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Voltage Profile Improvement of Distribution System using Distributed Generating Units

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ABSTRACT

The power system utilities are increasing everyday, to enhance the distribution power quality and maintain the voltage stability is a challenging task in the complex distribution This can be achieved through the Distributed Generation (DG). DGs are the final link between the high voltage transmission and the consumers,it is also known as Active Distribution networks (ADN). This will effectively improve the acive power loss reduction This paper represents technique to minimize power losses in a distribution feeder by optimizing DG model in terms of size, location and operating point of DG. Sensitivity analysis for power losses in terms of DG size and DG operating point has been performed. The proposed sensitivity indices can indicate the changes in power losses with respect to DG current injection. The proposed technique has been developed with considering load characteristics and representing constant current model. The effectiveness of the proposed technique is tested and verified using MATLAB software on long radial distribution system.

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1. INTRODUCTION

DG (distributed generation) is defined as installation and operation of small modular power generating technologies that can be combined with energy management and storage systems. It is used to improve the operations of the electricity delivery systems at or near the end user [1]. These systems may or may not be connected to the electric grid. Distributed generation system can employ a range of technological options from renewable to non-renewable and can operate either in a connected grid or off-grid mode. The size of a distributed generation system typically ranges from less than a kilowatt to a few megawatts.

There are various methods used for loss reduction in power system network like feeder reconfiguration, capacitor placement [12], high voltage distribution system, conductor grading, and DG unit placement. All these methods are involved with passive element except DG unit placement. Both capacitors and DG units reduce power loss and improve voltage regulation, but with the DGs loss reduction almost doubles that of Capacitors [2], [9].

The distributed generation units connected to local distribution systems are not dispatchable by a central operator, but they can have a significant impact on the power flow, voltage profile, stability, continuity, short circuit level, and quality of power supply for customers and electricity suppliers [3], [4].

2. PROBLEM FORMATION

The complexity of the distribution system and the power quality maintaining is achieved by allocating the DGs in the distribution bus. The proposed technique is based on optimal placement of DG units, which is concentrate with specifications like based on their size and location. The stability of the distribution system is depends on the following factors.

Voltage stability,
Real and Reactive power,
Power loss

2.1. Power losses

Power losses in distribution systems vary with numerous factors depending upon the system configuration, such as level of losses through transmission and distribution lines, transformers, capacitors, insulators, etc. Power losses can be divided into two categories: real power loss and reactive power loss [11].

Consequently, reactive power makes it possible to transfer real power through transmission and distribution lines to customers. The total real and reactive power losses in a distribution system can be calculated by,

$$P_{Loss} = \sum_{i=1}^{n_{br}} |I_i^2| r_i \quad (1)$$

$$Q_{Loss} = \sum_{i=1}^{n_{br}} |I_i^2| x_i$$

Where nbr is total number of branches in the system, Ii is the magnitude of current flow in branch I, ri and xi are the resistance and reactance of branch i, respectively. Different types of loads connected to distribution feeders also affect the level of power losses. The following sub-sections will discuss the power losses in a system with and without DG inclusion through representing loads with constant current models.

2.2. Distribution system with constant current load model

Constant current loads draw constant current from the distribution feeder and are independent of voltage. The relationship between power (P) consumed by the constant current load and the bulk voltage (V) can be represented as,

$$\frac{P}{\boldsymbol{P_0}} = \frac{V}{V_0} \quad (2)$$

A distribution system with N number of buses and N-1 number of constant current loads is shown in Figure 1.

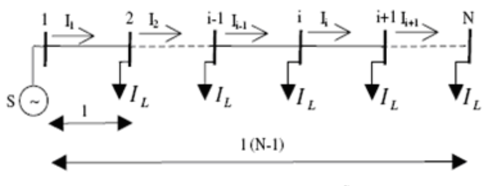

Figure 1. N-bus system with N-1 constant current loads

From the above figure Voltage at bus i can be expressed in terms of substation voltage and the total voltage drop from the substation to bus I as follows.

By applying the series expansion, we obtain:

$$V_i = V_1 - l_z \sum_{j=1}^{i-1} I_j \quad (3)$$

$$V_i = V_1 - l_z \left[(i-1)N - \frac{i-1}{2} i\right] I_L \quad (4)$$

The equations for initial system power losses is:

$$P_{Loss}^{ini} = l_r\Big[\Big[\Big(\frac{N-1}{6}\Big) N(2N-1]|I_L^2|\Big] \quad (5)$$

$$Q_{Loss}^{ini} = l_x[[\Big(\frac{N-1}{6}\Big) N(2N-1]|I_L^2|]$$

A DG is connected to the feeder at bus k, as shown in Figure 2, and injecting current $I_{DG} \angle\theta_{DG}$ into the network.

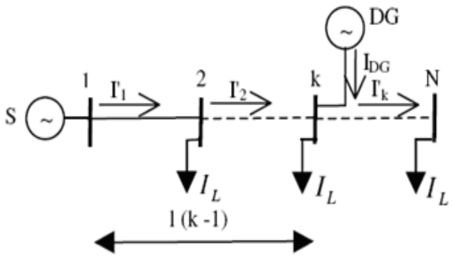

Figure 2. N-bus radial system with DG connected at bus K

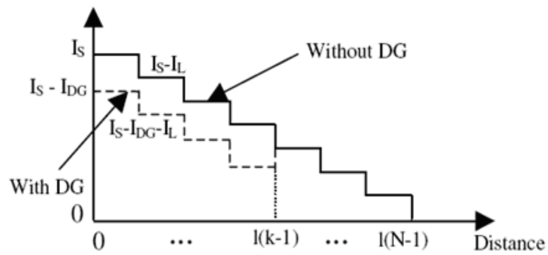

Figure 3. Current flow in the system with and without DG

As shown in Figure 3, the integration of DG into the system results in a reduction of current flow from the substation to the DG connection point k, but does not affect the current flow past the point of k to the remote end.

The current flows in branch i in the presence of DG is,

$$I_i' = \ I_i - I_{DG} \ \ i \ \leq k \quad (6)$$

$$= \ I_i \qquad i > k$$

The voltage at load bus i in the feeder is,

$$V_{i,i\neq 1}^{DG} = \ V_i = \ l_z(i-1)I_{DG} \qquad i \leq k \quad (7)$$

$$and \quad V_{i,i\neq 1}^{DG} = \ V_i = \ l_z(k-1)I_{DG} \qquad i \leq k$$

Equation (7) reveals that the voltage profile of the feeder is improved when DG is connected into the system. The voltage improvement at load buses (except the utility bus) before and after DG connection point is given in Equation (8) respectively as,

$$\Delta V_i^{DG} = \ l_z(i-1)I_{DG} \qquad i \leq k \quad (8)$$

$$\Delta V_i^{DG} = \ l_z(k-1)I_{DG} \qquad i > k$$

Thus, real and reactive power losses of the system have become as,

$$P_{Loss}^{DG} = \ l_r\big[\textstyle\sum_{i=1}^{k-1}|I_i - \ I_{DG}|^2 + \sum_{i=k}^{N-1}|I_i|^2\big] \quad (9)$$

$$Q_{Loss}^{DG} = \ l_x\left[\sum_{i=1}^{k-1}|I_i - \ I_{DG}|^2 + \sum_{i=k}^{N-1}|I_i|^2\right]$$

By rearranging Equation (9) the real and reactive power losses of the system with DG can be expressed in terms of the real and reactive power losses without DG and a loss reduction as,

$$P_{Loss}^{DG} = P_{Loss}^{ini} + f_{Loss} l_r \, |I_{DG}|$$

$$Q_{Loss}^{DG} = Q_{Loss}^{ini} + f_{Loss} l_x \, |I_{DG}| \quad (10)$$

Where $f_{Loss} = (k-1)I_{DG} - 2|I_L|\cos(\theta_L - \theta_{DG})\left[(k-1)N - \frac{k-1}{2}k\right]$ and θ_L is the phase angle of the load current. Therefore, the active and reactive loss reduction, ΔPloss and ΔQloss, with DG are given as,

$$\Delta P_{Loss}^{DG} = f_{Loss}\, l_r |I_{DG}| \quad (11)$$

$$\Delta Q_{Loss}^{DG} = f_{Loss}\, l_x |I_{DG}|$$

From Equation (11) we can obviously see that the power losses in the system can be reduced by the DG only if the loss factor, f Loss is less than zero. This factor is dependent on both size and location of DG. The derivative of DG P Loss with respect to DG current is,

$$\frac{\partial P_{Loss}^{DG}}{\partial |I_{DG}|} = 2l_r(k-1)|I_{DG}| - 2l_r|I_L|\cos(\theta_L - \theta_{DG})\left[(k-1)N - \frac{k-1}{2}k\right] \quad (12)$$

Similarly, the derivative of the reactive loss with respect to DG current is,

$$\frac{\partial Q_{Loss}^{DG}}{\partial |I_{DG}|} = 2l_x(k-1)|I_{DG}| - 2l_x|I_L|\cos(\theta_L - \theta_{DG})\left[(k-1)N - \frac{k-1}{2}k\right] \quad (13)$$

The derivatives of real and reactive power losses with respect to the phase angle of DG current are,

$$\frac{\partial P_{Loss}^{DG}}{\partial \theta_{DG}} = -2l_r|I_L||I_{DG}|[(k-1)N - \frac{k(k-1)}{2}]\sin(\theta_L - \theta_{DG}) \quad (14)$$

$$\frac{\partial Q_{Loss}^{DG}}{\partial \theta_{DG}} = -2l_x|I_L||I_{DG}|[(k-1)N - \frac{k(k-1)}{2}]\sin(\theta_L - \theta_{DG})$$

Any changes in DG current, in terms of magnitude and phase, will result in a change in the real and reactive power losses of the system. The influences of DG current and DG operating point on loss changes can be assessed through the above sensitivity indices.

The real power loss reduction obtains its maximum value only if derivative of Ploss with DG reaches zero value. Therefore, maximum DG current injection by DG for minimum real power loss is,

$$|I_{DG,max}^{Loss,P}| = \frac{|I_L|\cos(\theta_L - \theta_{DG})\left[(k-1)N - \frac{k(k-1)}{2}k\right]}{k-1} \quad (15)$$

3. TEST SYSTEM

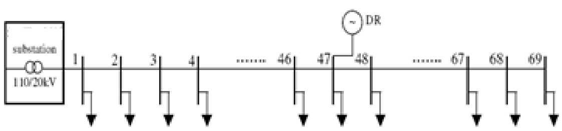

Figure 4. One line diagram of feeder

The one line diagram of proposed test system is shown in figure 4. and feeder details are given below

Feeder details:

Type: Radial feeder
Length: 48KM
Line impedance, z1: 0.6672+j0.3745ohm/KM
Nominal voltage: 22KV

4. RESULTS AND DISCUSSIONS

A DG is placed at bus 47 and injects only real power into the system. To inject real power only, the phase of DG current is made equal to the phase of local voltage at connection point.The magnitude of DG current varies from 0 to 2 p.u. Figure 5 shows the real power losses and its sensitivity with respect to the change in magnitude of DG current injection for constant current load model.

When the DG current increases, the rate of change of the real loss is changing from negative to positive, which means that the real loss starts decreasing, and after a certain level of DG current it starts to increase. Therefore, minimum real loss can be achieved only if the derivative of real loss with respect to DG current reaches zero value.

The maximum DG current for constant current load is 1.35 p.u. similar results are obtained for the case of reactive power loss and shown in Figure 6.

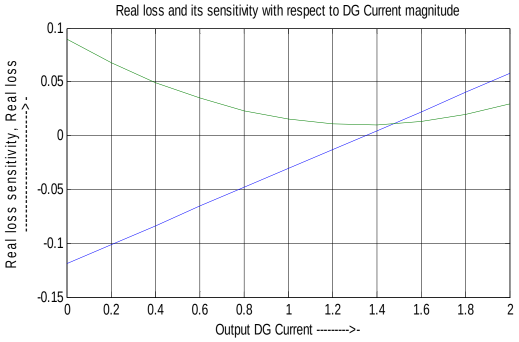

Figure 5. Real loss and its sensitivity with respect to DG current magnitude

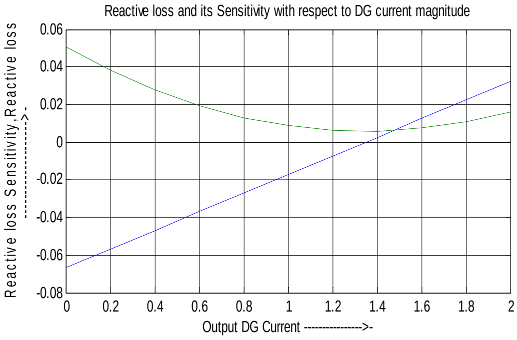

Figure 6. Reactive loss and its sensitivity with respect to DG current Magnitude

Figure 7 and Figure 8 shows the sensitivity of real and reactive power, respectively, for the change in phase angle of IDG, in the cases of constant impedance and constant current load models.

From these figures, we observe that both real and reactive power losses decrease with the increasing of DG current phase (their slopes are negative). However, there are points where the real and reactive power losses start increasing. These points are considered as the optimal phase of DG current for minimum real and reactive power losses.

By using the sensitivity analysis, optimal output currents from DG can be determined for different DG locations. Since it is not effective to place the DG closer to the sending end of the feeder, where there is enough support from the substation, DG is assumed to be placed only at the downstream load buses of the system

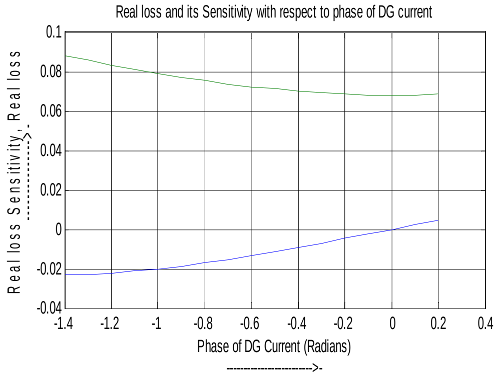

Figure 7. Real loss and its sensitivity with respect to phase of DG current

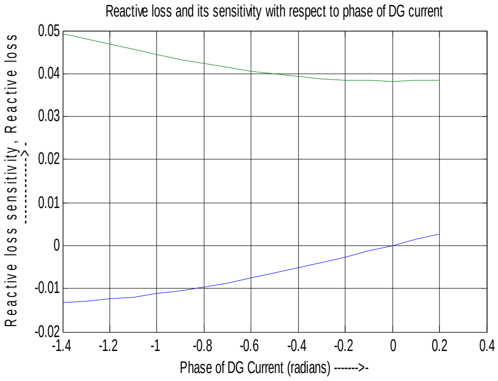

Figure 8. Reactive loss and its sensitivity with respect to phase of DG current

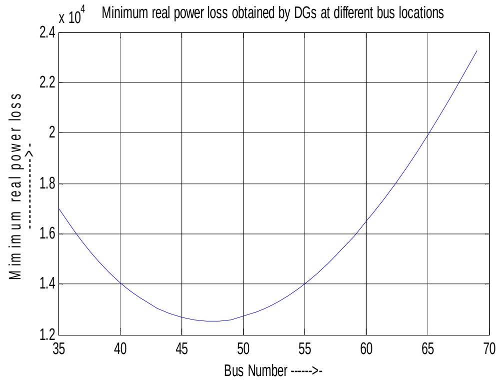

Figure 9. Minimum real power losses obtained by optimal sizes of DG

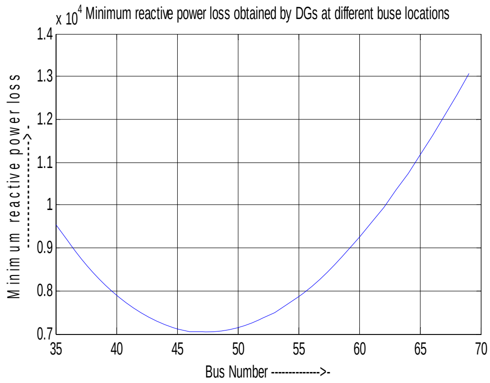

Figure 10. Minimum reactive power losses obtained by optimal sizes of DG

A range of DG location from bus 35 to bus 69 is examined. By placing a DG of the optimal size at the corresponding load bus for the bus 35 to bus 69, one at a time, the real and reactive power losses of the system are calculated and reported in Figure 9 and Figure 10, respectively.

The results show that, for both load models, minimum real and reactive power losses are obtained when DG is located at bus 47.

Figure 11 shows the voltage profile of the system with and without DG. From this figure, we can see that DG designed for minimum power losses also improves the voltage profile of the system. In the system without DG, lowest voltage level was approximately 0.927p.u. However, with DG of the optimal size for constant current load model connected at the optimal location (bus 47) is 0.98p.u

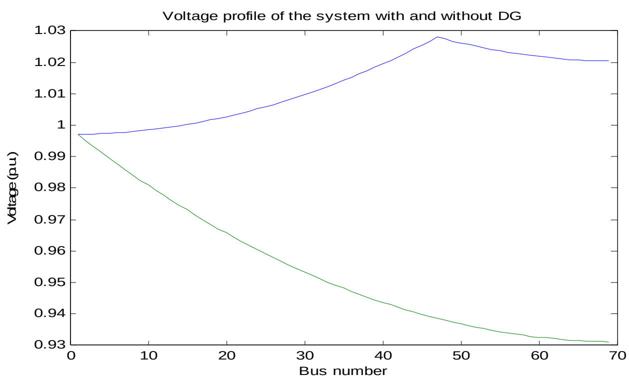

Figure 11. Voltage profile of the system with and without DG

5. CONCLUSION

The results show that the integration of DG is highly effective in reducing power losses and improving the voltage profile in the distribution system. The studies also reveal that maximum benefits from DG can be obtained only if proper DG planning is performed. The optimal DG model varies from system to system, depending on the system configurations, types of connected loads, and a trade-off among the objectives of DG usage

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