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Improvement of Power Quality in Distribution System with Incorporation of Distributed Generation Using Ladder Load Flow Method

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ABSTRACT : Distributed Generation (DG) is one of the adopted methods for improving electricity power demand of distribution systems which is more economical than building additional generation facilities. It can be in form of renewable energies, such as wind, mini-hydro and photovoltaic system or in the form of fuel-based system. Installing these generators in order to improve the power quality in distribution system requires an enhanced power load flow method to ensure the best possible placement. This paper presentsimprovement of power quality in distribution system with incorporation of DG using ladder load flow method.DG was incorporated into existing ladder load flow method to form a new equation for power flow analysis. Two set of equations were solved simultaneously using Ladder load flow iteration methods without and with incorporation of DG and simulation was carried out with MATLAB 7.9.0529 (R2012b) version by developing a Graphic User Interface (GUI) model using SIMULINK blocks. The model wasvalidated on standard IEEE 13-bus and 25-bus distribution test feeders for computation of active and reactive power.For 13-bus system, the results showed thattotal active power without DG was 0.8595 p.u. and 3.6925 p.u. with DG which indicate an increase in active power of 2.833 p.u (i.e 76.7% increase) while,the reactive power without DG was 0.5062 p.u. and 1.6960 p.u having installed DG (reactive power increase of 1.1898 p.u, i.e. 70% increase). For 25-bus system, total active power without DG was 3.3479 p.u. and 8.6888 p.u. with incorporation of DG which shows an increase in active power of 5.3409 p.u, i.e. 61.5% increase whilethe reactive power without DG was 2.0456 p.u. and 4.5817 p.u with DG (reactive power increase of 2.5361 p.u, which is 55.4% increase). The results revealed an improvement in power quality of the system after incorporation of DG into the distribution system which is in agreement with the experimental results, thus confirming the reliability of the model.The work provides an enhanced DG improvement model for power quality of electrical distribution system.

Keyword:Distributed generation, power quality, Ladder load flow, Graphic user interface, Simulink, Distribution system.

1 INTRODUCTION

Electrical distribution is one of the three stages of delivering electricity to consumers at residential, commercial, administrative and commercial areas. The supply of adequate and stable electricity to consumers is the back-bone of socio-economic development of any nation while inadequate and unstable supply of electricity to consumers would definitely draw that nation backward. The introduction of generating sources in distribution network called distributed generation (DG) will aid in supply of adequate and stable electricity to consumers, as well as improved power quality requirements [[12], [1]].DG is considered as an electrical source connected to the power network in a point very close to consumer's side which is small enough when compared with the centralized power plants. It can be in form of renewable energies, such as wind, mini-hydro and photovoltaic system or in the form of fuel-based system such as fuel cells and micro-turbines[[7],[5]].

The introduction of DG into distribution network poses new challenges and problems to the network operations in terms of dynamic operation, power quality, steady-state operation, reliability and stability for both customers and electricity supplier. These impacts may manifest themselves either positively or negatively depending on the distribution system operating conditions and the DG characteristics [[3], [13]].Distributed generation is more economical than running a power line to remote locations because it provides back-up power during utility system outages for facilities requiring uninterrupted service, provide higher power quality for electronic equipment and aids network stability in using fast response equipment for a secured transmission system [14]. DG helps to improve energy reliability, system security, service interruption mode and efficiency for consumers. [8]

A. Power Stability

Stability of power is the ability of the system to remain in operating equilibrium, or synchronism while disturbances occur on the system. There are three types of stability, namely, steady-state, dynamic and transient stability [[9], [11]].

i. Steady-state stability refers to the stability of a power system subject to small and gradual changes in load, and the system remains stable with conventional excitation and governor controls.

ii. Dynamic stability refers to the stability of power system subject to a relatively small and sudden disturbance.

iii. Transient stability refers to the stability of a power system subject to a sudden and severe disturbance beyond the capability of the linear and continuous supplementary stability control.

B. DG Penetration Level

The penetration level in the system is defined as the total DG power to the peak load demand P_{Load} expressed as a percentage [10].

$$\%DGlevel = \frac{P_{DG}}{P_{load}} \times 100\% \qquad 1$$

where

P_{DG} : Active power generated by DG

Some of the scenarios considered for penetration levels are;

i. Low penetration scenarios: The penetration level here is below 30% i.e. $P_{DG} < 0.3P_{load}$.

ii. Semi-Ideal penetration scenarios: Distributed generation capacity in this corresponds to half of load demand i.e. $P_{DG} < 0.5P_{load}$.

iii. Ideal scenarios: This considers complete penetration of DG ($P_{DG} = P_{load}$). This scenario minimizes power production by generator.

In order to evaluate and quantify the benefits of DG technologies as to improved power quality, suitable mathematical model along with distribution system models should be employed to run power flow calculations. As a result, applying a non-convectional ladderload flow model that is capable of indicating the best solution for a given distribution network can be more useful for system planning engineers [6].

Ladder load flow is one of the load flow methods used in radial distribution network with adequate robustness and convergence characteristics. Conventional load flow method such as Newton-Rapson, Gauss Seidel and Fast decoupled methods may fail or have problems when dealing with radial distribution networks because of the following [[2], [4]]:

i. High or large R/X ratio of the cables.

ii. Mix of low impedance (switch, voltage regulators) with high impedance element.

iii. Unbalance load operation.

iv. Radial or almost radial topology (weakly meshed).

The power injected at bus $(i+1)$ when considering a ladder power flow equation is given as [6]:

$$P_{i+1} = P_i - P_{Li+1} - R_{i+1}\frac{P_i^2+Q_i^2}{|V_i|^2} \quad 2$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{i+1}\frac{P_i^2+Q_i^2}{|V_i|^2} \quad 3$$

While voltage at receiving end is

$$|V_{i+1}|^2 = |V_i|^2 + \left(R_{i+1}^2 + X_{i+1}^2\right)\frac{P_i^2+Q_i^2}{|V_i|^2} - 2(R_{i+1}P_i + X_{i+1}Q_i) \quad 4$$

where

P_{i+1}: Active Power at bus$(i+1)$, Q_{i+1}: Reactive Power at bus $(i+1)$, P_i : Active Power at bus i, Q_i: Reactive Power at bus i, $|V_i|$: Voltage magnitude at bus i, $|V_{i+1}|$: Voltage magnitude at bus$(i+1)$, R_{i+1} : Resistance at bus $(i+1)$, X_{i+1}: Reactance at bus $(i+1)$, P_{Li+1}: Active Power loss at bus $(i+1)$, Q_{Li+1}: Reactive Power loss at bus $(i+1)$

2.MATERIALS AND METHOD

Mathematical Modeling of Ladder Load Flow with Incorporation of DG

DG was incorporated into the non-conventional Ladder load flow model to obtain the Modified Ladder load flow model. The model was developed by calculating the voltage at each bus, beginning at the generator bus to the load buses using currents calculated in backward sweep method. The calculated source voltage is used as mismatch calculation termination criteria to calculate active power and reactive power. In a bid to achieve this, script codes were written in MATLAB 7.9.0529(R2012b) version by developing a Graphic User Interface (GUI) model using SIMULINK blocks and simulations were carried out. Considering a balanced radial distribution network represented by an equivalent single line diagram in Figure 1 with generator arbitrarily placed at bus$(i+1)$. The line shunt capacitances at distribution voltage level are placed at the nodes of the system as reactive power injection.

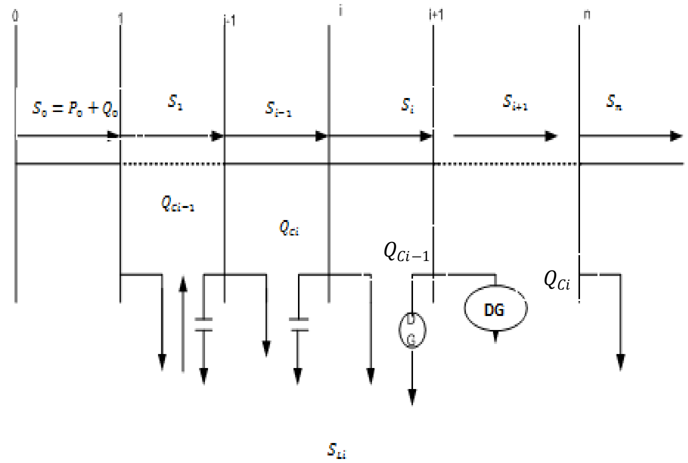

Figure 1: Single line diagram of distribution main feeder with distributed generation

From the line diagram of Figure 1, the equivalent aggregate load power is calculated as follows:

$$P_{i+1} = P_i - P_{Li+1} - R_{i+1}\frac{P_i^2+Q_i^2}{|V_i|^2} + P_{Gi+1} \quad 5$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{i+1}\frac{P_i^2+Q_i^2}{|V_i|^2} + Q_{Ci+1} + Q_{Gi+1} \quad 6$$

for$i = 0, 1, 2\ldots.. n-1$

where

R_{i+1}, X_{i+1} : Resistance and Reactance at bus $(i+1)$

P_{i+1}, Q_{i+1} : Active and Reactive power at bus $(i+1)$

P_i, Q_i : Active and Reactive power loss at bus i

P_{Li+1}, Q_{Li+1} : Active and Reactive power loss at bus $(i+1)$

P_{Gi+1}, Q_{Gi+1} : Active and Reactive power of DG at bus $(i+1)$

Q_{Ci+1} : Reactive power injection on shunt capacitor at bus $(i+1)$

Assumptions in Modified Ladder Load Flow Model:

i. The system is a balanced 3-phase system

ii. The distribution lines were modeled as series impedance, $Z_i = R_i + jX_i$

iii. The load at bus i was modeled as a constant power sink, $S_{Li} = P_{Li} + jQ_{Li}$

iv. Shunt capacitor placed at the nodes of the system was represented as reactive power injections.

v. Distributed generator was represented by PQV model as a negative load referred to a PQ model with constraint power factor.

vi. Generation at bus i was modeled as a constant power given by. $S_{Gi} = P_{Gi} + jQ_{Gi}$

3. SIMULATION

Simulation of Ladder Load Flow without and with incorporation of DG

The line, bus, generator and load data for this research was obtained from the Institute of Electrical and Electronics Engineers (IEEE) Distribution System Analysis Subcommittee. MATLAB code was written by developing GUI model using SIMULINK blocks to solve the resulting Ladder load flow equation without and with the incorporation of DG. The simulation was carried out according to the algorithm below.

Step 1: Read the system data and initially set all the voltage to $1.0\ p.u$ and branch current to 0.

Step 2: Calculate the active and reactive power

Step 3: Calculate the current for all the branches of the system

Step 4: Update the bus voltage using the computed branch current.

Step 5: If the absolute value of the difference between the previous iteration and present iteration at any node is more than some present values, then reset the counter by 1 and go to step 2, else, calculate the system loss and stop.

Step 6: Repeat the process for the system with incorporation of distributed generation.

The pictorial representation of the Ladder load flow solution method without and with incorporation of DG is depicted in Figure 2.

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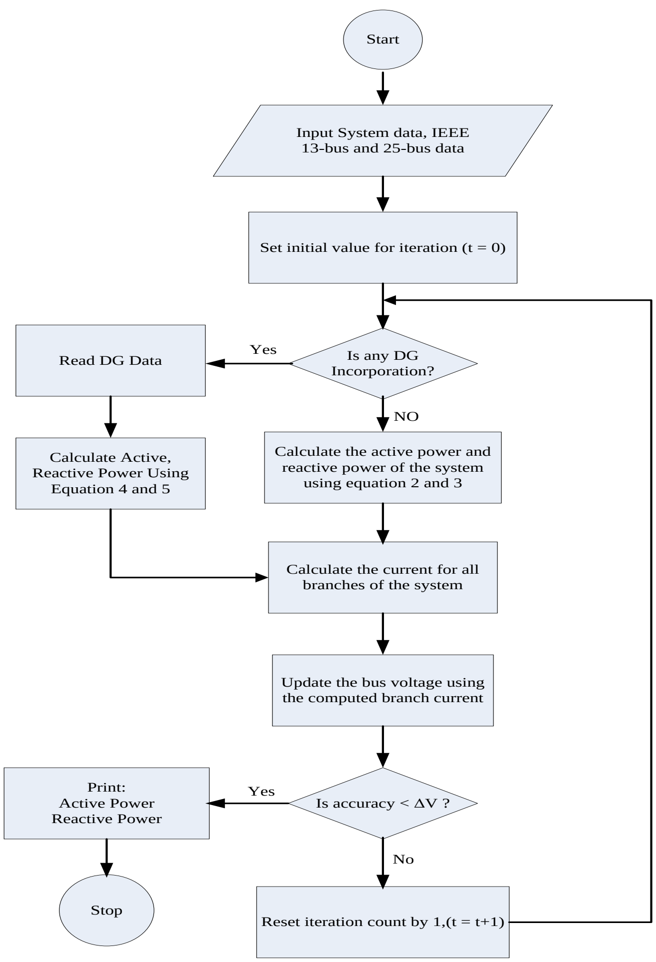

Figure 2: Flowchart of the Ladder Load Flow without and with DG

IV. DISCUSSION OF RESULTS

DG units were placed on 13-bus and 25-Bus test feeders using ladder load flow method. DG unit power factor is assumed constant at 0.9. Six cases are been considered. The corresponding results are presented in Figures 5 to 19. Test case one discusses Ladder load flow results of 13-bus feeder without DG.Case two presents the Ladder load flow results of 13-bus feeder with incorporation of DG.Case three analyses the comparison of active and reactive power results of 13-bus feeder without and with incorporation of DG. Case four analyses Ladder load flow results of 25-bus feeder without DG.Case five presents Ladder load flow results of 25-bus feeder with incorporation of DG. Case six presents a comparison of active and reactive power of 25-bus feeder without and with DG.

Test Case 1: 13-Bus Ladder Load Flow Results without DG

Test case one discusses Ladder load flow results of 13-bus feeder without DG.

13-bus feeder is a radial distribution system feeder fed at one end. The single line diagram is depicted in Figure 3.

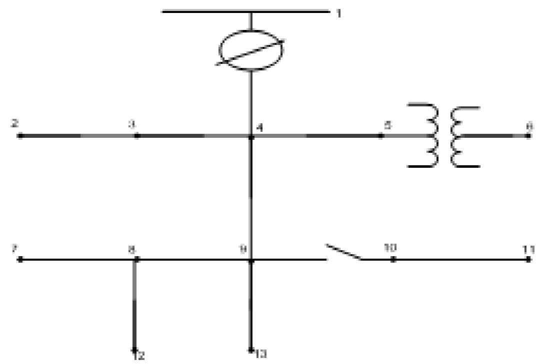

Figure 3: 13- Bus Test Feeder

In this case, feeder 1 is taken as reference bus; while other feeders are configured as bus number 1 to 12. Bus 1 is line between feeders 1 and 4 and line between feeders 4 and 3 is labelled as bus 2.The simulation is made with a pre-voltage of 4.16 kV and 100% of nominal voltage of 4.6 kV and base MVA value of 20(standard value of IEEE 13-bus feeder). Having carried out Ladder load flow analysis on this feeder, the computed simulations are presented in Figures 4 and 5.

Figure 4 shows how the active power varies with the bus numbers. The active power for buses 1, 2 and 3 are 0.1131, 0.0792 and 0.0560 p.u. respectively. Buses 4, 5 and 6 also have active power values of 0.0799, 0.0879 and 0.0434 p.u. respectivel. Buses 7, 8 and 9 recorded an increase in active power values of 0.0656, 0.0733 and 0.0780 p.u. respectively while buses 10, 11 and 12 have the values of active powers of 0.0773, 0.0485 and 0.0554 p.u respectively.

Figure 5 illustrates the correspondence between the reactive power and the bus numbers. Buses 1, 2 and 3 recorded reactive power values of 0.0653, 0.0462 and 0.0345 p.u. respectively. Reactive power at buses 4, 5 and 6 are 0.0462, 0.0517 and 0.0222 p.u. respectivel. Buses 7, 8 and 9 also recorded an increase in reactive powers of 0.0395, 0.0436 and 0.0478 p.u. respectively. Buses 10, 11 and 12 have the value of reactive power to be 0.0433, 0.0312 and 0.0349 p.u respectively.

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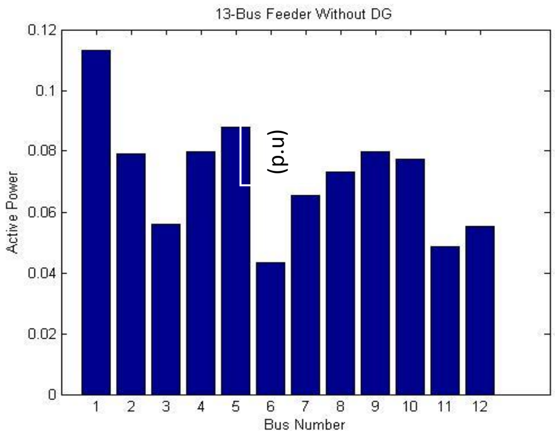

Figure 4: 13-Bus Active Power without Incorporation of DG

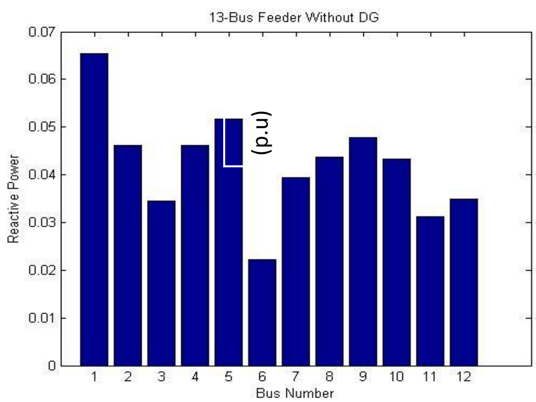

Figure 5: 13-Bus Reactive Power without Incorporation of DG

Test Case 2: 13-Bus Ladder Load Flow Results with Incorporation of DG

Case two presents the Ladder load flow results of 13-bus feeder with incorporation of DG.

In this case IEEE 13 bus is simulated with a total DG penetration level of 60 MW decentralized DGs of 5 MW which are placed in each bus with a base voltage of 13.8 kV, shunt capacitor of 200 kVar and base value of 40(standard values of DG). The computed simulation results of this Ladder load flow analysis are presented in Figures 6 and 7.

The variation of the active power with bus numbers with introduction of DG is illustrated in Figure 6. Buses 1, 2 and 3 have active powers of 0.2381, 0.3217 and 0.3015 p.u. respectively. The active power with incorporation of DG for buses 4, 5 and 6 are 0.3257, 0.3372 and 0.2857 p.u respectively. Buses 7, 8, and 9 recorded an increase in active power of 0.3111, 0.3188 and 0.3299 p.u. respectively with introduction of DG. Buses 10, 11 and 12 have the value of active power to be 0.3234, 0.2985 and 0.3009 p.u respectively with the incorporation of DG.

Figure 7 shows how the reactive power varies with the bus numbers with incorporation of DG. The reactive power with introduction of DG for buses 1, 2 and 3 are 0.1105, 0.1487 and 0.1400 p.u. respectively. Buses 4, 5 and 6 has the value of reactive power to be 0.1495, 0.1607 and 0.1089 p.u.. The reactive power with DG for buses 7, 8 and 9 are 0.1451, 0.1492 and0.1580 p.u. respectively. Buses 10, 11 and 12 have the value of reactive power of 0.1417, 0.1414 and 0.1425 p.u respectively.

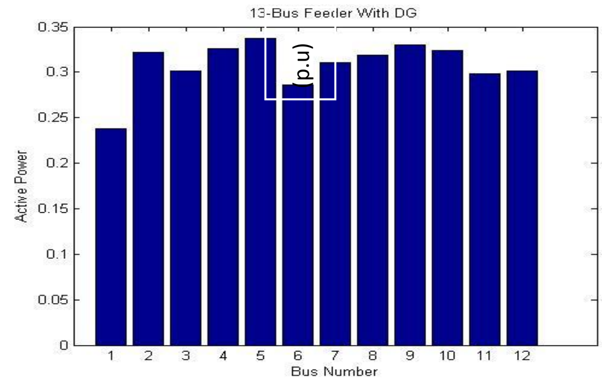

Figure 6: 13-Bus Active Power with Incorporation of DG

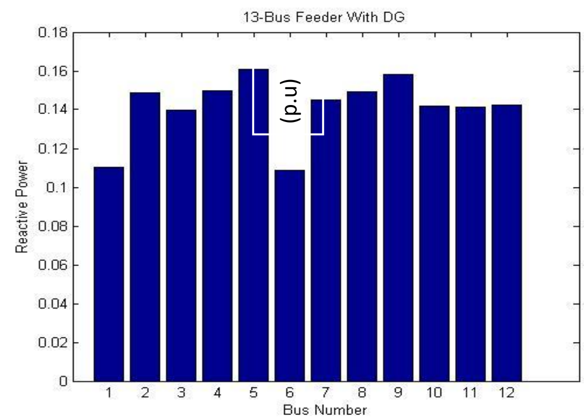

Figure 7: 13-Bus Reactive Power with Incorporation of DG

Test Case 3: Comparison of 13-bus Active and Reactive Power

Case three analyses the comparison of active and reactive power results of 13-bus feeder without and with incorporation of DG

In this case, the results of active and reactive power of IEEE 13 bus feeders without and with incorporation of DG are compared with each others. The computed simulations are presented in Figures 8 and 9.

Figure 8 illustrates the correspondence between the active power with incorporation of DG and the active power without incorporation of DG with the bus numbers.Buses 1, 2 and 3 have active powers of 0.2381, 0.3217 and 0.3015 p.u. respectively indicating an increase in active power when compared with the results of active power of 0.1131, 0.0792 and 0.0560 p.u. respective without DG. The active power with incorporation of DG for buses 4, 5 and 6 are 0.3257, 0.3372 and 0.2857 p.u respectively which correspond to active power of

0.0799, 0.0879 and 0.0434 p.u. respectively without incorporation of DG. Buses 7, 8, and 9 recorded an increase in active power of 0.3111, 0.3188 and 0.3299 p.u. respectively with introduction of DG when compared with the active power of 0.0656, 0.0733 and 0.0780 p.u. respectively without DG. Buses 10, 11 and 12 have the value of active power to be 0.3234, 0.2985 and 0.3009 p.u respectively with DG corresponding to active power of 0.0773, 0.0485 and 0.0554 p.u respectively without DG.

Figure 9 shows the reactive power with incorporation of DG and the reactive power without incorporation of DG with the bus numbers. The reactive power with introduction of DG for buses 1, 2 and 3 are 0.1105, 0.1487 and 0.1400 p.u. corresponding to reactive powers of 0.0653, 0.0462 and 0.0345 p.u. respectively without the introduction of DGs. Buses 4, 5 and 6 have the value of reactive power to be 0.1495, 0.1607 and 0.1089 p.u. respectively with DG which indicate an increase in reactive power when compared with the results of reactive power without DG. The reactive power with DG for buses 7, 8 and 9 are 0.1451, 0.1492 and0.1580 p.u. respectively which correspond to reactive power of 0.0395, 0.0436 and 0.0478p.u. respectively without incorporation of DG. Buses 10, 11 and 12 have the value of reactive power of 0.1417, 0.1414 and 0.1425 p.u respectively compared to reactive power of 0.1417, 0.1414 and 0.1425 p.u respectively without DG.

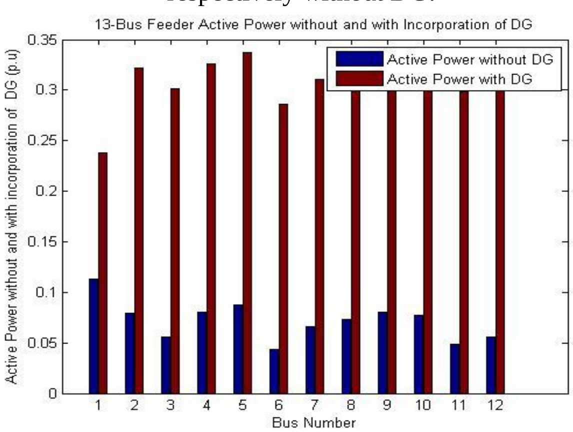

Figure 8: 13-Bus Comparison of Active Power without and with DG

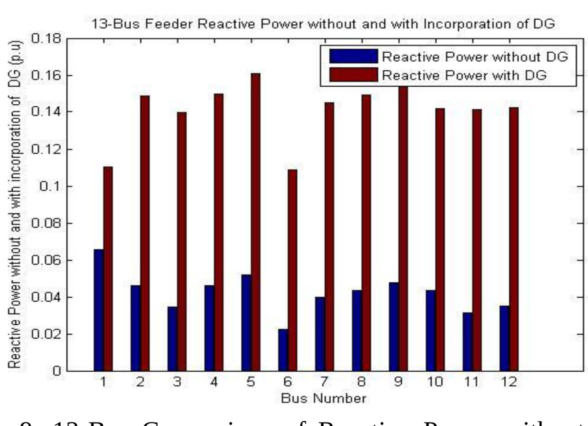

Figure 9: 13-Bus Comparison of Reactive Power without and with DG

Test Case 4: 25-Bus Ladder Load Flow Results without DG

Case four analyses Ladder load flow results of 25-bus feeder without DG.

25-bus feeder is an unbalanced radial distribution system test feeder formed as a result of two pieces of IEEE 13- bus distribution system test feeder. The single line diagram is depicted in Figure 10.

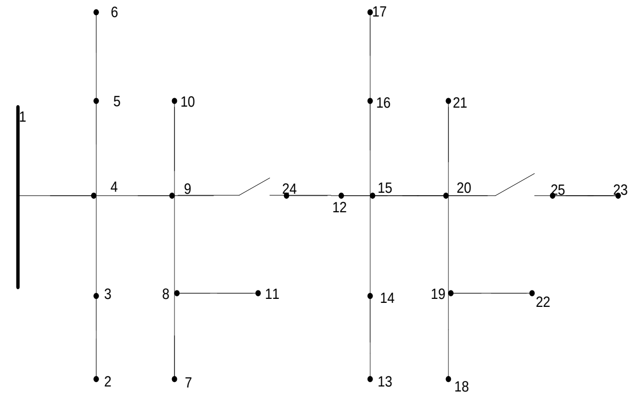

Figure 10: 25- Bus Test Feeder

In this case, feeder 1 is taken as reference bus; while other feeders are configured as bus number 1 to 24. Bus 1 is line between feeders 1 and 4 and line between feeders 4 and 3 is labeled as bus 2 while line between feeders 3 and 2 is labeled as bus 3.The simulation is made with a pre-voltage of 4.16 kV and base MVA value of 40 (available standard IEEE 25-bus feeder). The computed simulation results are presented in Figures 11 to 16.

Figure 11 shows the variation of active power with the bus numbers. The active power for buses 1, 2, 3 and 4 are 0.1528, 0.1183 0.1225 and 0.1229 p.u. respectively. Buses 5, 6, 7 and 8 have values of active power to be 0.1513, 0.1338, 0.1156 and 0.1513 p.u. respectively. Buses 9, 10, 11 and 12 recorded an increase in active power of 0.1513, 0.1370, 0.1234 and 0.1513 p.u. respectively. Active power at buses 13, 14, 15 and 16 are 0.1498, 0.1513, 0.1513 and 0.1513 p.u respectively, while active power for buses 17, 18, 19 and 20 are 0.1513, 0.1383, 0.1505 and 0.1200 p.u. respectively. Buses 21, 22, 23 and 24 have the values of active power of 0.1505, 0.1183, 0.1423 and 0.1423 p.u. respectively.

Figure 12 illustrates the correspondence between the reactive power and the bus numbers. Buses 1, 2, 3 and 4 recorded reactive power values of 0.0941, 0.0742, 0.0785 and 0.0789 p.u. respectively. Reactive power at buses 5, 6, 7 and 8 are 0.0933, 0.0593, 0.0740 and 0.0933 p.u. respectively while buses 9, 10, 11 and 12 have the value of reactive power of 0.0933, 0.0887, 0.0837 and 0.0933 p.u. respectively. Buses 13, 14, 15 and 16 have the values of reactive power of 0.0925, 0.0933, 0.0933 and 0.0933 p.u respectively. Active power at buses 17, 18, 19 and 20 are 0.0933, 0.0813, 0.0929 and 0.0607 p.u. respectively while, buses 21, 22, 23 and 24 have the values of reactive power of 0.0929, 0.0680, 0.0888 and 0.0888 p.u. respectively.

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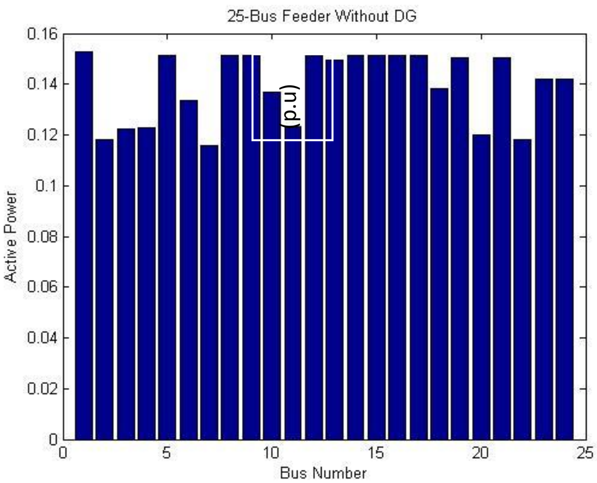

Figure 11: 25-Bus Active Power without Incorporation of DG

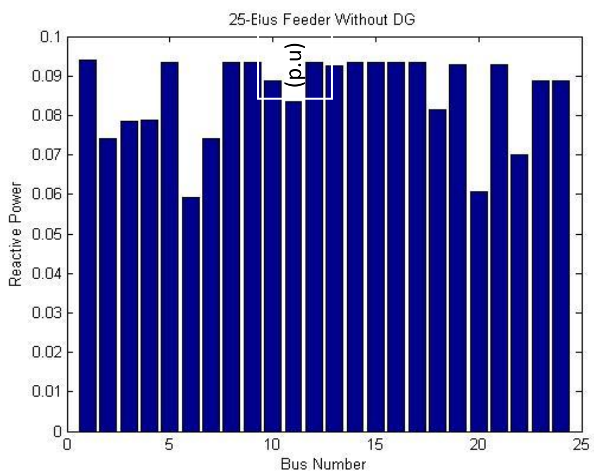

Figure 12: 25-Bus Reactive Power without Incorporation of DG

Test Case 5: 25-Bus Ladder Load Flow Results with Incorporation of DG

Case five presents Ladder load flow results of 25-bus feeder with incorporation of DG.

In this case, IEEE 25 bus is simulated with a total DG penetration level of 120 MW (5 MW in each 24 buses) decentralized DGs which are placed in each bus with a base voltage of 13.8 kV, shunt capacitor of 200 kVar and base value of 40 (standard available DG parameters). The computed simulation results of the Ladder load flow analysis are presented in Figures 13 and 14.

The variation of the active power with incorporation of DG with bus numbers is illustrated in Figure 13. Buses 1, 2, 3 and 4 have the values of active power of 0.2778, 0.2998, 0.3146 and 0.3126 p.u. respectively. The active power with incorporation of DG for buses 5, 6, 7 and 8 are 0.4013, 0.3542, 0.2971 and 0.4013 p.u respectively. Buses 9, 10, 11 and 12 have the values of active power of 0.4013, 0.3559, 0.3142 and 0.4013 p.u. respectively with introduction of DG, while buses 13, 14, 15 and 16 have the value of active power of 0.3998, 0.4013, 0.4013 and 0.4013 p.u respectively after incorporating DG. Active power with incorporation of DG at bus 17, 18, 19 and 20 are 0.4013, 0.3623, 0.4005 and 0.3052 p.u. respectively while buses 21, 22, 23 and 24 have the values of active power of 0.4005, 0.2998, 0.3923 and 0.3923 p.u. respectively.

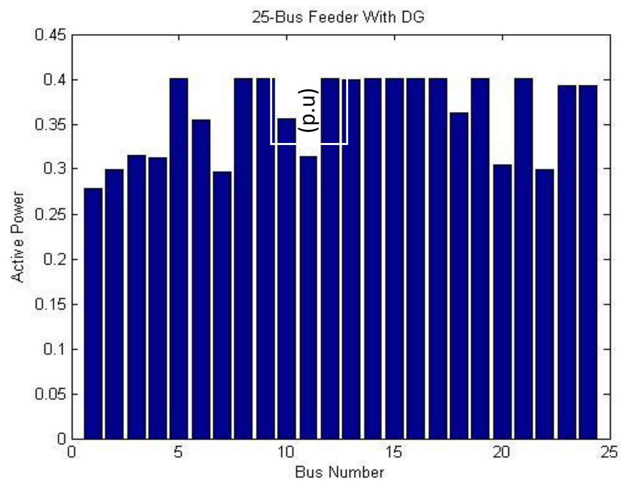

Figure 13: 25-Bus Active Power with Incorporation of DG

Figure 14 shows how the reactive power varies with the bus numbers with incorporation of DG. The reactive power with introduction of DG for buses 1, 2, 3 and 4 are 0.1533, 0.1587, 0.1728 and 0.1723 p.u respectively. Buses 5, 6, 7 and 8 have the values of reactive power to be 0.2175, 0.1150, 0.1610 and 0.2175 p.u. respectively with incorporation of DG. The reactive power with DG for buses 9, 10, 11 and 12 are 0.2175, 0.2025, 0.1873 and 0.2175 p.u. respectively while buses 13, 14, 15 and 16 have values of reactive power of 0.2167, 0.2175, 0.2175 and 0.2175 p.u respectively. Reactive power with incorporation of DG for buses 17, 18, 19 and 20 are 0.2175, 0.1807, 0.2171 and 0.1164 p.u. respectively while buses 21, 22, 23 and 24 have the values of reactive power of 0.2171, 0.1454, 0.2130 and 0.2130 p.u. respectively.

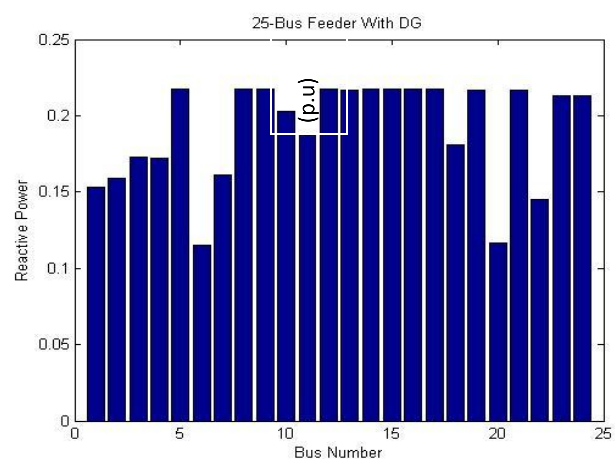

Figure 14:25-Bus Reactive Power with Incorporation of DG

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Test Case 6: Comparison of 25-bus Active and Reactive Power

Case six presents a comparison of active and reactive power of 25-bus feeder without and with DG. In this case, the results of active and reactive power of IEEE 25 bus feeders without and with incorporation of DG are compared with each other. The computed simulations are presented in Figures 15 and 16. The variation of the active power with incorporation of DG and the active power without incorporation of DG with the bus numbers is illustrated in Figure 15. Buses 1, 2, 3 and 4 have the values of active power of 0.2778, 0.2998, 0.3146 and 0.3126 p.u. respectively with DG correspond to active power of 0.1528, 0.1183 0.1225 and 0.1229 p.u. respectively without DG. The active power with incorporation of DG for buses 5, 6, 7 and 8 are 0.4013, 0.3542, 0.2971 and 0.4013 p.u respectively which corresponding to active power of 0.1513, 0.1338, 0.1156 and 0.1513 p.u. respectively without incorporation of DG. Buses 9, 10, 11 and 12 have the values of active power of 0.4013, 0.3559, 0.3142 and 0.4013 p.u. respectively with introduction of DG while, buses 13, 14, 15 and 16 have the values of active power of 0.3998, 0.4013, 0.4013 and 0.4013 p.u respectively after incorporating DG which corresponds to active power of 0.1498, 0.1513, 0.1513 and 0.1513 p.u respectively. Active power with incorporation of DG at bus 17, 18, 19 and 20 are 0.4013, 0.3623, 0.4005 and 0.3052 p.u. respectively while buses 21, 22, 23 and 24 have the values of active power of 0.4005, 0.2998, 0.3923 and 0.3923 p.u. respectivelywhich corresponds to active power of 0.1505, 0.1183, 0.1423 and 0.1423 p.u. respectively.

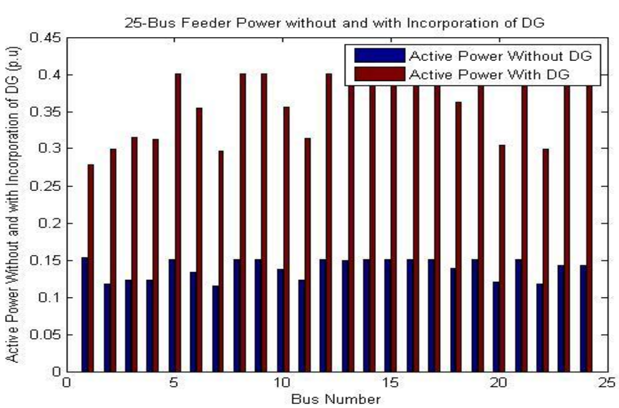

Figure 15: 25-Bus Comparison of Active Power without and with DG

Figure 16 shows the relationship between thereactive power with incorporation of DG and the reactive power without incorporation of DG with the bus numbers. The reactive power with introduction of DG for buses 1, 2, 3 and 4 are 0.1533, 0.1587, 0.1728 and 0.1723 p.u which correspond to reactive power of 0.0941, 0.0742, 0.0785 and 0.0788 p.u. respectively without the introduction of DG. Buses 5, 6, 7 and 8 have the values of reactive power to be 0.2175, 0.1150, 0.1610 and 0.2175 p.u. respectively with incorporation of DG correspond to reactive power of 0.0933, 0.0593, 0.0740 and 0.0933 p.u. respectively without the incorporating DG. The reactive power with DG for buses 9, 10, 11 and 12 are 0.2175, 0.2025, 0.1873 and 0.2175 p.u. respectively which correspond to reactive power of 0.0933, 0.0887, 0.0837 and 0.0933 p.u. respectively without incorporation of DG while buses 13, 14, 15 and 16 have values of reactive power of 0.2167, 0.2175, 0.2175 and 0.2175 p.u respectively correspond to reactive power of 0.0925, 0.0933, 0.0933 and 0.0933 p.u respectively. Reactive power with incorporation of DG for buses 17, 18, 19 and 20 are 0.2175, 0.1807, 0.2171 and 0.1164 p.u. respectively while buses 21, 22, 23 and 24 have the values of reactive power of 0.2171, 0.1454, 0.2130 and 0.2130 p.u. respectively which correspond to reactive power of 0.0929, 0.0680, 0.0888 and 0.0888 p.u. respectively without DG.

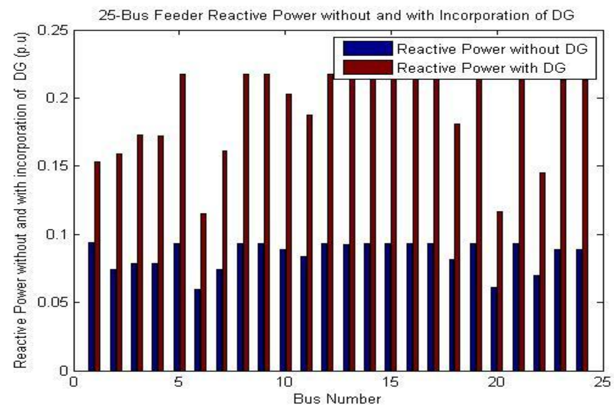

Figure 16: 25-Bus Comparison of Reactive Power without and with DG

The results also showed that the total active and reactive power with incorporation of DG were higher than total active and reactive power without introduction of DG. Power along distribution lines were improved, hence, an enhanced performance for the power infrastructure. The ladder load flow results have demonstrated the effectiveness and feasibility of the distributed generators power injection model. The results show an appreciable level of electrical power improvement in distribution system with the incorporation of DGs.

V. CONCLUSSION

An enhanced DG improvement model for power quality analysis of electrical distribution systems has been presented. In the work, DG was incorporated into the ladder power flow model and the effects investigated. Ladder load flow iteration techniques were used to solve two sets of simultaneous equations without and with incorporation of DG. A GUI model was developed in MATLAB using SIMULINK blocks. The developed model was validated with standard IEEE 13-bus and 25-bus distribution test feeders for computation of active and reactive power as performance metrics.The results from the two test systems and different allocations demonstrated the applicability of the method. Incorporation of DG into the distribution network has demonstrated technical benefit that compliments the distribution system performance through improved active and reactive power values.Results of this work show that installing DG units at appropriate location achieved great improvement for active and reactive power of distribution system.

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