International Journal of Engineering Applied Sciences and Technology, 2016
Vol. 1, Issue 10, ISSN No. 2455-2143, Pages 95-102
Published Online August - September 2016 in IJEAST (http://www.ijeast.com)

VOLTAGE REGULATION IN A RADIAL DISTRIBUTION NETWORK BY PHOTOVOLTAIC DISTRIBUTED GENERATION

T.Murali Mohan
Department of EEE
JNT University Kakinada,
Kakinada, AP, India

V.S.Vakula
Department of EEE
JNTUK, Vizayanagaram,
AP, India

Abstract— **Voltage regulation in a radial distribution network is an important issue as the network is powered from one end only. This paper presents the effect of photovoltaic distributed generation (PVDG) and capacitor banks on the voltage regulation of a radial network. The placement of these compensators is done each at a time and a combination of them as other cases. The PVDG and capacitor banks are so modeled and incorporated in the network at appropriate places. The effect is studied by means of forward/backward sweep load flow algorithm for an IEEE-33 bus radial network. The results show that the distributed compensating devices can give better results than the other options.**

Keywords— **Photovoltaic system, Distributed generation, forward/backward sweep algorithm**

I. INTRODUCTION

Load flow analysis is a basic method to analyze the steady state behaviour of a distribution network. It helps the system operator to maintain the voltage profile at all nodes of the network within the acceptable limits by incorporating ancillary services such as real power and reactive power generating sources. It is mandatory to operate the system with uniform voltage profile at all nodes of the system [1]-[5]. However, it is impossible to have uniform voltage profile and minimum losses without the support of some additional services. This is due to the radial nature of the network.

In recent days the integration of renewable energy sources into the grid is a common practice. These sources are called as distributed energy sources. They are solar photovoltaic systems, wind generators, fuel cells etc. The photovoltaic source is considered as a prominent source of DG and it is interconnected into the network and analyzed the system behaviour [5]-[10]. The capacitor bank normally acts as reactive power source and that is incorporated independently and also in combination with PV distributed generation. The method of load flow technique is the forward /backward sweep algorithm. An IEEE-33 bus system is used for investigating the system behaviour under the influence of PVDG [11]-[22].

II. MODELING OF DISTRIBUTED GENERATIONS

A. Photovoltaic Systems –

Basically a PV system generates dc power but with the help of inverters it is converted into ac power. Normally the power factor at the converter terminals is close to unity. Hence it is assumed as a real power generating source. Suppose if a PVDG of particular rating is connected at any node, the resultant power is being injected into the bus is given by the following equation (1).

$$P_i = P_{Gi} - P_{Di} \quad (1)$$

$$Q_i = Q_{Gi} - Q_{Di} \quad (2)$$

Where

P_i is the real power injection at bus i

P_{Gi} is the real power generation at bus i

P_{Di} is the real power demand at bus i

Q_i is the reactive power injection at bus i

Q_{Gi} is the reactive power generation at bus i

Q_{Di} is the reactive power demand at bus i

It is only an assumption that if a PV source is connected at a node, it will feed the power to only that particular bus. Similarly if a capacitor bank is connected, first it feeds the local node demand and remaining will be shared to the neighbouring loads. However, for simplicity the DG source ratings are chosen less than the local loads.

B. Radial Network Modelling

Basically our discussion is on distribution networks which are basically low voltage networks. It is clear that in low voltage networks the capacitance of the lines is very small and it is neglected. Only line resistance and inductance of the lines are

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present in the system. In addition to that it is assumed that as the loads and sources are balanced, a three phase ac network is represented as a single phase system shown in figure 1.

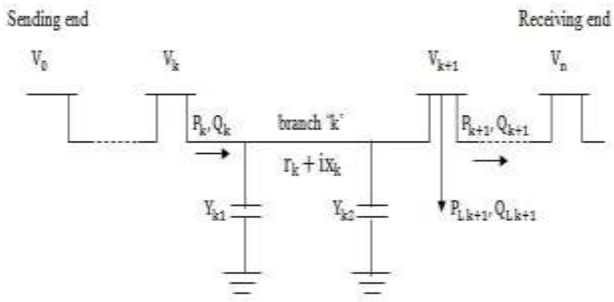

Fig. 1. Single line diagram the radial distribution system

The above figure represents the single line diagram, which shows a branch 'k' connected between the two buses 'k' and 'k+1'. The main advantages of radial network are simple in construction, less initial cost, useful when generation is at low voltage. The power flow analysis should be used to find out the power flows though the branches, the node voltages and the voltage angles.

C. Distributed Generation

The electrical interconnection of the distributed generation involves the design and the protection of the distributed generation equipment. If a fault occurs on the distribution system, protection and safety devices ensure that the fault current supplied by the distributed generator will get interrupted. The distribution breaker should trip the distributed generator from giving the supply to the distributors. After the fault is cleared, the automatic reclosing of the distributed generators should take place.

III. LOAD FLOW METHOD

Power flow analysis is an important tool for any electrical system to analyze the steady state performance of the network, for evaluation of the existing power system and for the planning of the future extension of the system to meet the increased load demand. The load flow solution mainly results in the calculation of the real power and reactive power losses in the system, the voltage magnitudes and the phase angles of all the nodes in the system. The results are calculated subjecting to the control of capabilities of generators, condensers and tap changing of transformers etc. These results of the load flow systems are very useful in analyzing the voltage profiles of the system under different operating conditions

A. Backward Sweep

In backward sweep, the current flows or the power flows are calculated by updating the possible voltages. By updating the voltages from the previous iterations, the effective power flow calculations are updated in the present iteration. These calculations are done starting from the branches in last layer and proceeding towards the branches connected to the root node.

The voltages obtained in the forward path are held constant during the backward propagation and the updated power flows in each branch are transmitted backward along the feeder using the backward path.

$$P_k = P'_{k+1} + r_k \frac{\left(P'^2_{k+1} + Q'^2_{k+1}\right)}{V^2_{k+1}} \tag{3}$$

$$Q_k = Q'_{k+1} + x_k \frac{(P'^2_{k+1} + Q'^2_{k+1})}{V^2_{k+1}} \tag{4}$$

B. Forward Sweep

In the forward propagation, the effective power flows in each branch are held In forward sweep, the voltage magnitudes and the voltage angles at each node, starting from the feeder source node are calculated by updating the possible current flows or power flows.

$$V_{k+1} = \left[V_k^2 - 2(P_k r_k + Q_k x_k) + (r_k^2 + x_k^2)\frac{(P_k^2 + Q_k^2)}{V_k^2}\right]^{1/2} \tag{5}$$

$$\delta_{k+1} = \delta_k + tan^{-1}\frac{(Q_k r_k - P_k x_k)}{[V_k^2 - (P_k r_k + Q_k x_k)]} \tag{6}$$

IV. ALOGORITHM FOR LOAD FLOW CALCULATIONS

Step 1: Read the line and load data of the given distribution system. Assume initial node voltages at 1 pu and set tolerance value E = 0.0001

Step 2: Set iteration count 1

Step 3: Initialize the real power and reactive power vectors to zero.

Step 4: Calculate the real power and reactive power flow in each branch.

Step 5: Calculate node voltages, real and reactive power losses in each branch

Step 6: Check for convergence i.e., $\Delta V < E$, tolerance value in successive iterations. If convergence is obtained, go to next step. Otherwise, increment iteration number and go to step 4.

Step 7: Calculate the real and reactive power losses from all the branches and the total power losses.

Step 8: Print each node voltage, real and reactive power losses of all the branches and the total power losses.

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V. CASE STUDES AND RESULTS

Case 1: When there is no change in the system data of the considered IEEE 33 bus distribution system .The load flow analysis results are as follows.

No. of iterations = 6
The total active power loss = 293.37KW
The total reactive power loss = 195.40KVAR

Case 2: When 745 KW of Real DG is connected at bus no 12, then the load flow results are as follows.

No. of iterations = 5
The total active power loss = 196.80 KW
The total reactive power loss =130.44KVAR

Case 3: When 745 KW of real DG is connected at bus no. 29, then the load flow results are as follows.

No. of iterations = 5
The total active power loss = 198.28 KW
The total reactive power loss = 133.44 KVAR

Case 4: When 372.5 KW of real DG is connected at bus no. 12, then the load flow results are as follows.

No. of iterations = 5
The total active power loss = 232.96 KW
The total reactive power loss = 154.42 KVAR

Case 5: When 453 KVAR of Reactive DG is connected at bus no. 12, then the load flow results are as follows.

No. of iterations = 5
The total active power loss = 165.60 KW
The total reactive power loss = 111.79 KVAR

Case 6: When 453 KVAR of reactive DG is connected at bus no. 29, then the load flow results are as follows.

No. of iterations = 5
The total active power loss = 241.36 KW
The total reactive power loss = 160.34 KVAR

Case 7: When 745 KW of real DG is connected at bus no. 12 and 453 KVAR of reactive DG is connected at bus no. 29, then the load flow results are as follows.

No. of iterations = 5
The total active power loss = 148.73 KW
The total reactive power loss = 98.05 KVAR

Case 8: When 453 KVAR of reactive DG is connected at bus no. 12 and 745 KW of real DG is connected at bus no. 29, then the load flow results are as follows.

No. of iterations = 5
The total active power loss = 165.60 KW
The total reactive power loss = 111.79 KVAR

Case 9: When both 745 KW of real DG and 453 KVAR of reactive DG are connected at bus no. 12, then the load flow results are as follows.

No. of iterations = 5
The total active power loss = 164.77 KW
The total reactive power loss = 109.32 KVAR

Case 10: When both 745 KW of real DG and 453 KVAR of reactive DG are connected at bus no. 29, then the load flow results are as follows.

No. of iterations = 5
The total active power loss = 151.23 KW
The total reactive power loss = 101.78 KVAR

A. COMPARISON OF CASE 1, CASE 2, CASE 3 AND CASE 4

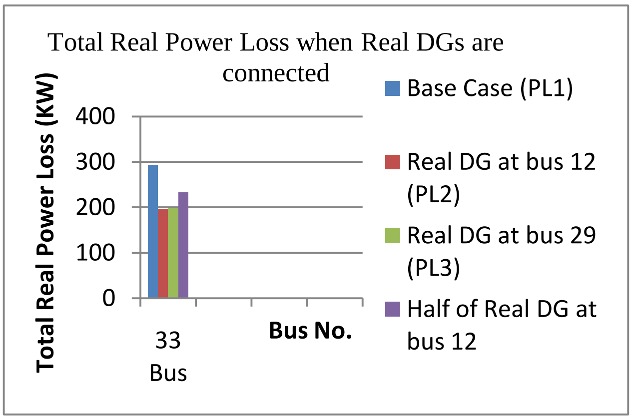

Fig.2.Real power loss comparison when real DG is connected

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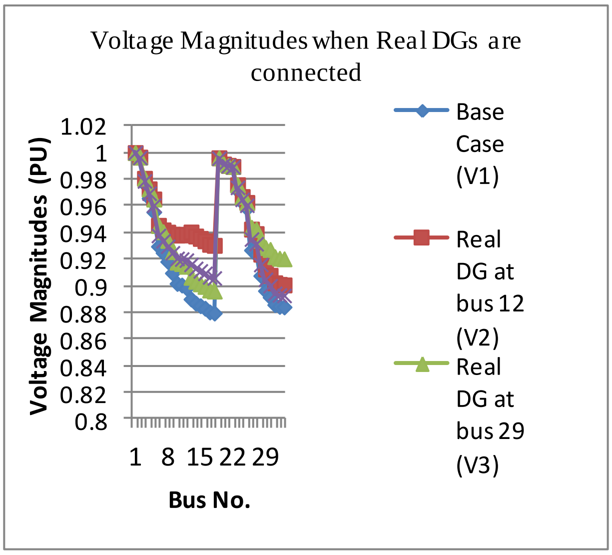

Fig. 3. Voltage comparison when real DG is connected

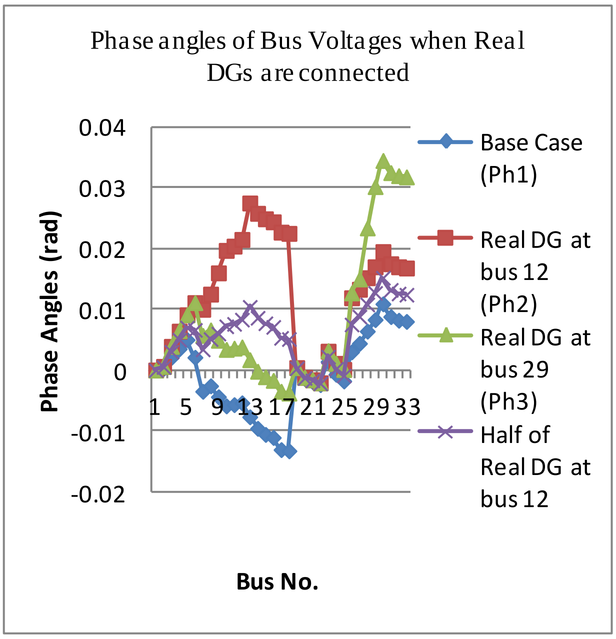

Fig. 4. Phase angle comparison when real DG is connected

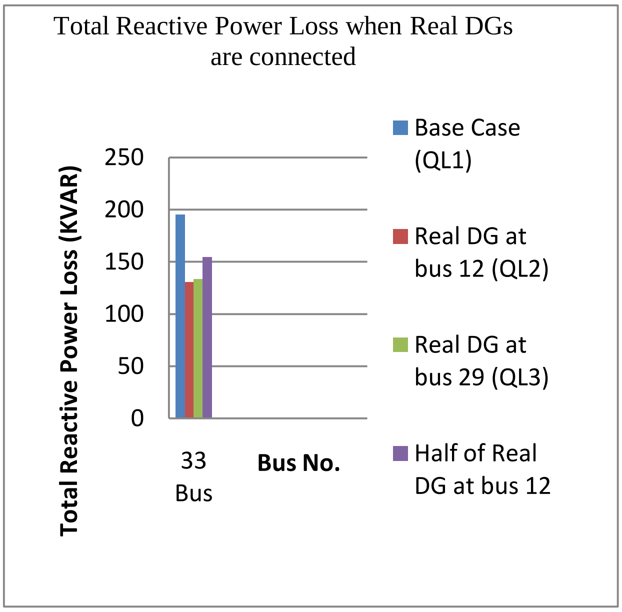

Fig.5. Reactive power loss comparison when real DG is connected

Figure 2 to figure 5 show the plots when real DGs are connected. In figure 2 the real power loss characteristics when real DGs are connected. It is observed that location 12 and 29 giving the same loss but less than the without DG case. It is also observed that the partial shaded PVDG of half of its rating is having impact on the reduction of real power loss. From figure 3, figure 4 and figure 5, it is observed that the location 12 gives the better performance.

B. COMPARISON OF CASE 1, CASE 5 AND CASE 6

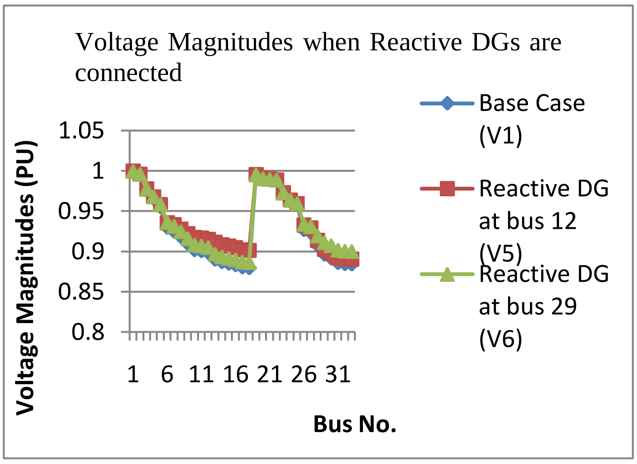

Fig. 6.Voltage comparison when reactive DG is connected

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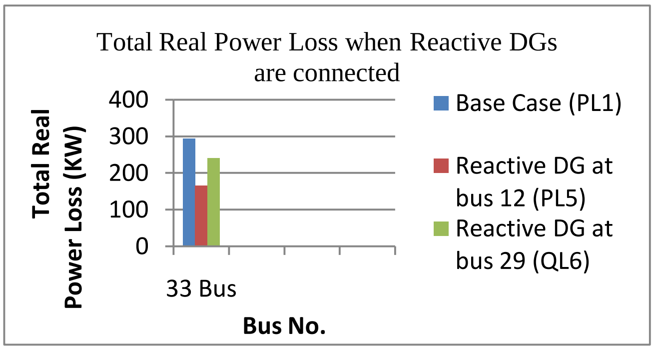

Fig. 7 Real power loss comparison when reactive DG is connected

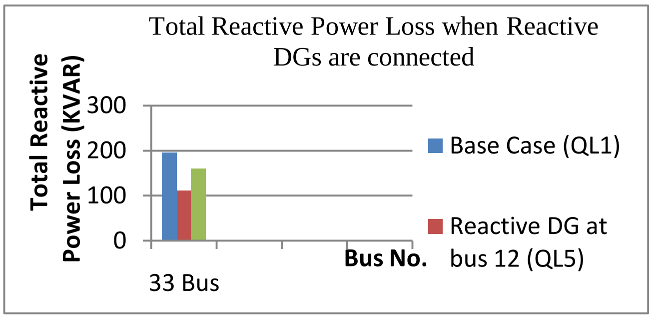

Fig. 8 Reactive power loss comparison when reactive DG is connected

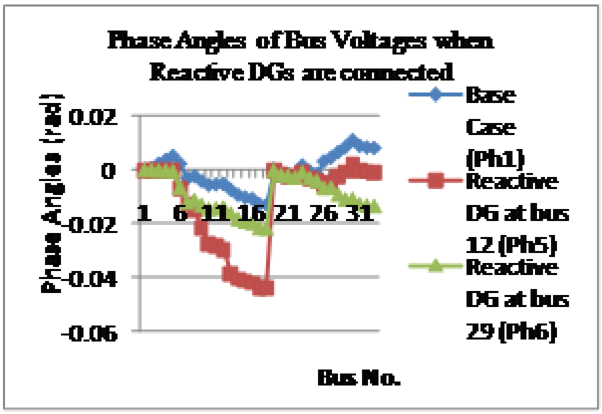

Fig.9. Phase angle comparison when reactive DG is connected

Figure 6 through figure 9 illustrates the behavior of the radial network when capacitor banks or reactive DGs are connected. It is observed that the location 12 gives the lower losses and better voltage profile.

C. COMPARISON OF CASE 1, CASE 7 AND CASE 8

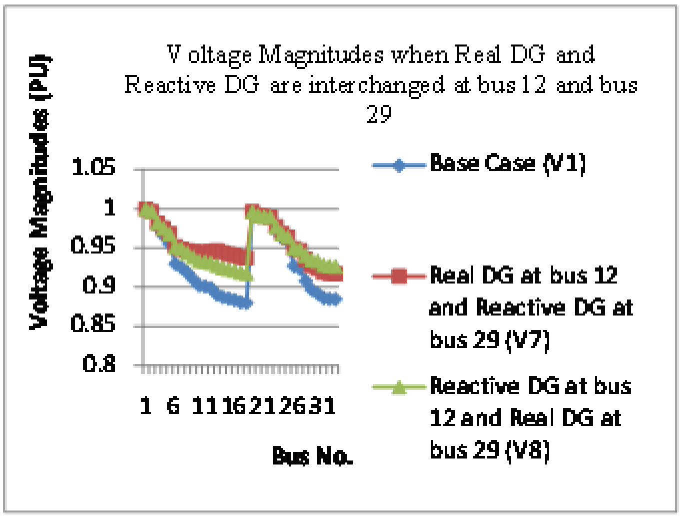

Fig. 10 Voltage comparison when real DG and reactive DG are interchange

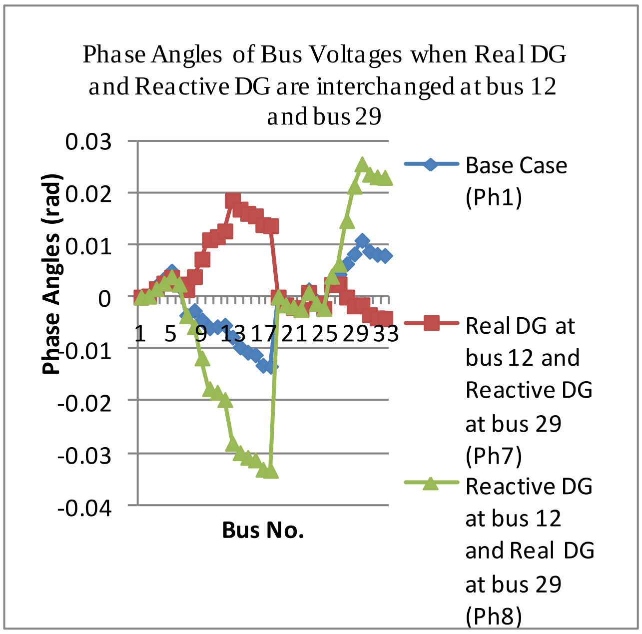

Fig. 11 Phase angle comparison when real DG and ractive DG are interchange

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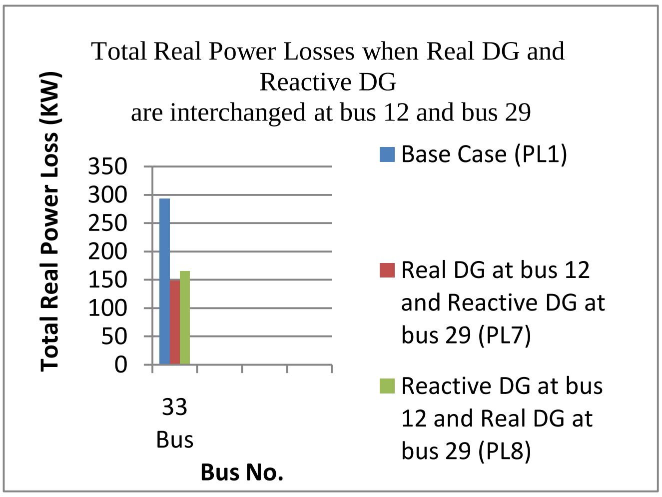

Fig. 12 Real power loss comparison when real DG and reactive DG are interchanged

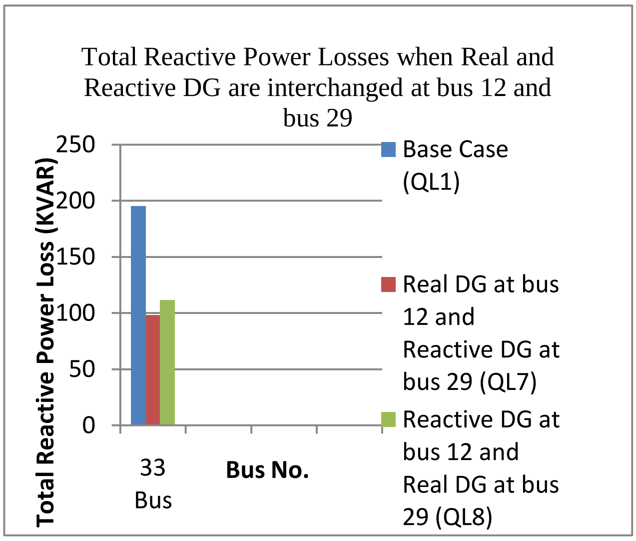

Fig. 13 Reactive power comparison real DG and reactive DG are interchanged

Figure 10 to figure 13 illustrate the behavior of the network when real and reactive DGs are interchanged at bus numbers 12 and 29. It is observed that real DG at bus number 12 and reactive DG at bus number 29 gives the better performance than the vice-versa.

D. COMPARISON OF CASE 1, CASE 9 AND CASE 10

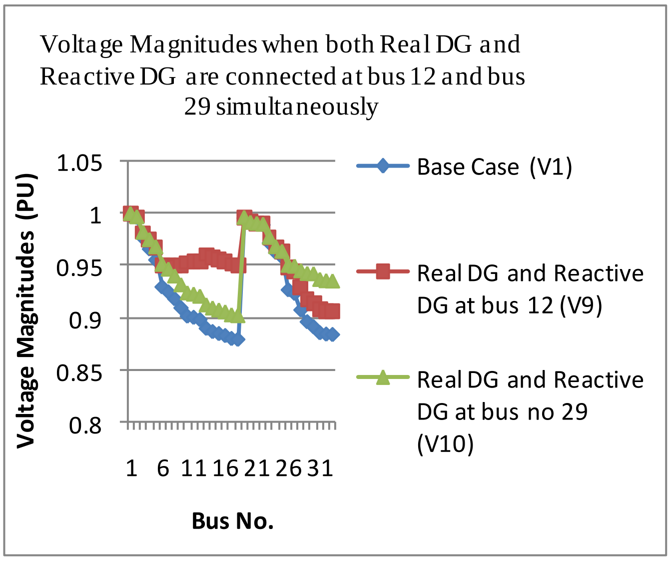

Fig. 14 Voltage comparison when both real and reactive DGs are connected at same bus

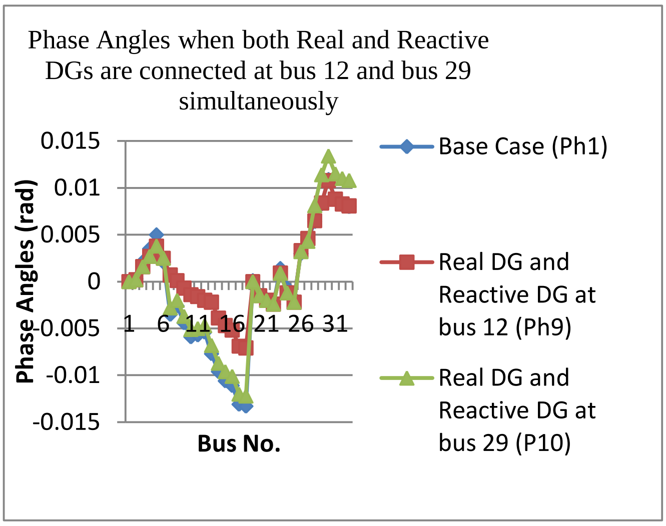

Fig. 15 Phase angle comparison when both real and reactive DGs are connected at same bus

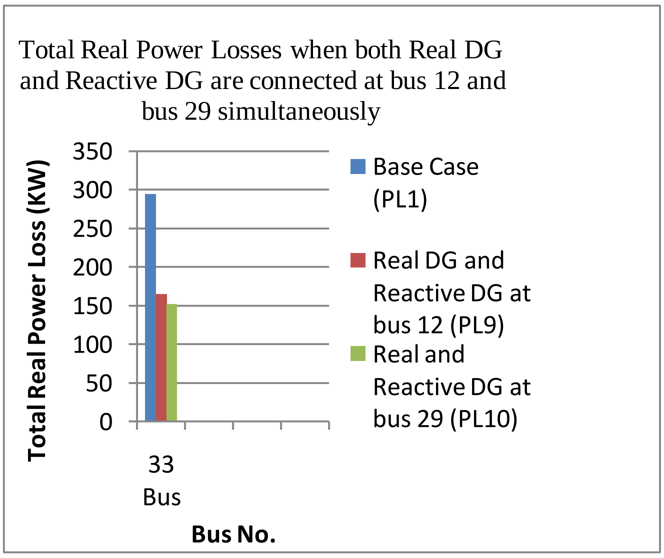

Fig. 16 Real power loss comparison when both real and reactive DGs are connected at same bus

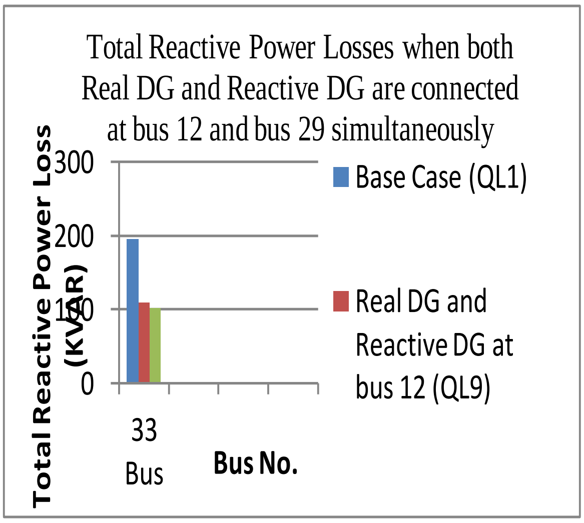

Fig. 17 Reactive power loss comparison when both real and reactive DGs are connected at same

Figure 14 to figure 17 illustrate the system behavior when real and reactive DGs are connected simultaneously. It is observed that placing both the DGs at the location 12 gives very good voltage profile than placing both DGs at bus number 29. In view of the losses the location 12 gives little bit more loss than the location 29.

VI. CONCLUSION

Mathematical models for radial network, real and reactive power DGs are developed. A load flow analysis method of forward/ backward sweep algorithm is used and relevant equations are derived. An IEEE 33 bus system is used for analysis and four different cases are applied for observing the system behavior. In first case where real DGs are connected shows that location 12 gives the better voltage profile and minimum losses. In second case it is observed that location 12 gives the better profile in the perspective of voltage and losses. In third case it is observed that real DG at location 12 and reactive DG at location 29 gives a better response than the vice-versa. In the last case it is observed that placing the both the DGs at location 12 give the better performance than at location 29.

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