Novel Method for Loss Reduction and Voltage Profile Improvement with Multiple DGs

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Abstract— Distributed generation (DG) can be integrated into distribution systems to meet the increasing load demand. This paper discusses the sizing and sitting issue of DG placement in radial distribution systems using novel method. The main objective of the work is to minimize the active and reactive power loss and enhance voltage profile of overall system. This paper presents a methodology for optimal distributed generation (DG) location and sizing in distribution systems. The main objective of the added DG units is minimizing the total electrical network losses with acceptable voltage profile. The effectiveness of the novel method has been successfully tested on IEEE 33 bus radial distribution system in ETAP software and the results are found to be in very good agreement.

Index Terms— Voltage profile, real power losses, reactive power losses, radial distribution system, distributed generation,
.

1 Introduction

The electric utility system is usually divided into three subsystems which are generation, transmission, and distribution. The distribution system is commonly broken down into three components: distribution substation, distribution primary and secondary. At the substation level, the voltage is decreased and the power is distributed in smaller amounts to the customers. Consequently, one substation will supply many customers with power. Thus, the number of transmission lines in the distribution systems is many times that of the transmission systems. Furthermore, most customers are connected to only one of the three phases in the distribution system.

When you on the traditional power grid energy generation and distribution was relatively simple. The generator produced electricity at plant and the transmission system carried electricity from the plant to substations. At the substation, voltage was reduced and electricity continued to travel along the distribution system where transformers converted into voltage used by customer. At the customer site electricity passed through the meter which recorded usage as electricity was consumed. Energy flow was essentially one way. On a smart grid with distributed generation, energy can be generated close to the point of use and those who produce this power have the option to resell it to the utility [1],[2].

A generator is installed behind the metre to provide power. When this generator is not in operation power can be drawn from the grid. However, if there is an outage or when power prices peak, users can go off-grid and use a private generator to produce power. Solar, wind and thermal energy are renewable sources that can generate energy close to the point of use. Unlike major power stations, renewable energy resources can be installed in small increments and they have extremely low on-going costs. Though renewable energy resources are less predictable than the power generated by traditional means, hybrid systems can utilize both renewable and traditional power. With access to distributed generation resources within a smart grid, utilities can configure the existing systems to meet peak power needs and diversify the range of energy resources to increase the reliability of energy flow [3],[4]. For customers distributed generation supports

(i) Reduced energy costs

(ii)Reduced reliance on fossil fuels and

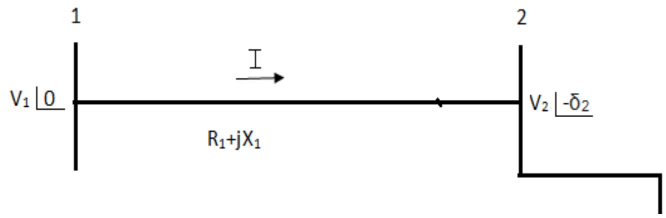
(iii) Increased use of renewable resources

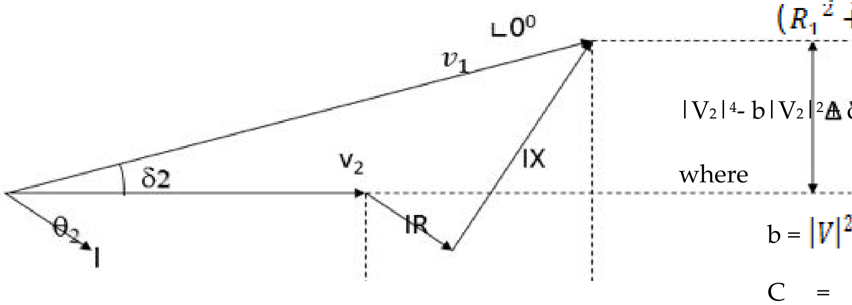
Despite its relative unpredictability, renewable energy can fit with the load curve. For instance, in summer the sun produces high energy during the hardest part of the day when air conditioning is required, so solar energy is in affect converted into electric energy for cooling. Within the smart grid, integrated into the smart home and monitored by smart metering distributed generation is a new paradigm for energy distribution and use. For the first time energy flows to users as well as away from the users enabling utilities and their customers to work together to ensure that power is high quality, reliable, green and low cost.

Distribution systems hold a very significant position in the power system since it is the main point of link between bulk power and consumers. Effective planning of radial distribution network is required to meet the present growing domestic, industrial and commercial load day by day.

2 Load Flow Analysis

Consider a branch connected between buses 1 and 2 as shown in Fig. 1





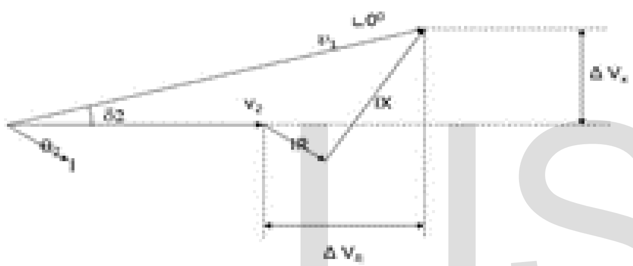


Fig. 2 Phasor diagram of a branch 1 connected between buses 1 and 2

From Fig. 2, the Eqns. are

$$|V_1|^2 = (|V_2| + \Delta V_R)^2 + (\Delta V_X)^2 \quad (1)$$

$$|V_1|^2 = (|V_2| + (IR_1\cos\theta_2 + IX_1\sin\theta_2)^2 + (IX_1\cos\theta_2 - IR_1\sin\theta_2)^2 \quad (2)$$

To eliminate 'I' in Eqn. (2)

$$I\cos\theta_2 = \frac{P_2}{V_2}$$

$$I\sin\theta_2 = \frac{Q_2}{V_2}$$

where

P2 = Total active power load of all buses beyond bus 2
including local load and
active power losses beyond bus 2

Q2 = Total reactive power load of all buses beyond bus 2
including local load and
reactive power losses beyond bus 2

The Eqn. (2) becomes

$$|V_1|^2|V_2|^2 = |V_2|^4 + (P_2R_1 + Q_2X_1)^2 + 2|V_2|^2 (P_2R_1 + Q_2X_1) + (P_2X_1 - Q_2R_1)^2$$

$$|V_2|^4 + 2|V_2|^2(P_2R_1 + Q_2X_1) + (P_2^2 + Q_2^2)(R_1^2 + X_1^2) - |V_1|^2|V_2|^2 = 0 \quad (3)$$

$$|V_2|^4 - b|V_2|^2 + c = 0 \quad (4)$$

where

$$b = |V|^2 - 2P_2R_1 - 2Q_2X_1 \quad (5)$$

$$C = (P_2^2 + Q_2^2)(R_1^2 + X_1^2) \quad (6)$$

where

$|V_1|$ = Substation voltage (taken as 1.0 p.u)

R_1 = Resistance of branch 1

X_1 = Reactance of branch 1

The four possible solutions for the $|V_2|$ from Eqn. (4) are

i) [1/2 [b-{b^2-4c}^(1/2)]]^(1/2)
ii) - [1/2 [b-{b^2-4c}^(1/2)]]^(1/2)
iii) - [1/2 [b+{b^2-4c}^(1/2)]]^(1/2)
iv) [1/2 [b+{b^2-4c}^(1/2)]]^(1/2)

It is found for realistic systems, when P2, Q2, R1, X1 and V are expressed in p.u., 'b' is always positive because the term $(2P_2R_1 + 2Q_2X_1)$ is extremely small as compared to $|V|^2$. In addition the term '4c' is negligible compared to b^2. Therefore, $\{b^2 - 4c\}^{\frac{1}{2}}$ is nearly equal to 'b' and hence the first two solutions of $|V_2|$ are nearly equal to zero and third solution is negative and hence not feasible. The fourth solution of $|V_2|$ is positive and hence it is only the possible feasible solution. Therefore, the possible feasible solution of Eqn. (4) is

$$|V_2| = \left[\frac{1}{2}\left[b + \{b^2 - 4c\}^{\frac{1}{2}}\right]\right]^{\frac{1}{2}} \quad (7)$$

In general the solution for $|V_{i+1}|$ is

$$|V_{i+1}| = \left|\frac{1}{2}\left[b_i - \{b_i^2 - 4c_i\}^{1/2}\right]\right|^{\frac{1}{2}} \quad (8)$$

where

$$b_i = |V_i|^2 - 2P_{i+1}R_k - 2Q_{i+1}X_k \quad (9)$$

$$C_i = (P_{i+1}^2 + Q_{i+1}^2)(R_k^2 + X_k^2) \quad (10)$$

Where

i = 1,2............nbus

k = 1,2,3............nbus – 1

nbus= total number of buses.

The real and reactive power loss of branch 'k' is given by

$$P_{loss}[k] = \frac{R_k\left(P^2{}_{i+1} + Q^2{}_{i+1}\right)}{|V_{i+1}|^2} \quad \ldots\ldots(11)$$

$$Q_{loss}[k] = \frac{X_k\left(P^2{}_{i+1} + Q^2{}_{i+1}\right)}{|V_{i+1}|^2} \quad \ldots\ldots(12)$$

The Total Active and Reactive Power Losses (TPL, TQL) are given by

$$\text{TPL} = \sum_{k=1}^{nbus-1} P_{loss}[k] \quad (13)$$

$$\text{TQL} = \sum_{k=1}^{nbus-1} Q_{loss}[k] \quad (14)$$

The phase angle of (δ_2) of voltage V_2 can be calculated as follows From Fig. 2.2,

$$\tan\delta_2 = \frac{\Delta V_X}{|V_2| + \Delta R_X}$$

$$\tan\delta_2 = \frac{IX_1\cos\theta_2 - IR_1\sin\theta_2}{|V_2| + IR_1\cos\theta_2 + IX_1\sin\theta_2}$$

On simplification we will get

$$\delta_2 = \tan^{-1}\left\{\frac{P_2X_1 - Q_2R_1}{P_2R_1 + Q_2X_1 + |V_2|^2}\right\} \quad (15)$$

In general

$$\delta_{i+1} = \tan^{-1}\left\{\frac{P_{i+1}X_k - Q_{i+1}R_k}{P_{i+1}R_k + Q_{i+1}X_k + |V_2|^2}\right\} \quad (16)$$

Usually, the substation voltage V1 is known and is taken as 1.0 ∟0^0p.u. Initially, $P_{loss}[k]$ and $Q_{loss}[k]$ are set to zero for all k.[6],[7] Then the initial estimate of P_{i+1} and Q_{i+1} will be the sum of the loads of all the buses beyond bus 'i' plus the local load of bus 'i' plus the losses beyond bus 'i' Compute V_{i+1},$P_{loss}[k]$, $Q_{loss}[k]$, δ_{i+1} using Eqns. (8), (9), (10) and (15). This will complete one iteration of the solution. Update the loads P(i+1) and Q(i+1) (by including losses) and repeat the same procedure until the voltage mismatch reach a tolerance level of 0.0001 p.u. in successive iterations [8],[9].

3 OPTIMAL LOCATION OF GENERATORS

The distributed generator (DG) optimal location will determined considering the power losses at each bus
Algotithm:
Step 1: Run base case load flow studies.
Step 2: After performing base case power flow, select top 3 candidate bus locations to place generator where the losses are high [10], [11].
Step 3: At first select top candidate bus location, place one generator and observe the losses and voltage profile.
Step 4: Similarly place generators at various locations and observe the losses and voltage profile [12,13,14].

The power losses at each bus will be determined with the ETAP software.

4 RESULTS & DISCUSSIONS

ETAP software is used for construction of IEEE 33 bus radial distribution system shown in figure 4. IEEE 33 bus radial distribution system has 5 tie lines and 38 lines.

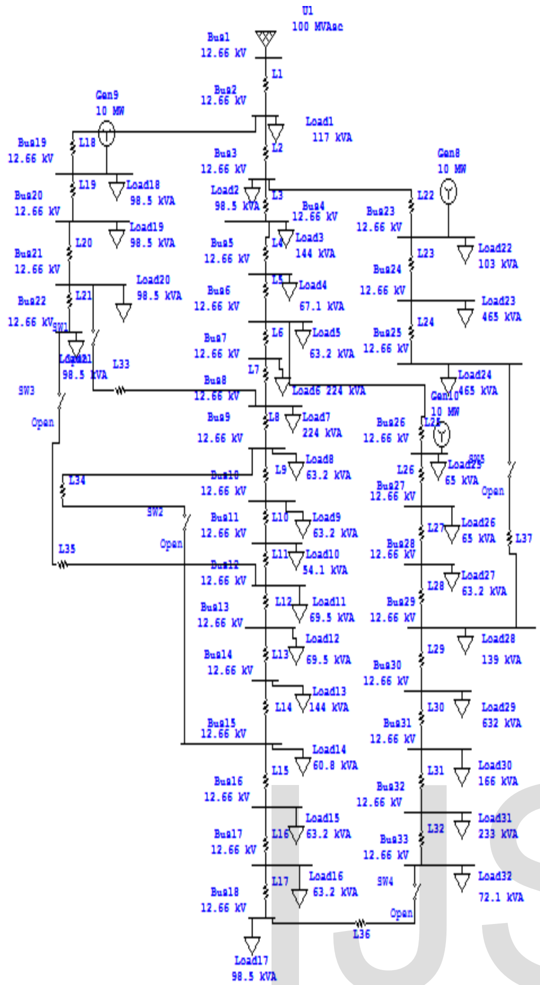


FIG 3: 33 Bus Network with Tie lines open

Voltage profile and load profile are tabulated in Table I. with tie lines open.

Table I: Voltage and loss profile after placing DG without Tie lines

S.No.	**Tie Lines open**			
1	Number of Generators	4Generators	3Generators	2Generators
2	Loss MW	0.048	0.048	0.057
3	Loss MVAR	0.039	0.039	0.044
4	Min Voltage	0.9656	0.9656	0.9652
5	Max Voltage	0.9999	0.9992	0.999

Voltage profile and load profile are tabulated in Table II with tie lines closed. As shown in table II the losses has been reduced with more number of generators than with two generators ie. from 0.057MW to 0.048MW. The voltage profile also has been improved with more number of generators than with two generators ie. from 0.999p.u to 0.9999p.u.

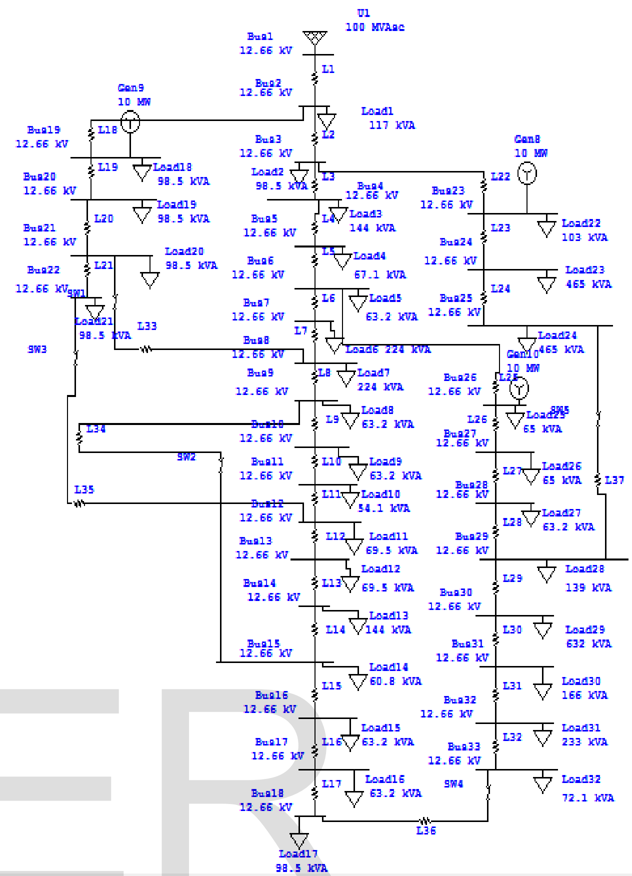


FIG 4: 33 Bus Network with Tie lines closed

Table II: Voltage and loss profile after placing DG with Tie lines

S.No.	Tie Lines closed			
1	Number of Generators	4Generators	3Generators	2Generators
2	Loss MW	0.038	0.065	0.067
3	Loss MVAR	0.032	0.052	0.054
4	Min Voltage	0.9781	0.969	0.9682
5	Max Voltage	0.9999	0.9997	0.999

Voltage profile and load profile are tabulated in Table II with tie lines closed. As shown in table II the losses has been reduced with more number of generators than with two generators ie. from 0.067MW to 0.038MW. The voltage profile also has been improved with more number of generators than with two generators ie. from 0.968p.u to 0.978p.u.

Wherever losses are more generator is placed. By placing generator voltage profile has improved. It is noticed that there is a considerable decrease in the power loss values when the distributed generator is placed in the distribution system. This confirms that DG units can normally contributes to the power loss reduction, mainly because they are usually placed near the load being supplied.

4 Conclusion

DG has an important role in reducing the power losses, improving the grid reliability, providing better voltage support and improving the power quality. The effectiveness of the novel method has been successfully tested on IEEE 33 bus radial distribution system in ETAP software and observed reduction of the power losses and voltage profile improvement with more generators than with one generator with and without tielines.

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