IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 10, Issue 4 Ver. III (July – Aug. 2015), PP 01-08
www.iosrjournals.org

Placement and Sizing of Capacitor and Renewable DG for Loss Minimization at Different Load Levels Using Matlab/Simulink

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Abstract: *The proposed paper presents a simple methodology for active power loss minimization and it is carried through optimal placement and sizing of capacitor and Distributed Generation (DG).The placement of capacitor and DG is done through loss sensitivity factor which is one of the concepts in the field of distribution system and it is used to identify the potential nodes. In our proposed method we have considered a single capacitor and single DG for placement. After identifying the potential node, the capacitor sizing is done by calculating compensative reactive power* (Q_c) *for different load levels. Next, the sizing of distributed generation is carried on by considering different penetration levels i.e., from 10% to 90% of the total system active power load at different load levels. So, finally we reach to a conclusion of loss minimization at some particular penetration level for different load levels. Thus, the reactive power compensation through capacitor and the active power injection from renewable Distributed Generation which is placed near to the load centres contributes for system voltage support and active power loss minimization. Nevertheless, the acceptable method also meet the necessities like reasonable speed, storage, highly authentic, assumed versatility and simplicity. Finally the proposed methodology is implemented through MATLAB/SIMULINK on 12, 15, 33 bus radial distribution system.*

Keywords: *Active power loss, Capacitor and DG placement, Different load levels, Loss indices, Penetration levels, Radial Distribution System, Voltage profile improvement.*

I. Introduction

One of the major troubles in the power industry is the day to day increase in power requirement but the inaccessibility of enough resources to meet the power demand using the conventional energy sources. Now-a-days renewable energy sources are the key to a sustainable energy supply as they are non polluting and low maintenance cost. Distributed Generation (DG) which comprises of several renewable resources, is a small power generation unit that can be connected instantly to distribution network or inside the adeptness's of the large consumers [1]. The loss reduction in distribution systems has accepted greater implication now-a-days as several studies described that at the distribution level mostly 13% of total generated power is desolated as losses . We have a numerous benefits from DG [2, 3] .Legion studies used various advances to assess the benefits from DG's mostly concentrating on loss reduction, reduction of loading level. To achieve the benefits the DG should be authentic, dispel, of the proper sizing and at the proper placement [4, 5].so for the reduction of line loss of power system it is crucial to determine the size and placement of DG Also, capacitor is installed to improve the power factor and voltage profile, therefore to meet the mentioned objectives the optimal placement of and sizing of capacitor is essential. We have several optimization techniques and algorithms in the past for the optimal placement and sizing of capacitors.Schmill [6] proposed his most famous2/3 rule for the placement of only one capacitor. Duran et al [7] employed dynamic programming for capacitor placement and he considered the capacitor sizes as discrete variables. Grainger and Lee [8] employed a non linear programming method and the capacitor placement and sizing is expressed as continuous variables. Sundharajan and Pahwa [9] employed genetic algorithm approach for the placement of capacitor. All the proposed methods mentioned above employ capacitors as continuous variables but in general capacitors are available as discrete. We do have several approaches in the past for the optimal placement and sizing of renewable DG units.Chiradeja and Ramkumar [3] proposed a simple approach and indices for improvement of voltage profile, reduction of loss and reduction of environmental impacts by optimal placement and sizing of DG. Mithulanathan et al [10] proposed a genetic algorithm based approach for the reduction in real power loss by optimal placement of DG. .Naresh Acharya [11] has given a heuristic method for placement and sizing of DG to reduce the real power losses but it requires more computational attempts. Kamel and Karmanshahi [12] employed an algorithm for optimal placement and sizing of DG at any bus and found reduction in loss in the distribution system. Khan and Choudhry [13] employed an algorithm for voltage profile improvement and to minimize loss under arbitrarily distributed load conditions and with low power factor for unit as well as multiple DG's. .In the several studies concerned to location and sizing of DG the loads are in general modelled as constant power loads or constant current loads, in our study we implemented a constant power load. DG penetration has a lot of underlying benefits to the existing systems but also produces substantial challenges [14].When the DG is connected the way and the amount of power flow in the distribution network depends on several elements in addition to size, of DG, placement of DG, consumer need and the network structure etc.Hence the DG connection may increase or decrease the distribution loss depending on the mentioned elements. DG source which is an active voltage source may also contribute for the improvement of voltage profile at distribution side. Numerous analyses have been done in the literature survey [15, 16] to study the affect of DG penetration level on the distribution loss. Hence, in our proposed paper we have considered different penetration levels for the sizing of DG and employed the placement and sizing at different load levels.

II. Theoritical Analysis

An equivalent single phase feeder is considered for a balanced Radial Distribution Network is as follows and it represents the sending end bus and its voltage, receiving end bus and its voltage, feeder branch current and impedance of the branch.

Fig1: An equivalent single phase feeder

The loads of a distribution system that are connected to various buses are assumed to be constant power loads. Consider a bus-i where a constant power loads S_{Li}=P_{Li}+jQ_{Li} has been connected and the equivalent current injection at bus i is represented as follows:

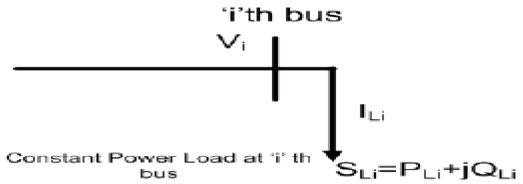

Fig2: Equivalent current injection at bus i

2.1 PQ Model of DG:

As DGs are generally smaller in size compared to conventional power sources the constant power model is sufficient for the analysis of distribution system also as they regulate power and power factor they are modelled as negative loads .The PQ model is as shown below:

Fig3: Load models and DG as their power factor

2.2 Active power loss in a distribution system:

The total active power loss P_a in a distribution system having *m* number of branches can be obtained as follows:

$$\boldsymbol{P_{at}}=\sum_{i=0}^{m} \boldsymbol{I_i^2}\ \boldsymbol{R_i} \qquad (1)$$

Where, I_i is the magnitude of the branch current and R_i is the resistance of i^{th} branch.

2.3 Identification of potential node for Capacitor and DG placement:

The identification is done through power loss indices, the capacitor placement is performed by considering the active power loss indices by making the reactive power zero at each node or load one at a time. Similarly the DG placement is performed by considering the active power loss indices by making the active power zero at each node or load one at a time. So, finally the most sensitive node whose indices are '1' is considered as the potential node for capacitor and DG placement and the same procedure is carried on for all the proposed buses. Thus after calculating the injected powers at each node by making the reactive and active power zeros each time the power loss indices(PLI) can be calculated as follows:

$$\textbf{PLI}=\frac{(\textbf{Loss Reduction}[\textbf{i}]-\textbf{Min.Reduction})}{(\textbf{Max.Reduction}-\textbf{Min .Reduction})} \qquad (2)$$

Where, **Loss Reduction[i] =**$\boldsymbol{P_{base}}$ **-**$\boldsymbol{P_{(i)}}$ (3)

P_{base} is the base case active power power.

$P_{(i)}$ is the active power loss obtained at each node by making reactive power zero for capacitor placement/active power zero for DG placement.

2.4 Sizing of capacitor and DG:

After the placement the sizing of capacitor is done initially by calculating Q_c which is the required reactive power for compensation and it is obtained as follows:

$$Q_c=P\,(\tan\phi_1-\tan\phi_2) \quad (4)$$

$$\phi_1=\cos^{-1}\frac{P}{S} \quad (5)$$

$$S=\sqrt{P^2+Q^2} \quad (6)$$

$$X_c=\frac{V^2}{Q_c} \quad (7)$$

$$C=\frac{1}{2\pi * f * X_c} \quad (8)$$

Q_c is the required compensation in KVAR

P is the active power injected including losses in KW

Q is the reactive power injected including losses in KVAR

$\cos\phi_2$ is the power factor to be maintained by the system, and in our paper it is chosen as 0.98 So, finally Q_c is calculated in percentage and that percentage of total reactive power load is modelled as negative load at the identified potential node and the similar procedure is performed for different load levels for all the proposed buses for capacitor sizing.

Considering capacitor sizing that is done previously for different load levels, here DG sizing is done by considering different penetration levels from 10% to 90% of the total active power load that to be placed at the most potential node obtained through PLI for DG placement. At some level it is observed that the losses are increased instead of decreasing even though there is an improvement in the voltage profile and that level can be concluded as the optimal placement for both the Capacitor and DG placement.

III. Simulation Analysis

3. 1 12 bus RDS analysis:

3.1.1 Single line diagram for a 12 bus RDS:

Test1 is performed on 12 bus system, the line and load data for IEEE 12 bus radial distribution system is available in [17].

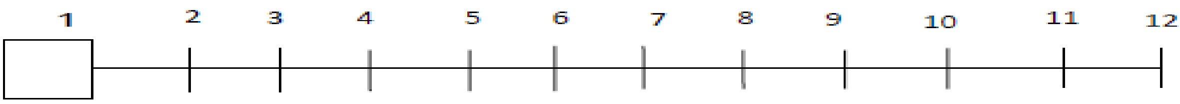

Fig4: Single line diagram

3.1.2 Simulation diagram:

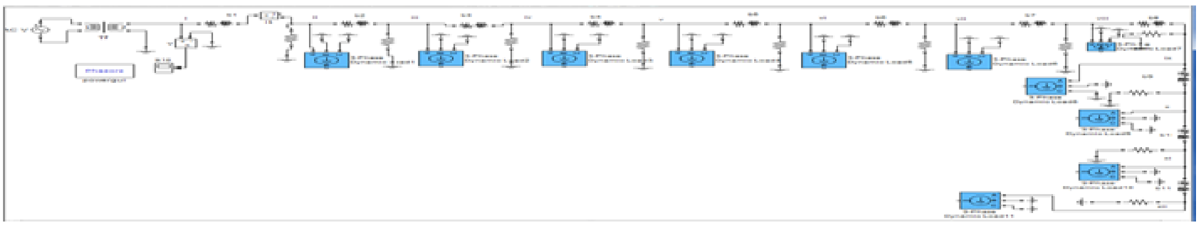

Fig5: Implemented simulation diagram

Table 1. Results of 12 bus system for different load levels at base case

Different load levels	Active power loss(KW)	Minimum voltage profile(pu)
0.5 p.u	4.881	V(12)=0.9736
1 p.u	20.311	V(12)=0.9458
1.2 p.u	29.841	V(12)=0.9342

The base case results are compared with [17], through the loss sensitivity factor method the potential nodes for capacitor and DG placement is obtained as 8 and 11 respectively. The reactive power to be injected by capacitor and active power injected by DG can be considered as 77% and 50% of the total reactive power and active power of the system respectively at different load levels.

V (*) represents minimum voltage is observed at that particular bus.

DOI: 10.9790/1676-10430108

Table2.Distribution loss and voltage profile analysis using simulink with placement and sizing of capacitor and DG

Different load levels	Active power loss(KW)	Voltage profile(pu)
0.5 p.u	0.989	V(5)=0.9964
1 p.u	3.764	V(6)=0.9926
1.2p.u	5.509	V(6)=0.9911

For a 12 bus system, at 0.5 pu load the active power loss is improved from 4.881KW to 0.989 KW and minimum voltage profile is improved from 0.9736 pu to 0.9964 pu at bus 5.Similarly, for 1 pu load the active power loss is improved from 20.311 kW to 3.764 KW and minimum voltage profile is improved from 0.9458 pu to 0.9926 pu at bus 6.Similarly, for 1.2 pu load, the active power loss is improved from 29.841KW to 5.509 KW and minimum voltage profile is improved from 0.9342 pu to 0.9911 pu at bus 6.

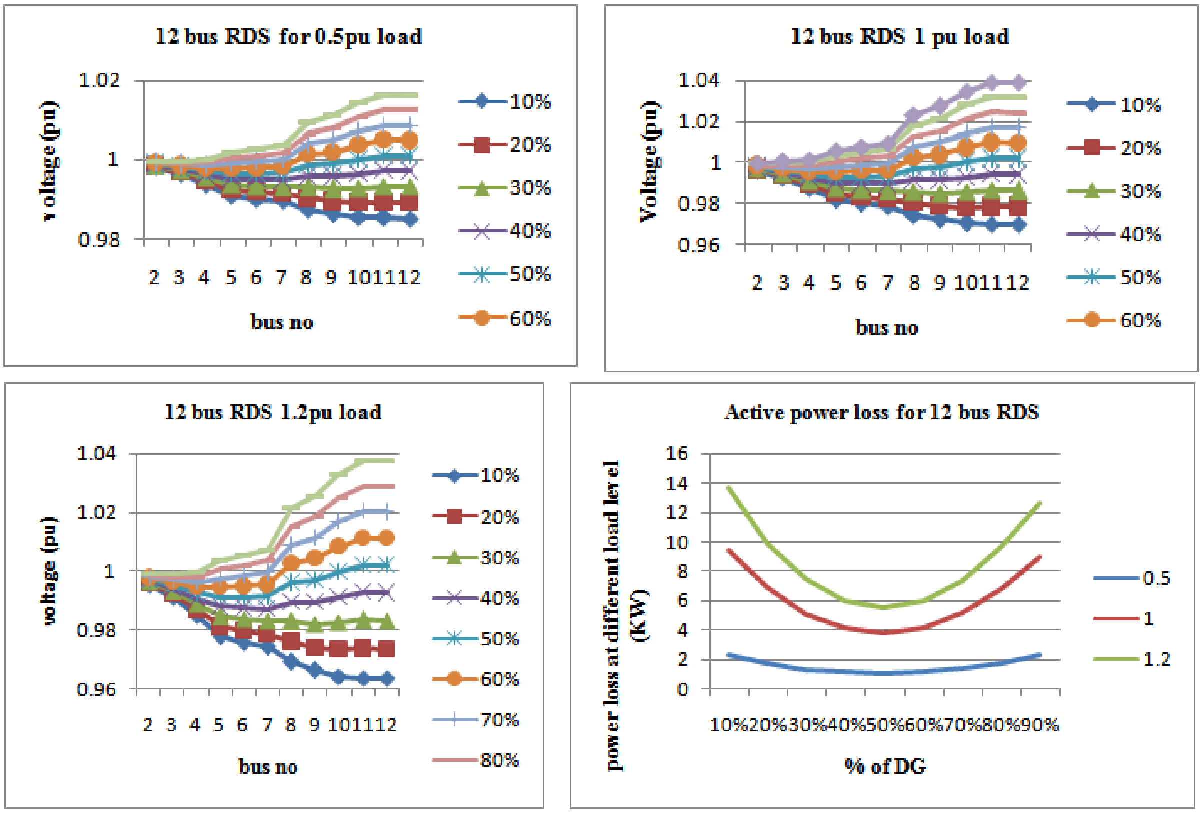

Fig6: Voltage profiles & active power loss of 12 bus radial distribution system

3.2 15 bus RDS analysis:

3.2.1 Single line diagram for a 15 bus RDS:

Test2 is performed on 15 bus system, the line and load data for IEEE 12 bus radial distribution system is available in [18].

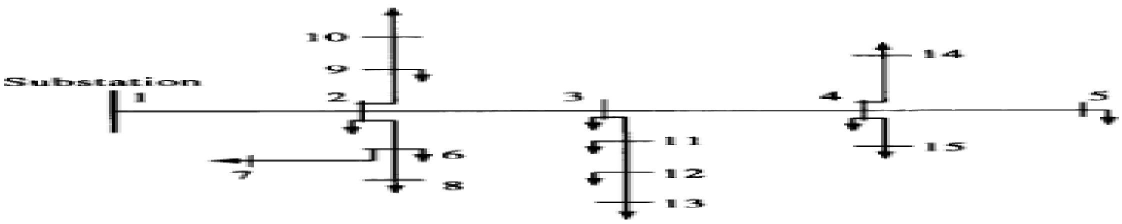

Fig7: Single line diagram

3.2.2 Simulation diagram:

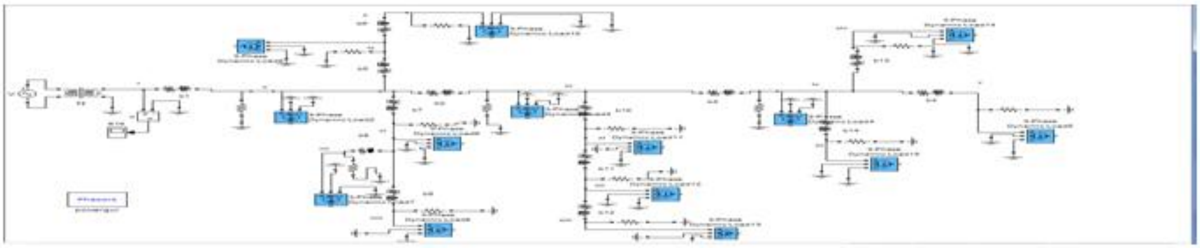

Fig8: Implemented simulation diagram

Table 3. Results of 15 bus system for different load levels at base case

Different load levels	Active power loss (KW)	Minimum voltage profile(pu)
0.5 p.u	14.795	V(13)=0.9719
1 p.u	62.020	V(13)=0.9424
1.2 p.u	91.214	V(13)=0.9300

The base case results are compared with [19], through the loss sensitivity factor method the potential nodes for capacitor and DG placement is obtained as 15 and 13 respectively. The reactive power to be injected by capacitor and active power injected by DG can be considered as 80% and 30% of the total reactive power and active power of the system respectively at different load levels.
V (*) represents minimum voltage is observed at that particular bus.

Table4.Distribution loss and voltage profile analysis using simulink with placement and sizing of capacitor and DG

Different load levels	Active power loss (KW)	Voltage profile (pu)
0.5 p.u	8.431	V(7)=0.9863
1 p.u	34.447	V(7)=0.9720
1.2p.u	50.192	V(7)=0.9661

For a 15 bus system, at 0.5 pu load the active power loss is improved from 14.795 KW to 8.431 KW and minimum voltage profile is improved from 0.9719 pu to 0.9863 pu at bus 7.Similarly, for 1 pu load the active power loss is improved from 62.020 KW to 34.447 KW and minimum voltage profile is improved from 0.9424 pu to 0.9720 pu at bus 7.Similarly, for 1.2 pu load, the active power loss is improved from 91.214 KW to 50.192 KW and minimum voltage profile is improved from 0.9300 pu to 0.9661pu at bus 7.

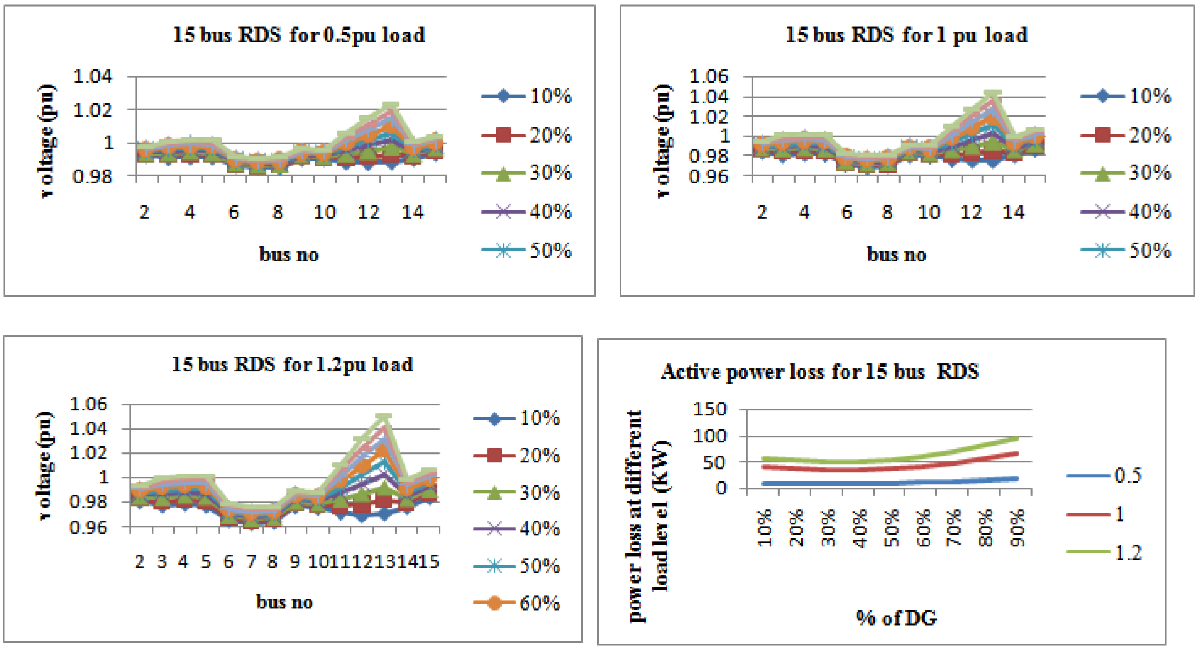

Fig9: Voltage profiles & active power loss of 15 bus radial distribution system

3.3 33 bus RDS analysis:

3.3.1 Single line diagram for a 33 bus RDS:

Test2 is performed on 15 bus system, the line and load data for IEEE 12 bus radial distribution system is available in [20].

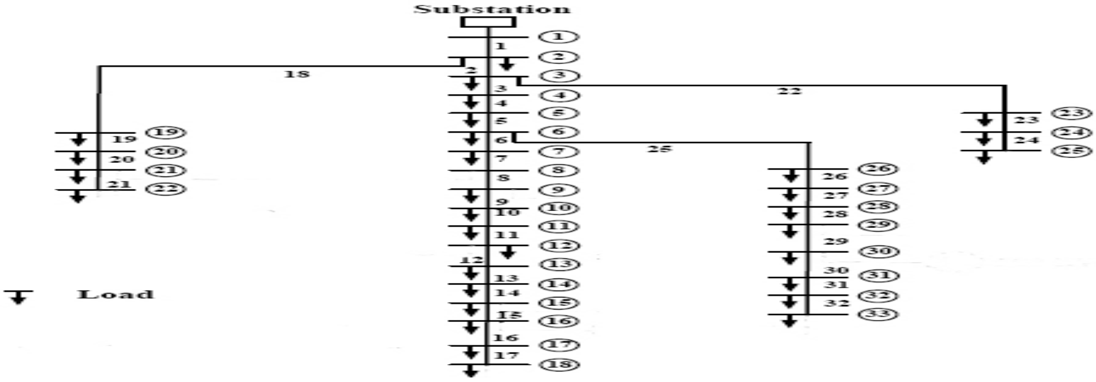

Fig10: Single line diagram

3.3.2 Simulation diagram:

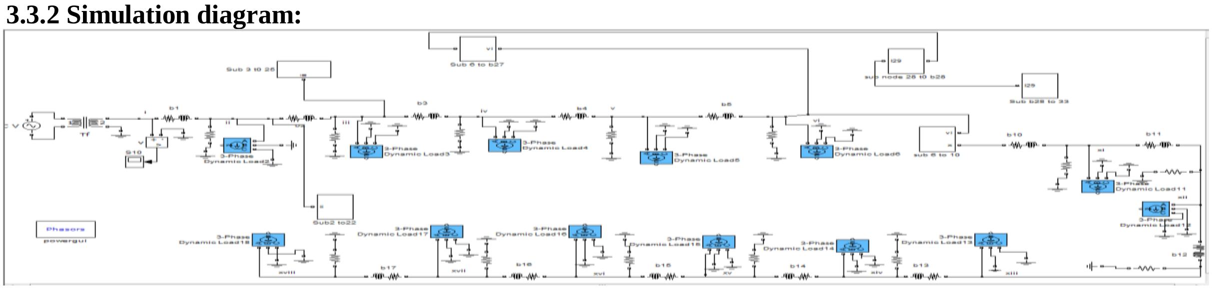

Fig11: Implemented simulation diagram

Table 5.Results of 33 bus system for different load levels at base case using simulink

Different load levels	Active power loss (KW)	Minimum voltage profile (pu)
0.5 p.u	47.073	V(18)=0.9582
1 p.u	202.942	V(18)=0.9130
1.2 p.u	301.508	V(18)=0.8938

The base case results are compared with [19], through the loss sensitivity factor method the potential nodes for capacitor and DG placement is obtained as 30 and 32 respectively. The reactive power to be injected by capacitor and active power injected by DG can be considered as 67% and 40% of the total reactive power and active power of the system respectively at different load levels and for 0.5 pu load the DG is considered as 30%.

V(*) represents minimum voltage is observed at that particular bus.

Table 6. Distribution loss and voltage profile analysis using simulink with placement and sizing of capacitor and DG

Different load levels	Active power loss (KW)	Voltage profile(pu)
0.5 p.u	18.363	V(18)=0.9732
1 p.u	75.139	V(18)=0.9500
1.2p.u	109.223	V(18)=0.9392

For a 33 bus system, at 0.5 pu load the active power loss is improved from 47.073 KW to 18.363 KW and minimum voltage profile is improved from 0.9582 pu to 0.9732 pu at bus 18.Similarly, for 1 pu load the active power loss is improved from 202.942 KW to 75.139 KW and minimum voltage profile is improved from 0.9130 pu to 0.9500 pu at bus 18.Similarly,for 1.2 pu load, the active power loss is improved from 301.508 KW to 109.223KW and minimum voltage profile is improved from 0.8938 pu to 0.9392 pu at bus 18.

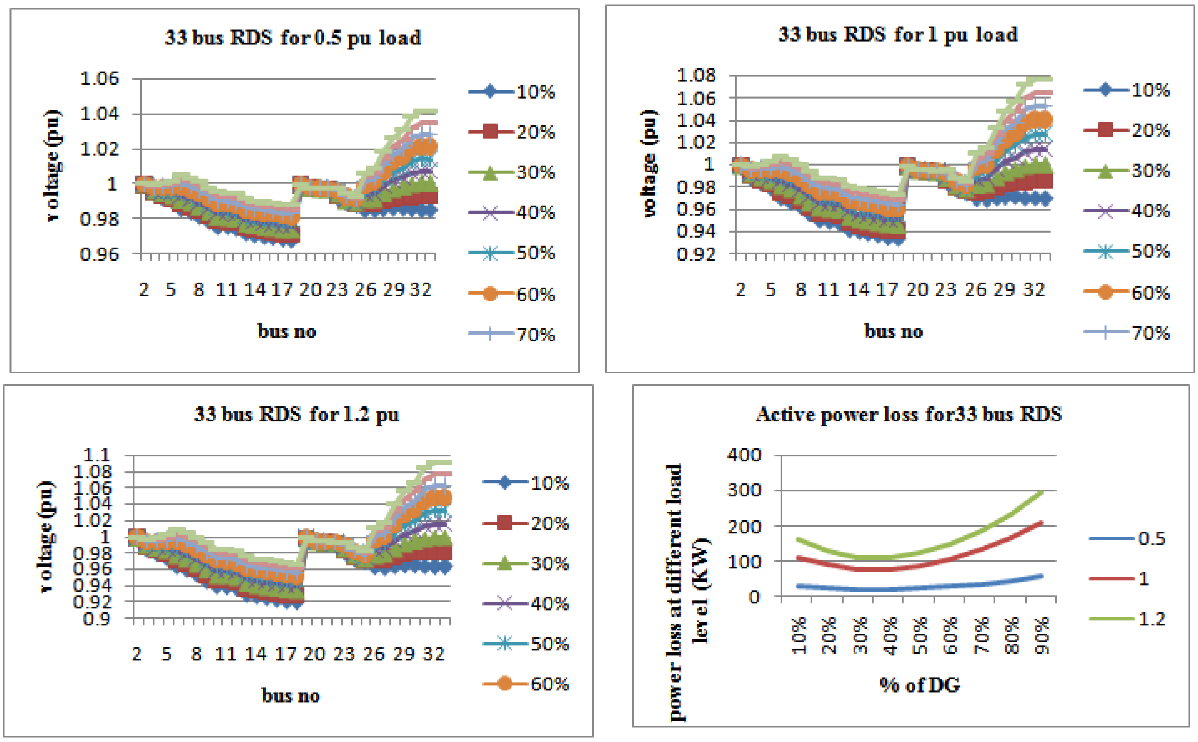

Fig12: Voltage profiles & active power loss of 33 bus radial distribution system

IV. Conclusion

In this paper a simulink model is constructed ,with this methodology for 12 bus system without capacitor and DG the total active power losses are 4.881KW, 20.311KW, 29.841KW and minimum voltage profiles are 0.9736pu, 0.9458pu, 0.9342pu at 0.5, 1, 1.2 pu load levels respectively. After placement of capacitor and DG active power losses are reduced to 0.989 KW,3.764KW,5.509KW and minimum voltage profiles are 0.9964pu,0.9926pu,0.9911pu load levels respectively. For 15 bus system without capacitor and DG the total active power losses are 14.795KW,62.020KW, 91.214KW and minimum voltage profiles are 0.9719pu,0.9424pu,0.9300pu at 0.5,1,1.2 pu load levels respectively. After placement of capacitor and DG active power losses are reduced to 8.431 KW, 34.447KW, 50.192KW and minimum voltage profiles are 0.9863pu, 0.9720pu, 0.9661pu load levels respectively. . For 33 bus system without capacitor and DG the total active power losses are 47.073KW,202.942KW, 301.508KW and minimum voltage profiles are 0.9582pu,0.9130pu,0.8938pu at 0.5,1,1.2 pu load levels respectively. After placement of capacitor and DG active power losses are reduced to 18.363 KW, 75.139KW, 109.223KW and minimum voltage profiles are 0.9732pu, 0.9500pu, 0.9392pu load levels respectively. The above method can be tested by placing multiple DG’s and can be extended to different standard radial distribution systems as future work.

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