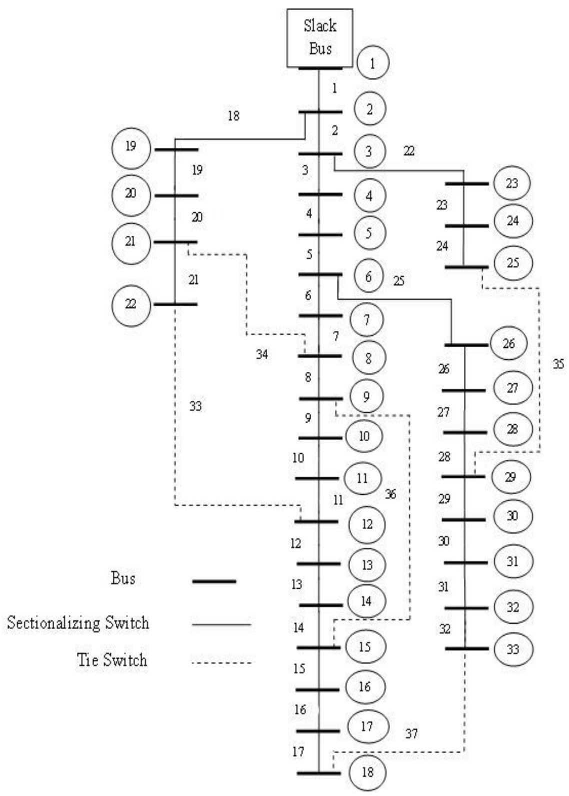

Figure 4. 33 Bus Radial Distribution System

In the simulation of the network, four cases have been considered to analyze the superiority of the proposed method.

case I: The system without Reconfiguration and DGs (Base Case).

Case II: The system with Reconfiguration and without DGs.

Case III: The system with DGs.

Case IV: The system of Reconfiguration and DGs

All cases are simulated in ETAP software as shown in Fig.5.

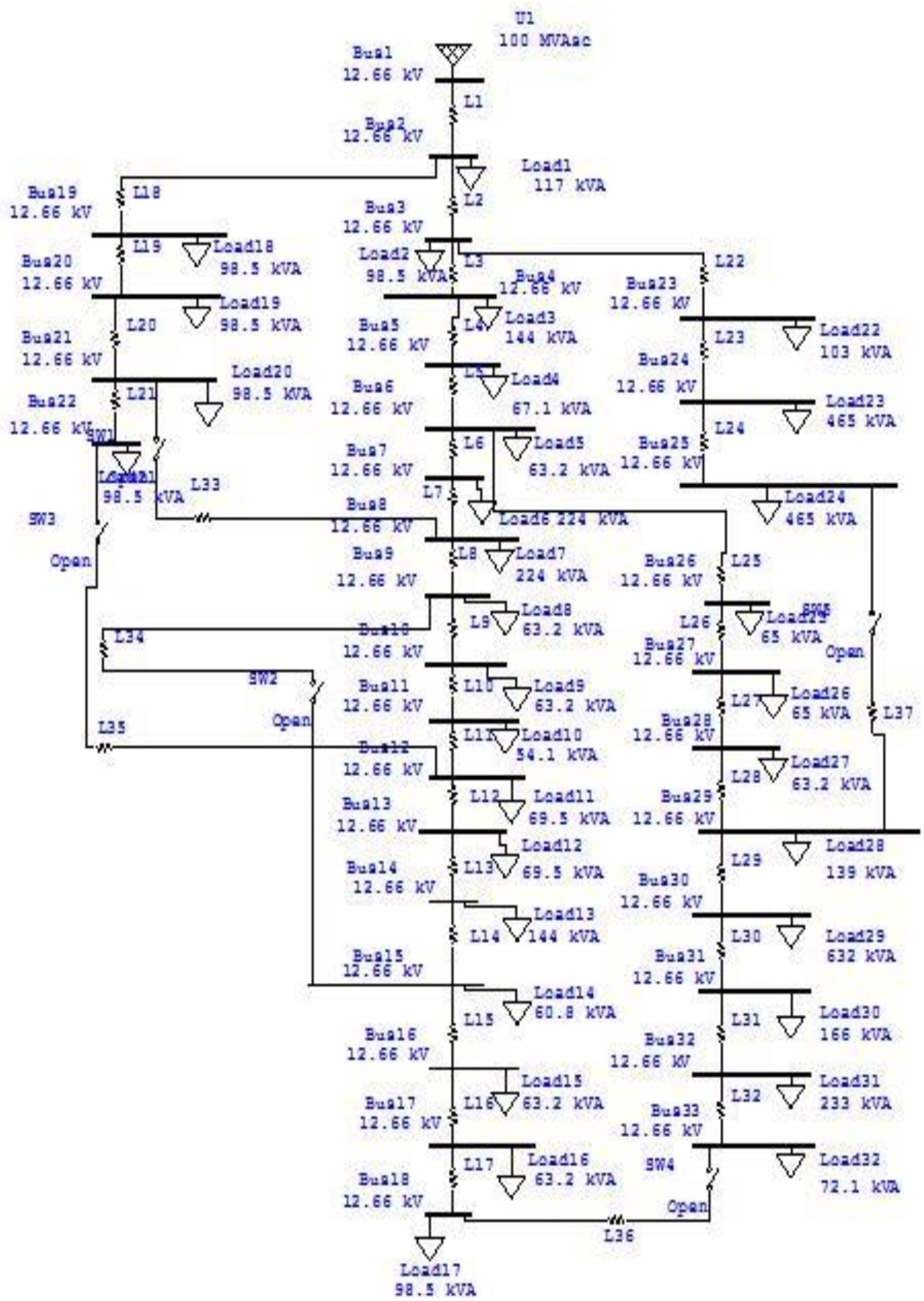

Figure 5. 33 Bus System Base Case

Using Loss Sensitivity Analysis, Sensitivity factors are computed to find the optimal location of DG unit at candidate bus location for cases 3 and 4.After computing sensitivity analysis at all lines, they are sorted and ranked as shown in Table 1.

Table 1: Loss Sensitivity Factors

Line	Loss sensitivity factor	Line	Loss sensitivity factor
23	**4.703**	5	0.613
24	**4.699**	15	0.559
30	**1.833**	2	0.554
7	1.775	3	0.549
19	1.689	22	0.507
29	1.270	6	0.468
28	1.205	20	0.460
12	1.099	14	0.442
16	0.965	4	0.285
17	0.822	11	0.280
31	0.816	32	0.255
13	0.807	26	0.213
21	0.796	18	0.184
27	0.793	25	0.152
9	0.782	1	0.115
8	0.771	10	0.111

Only top three locations have been selected to install DG units. The limits of DG units are chosen between 0 to 1.5 MW as shown in Table 2.

Table 2: Sizing of DG

Bus No	Size of the DG
24	0.785 MW
25	0.42 MW
31	1.113 MW

To assess the performance of the proposed method, simulation results are tabulated in Table 3. It is observed that the Base case losses are 0.157 MW and 0.104 Mvar and these are reduced in cases II, III and IV. The minimum voltage in Base case is 0.9245 p.u and when compared to other cases, the minimum voltage has been improved.

Table 3: Results of 33 BUS Systems for Different Cases

Cases	Description	Parameters	Values
Case I	Base Case	Losses (MW)	0.157
		Losses (MVar)	0.104
		Minimum Voltage (p.u)	0.9245
		Maximum Voltage (p.u)	0.9973
Case II	With Tie Lines	Losses (MW)	0.107
		Losses (MVar)	0.076
		Minimum Voltage (p.u)	0.9567
		Maximum Voltage (p.u)	0.9973
Case III	With DG	Losses (MW)	0.043
		Losses (MVar)	0.035
		Minimum Voltage (p.u)	0.9509
		Maximum Voltage (p.u)	1.0
Case IV	Tie Lines and DG	Losses (MW)	0.017
		Losses (MVar)	0.016
		Minimum Voltage (p.u)	0.9866
		Maximum Voltage (p.u)	1.0

This shows the losses have been reduced and voltage profile has been improved by the proposed method in Case IV as shown in Fig.6.

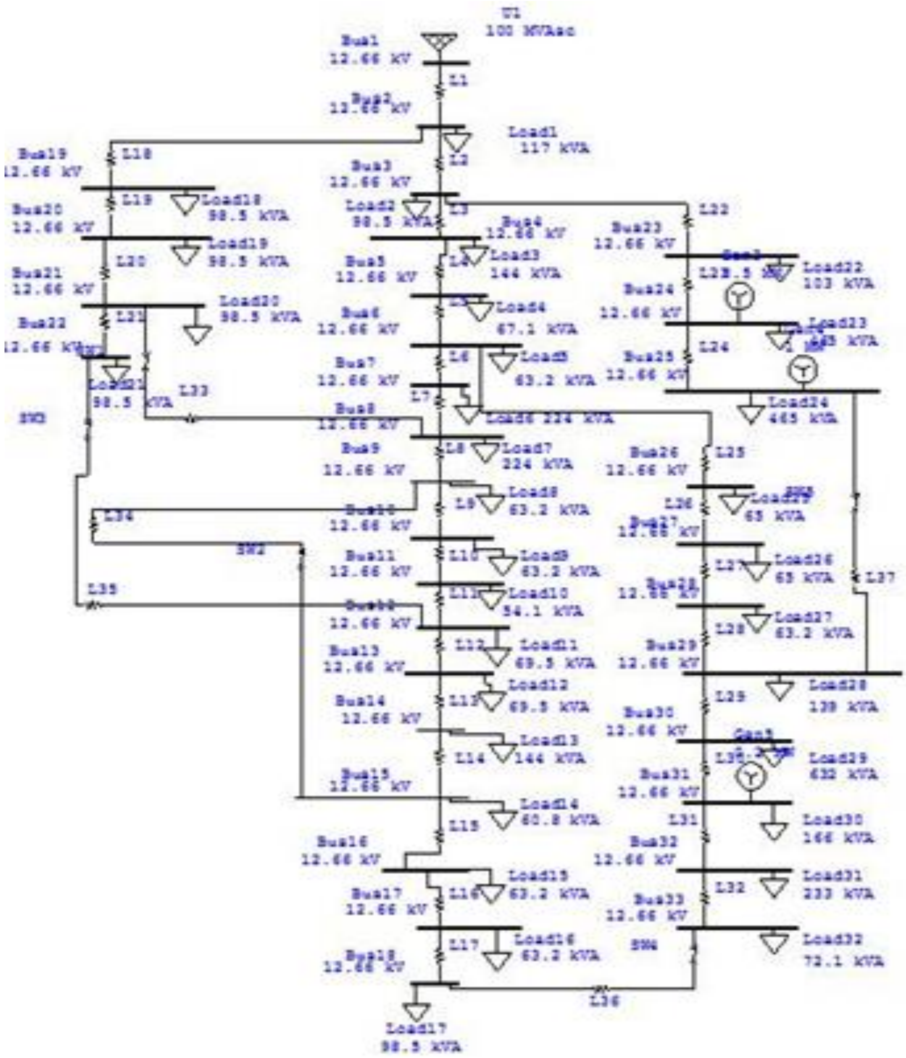

Figure 6. 33 Bus Systems with Tie Lines and DG

4. Conclusion

In this paper, a new approach has been proposed to reconfigure and to find the optimal location of DG in the distribution system. The Loss Sensitivity Index method has been tested on IEEE 33 Bus Radial Distribution System in ETAP software. Loss Sensitivity factors are computed to find the optimal location of DG unit at candidate bus locations and are sorted and ranked. In this paper different cases have been considered to test the superiority of the proposed method. The results show that the network reconfiguration also with DG placement is more efficient for loss reduction and voltage profile improvement. The losses have been reduced from 0.157 MW and 0.104 Mvar to 0.017 MW and 0.016 Mvar respectively. The minimum voltage has been improved from 0.9245 p.u to 0.9866 p.u.

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