IMPACT OF MULTIPLE DGS ON UNBALANCED RADIAL DISTRIBUTION SYSTEMS

K.Jithendra Gowd*, Ch.Sai Babu S.Sivanagaraju****
*JNTUA College of Engineering, Anantapur, Andhra Pradesh
** University College of Engineering, JNT University, Kakinada, Andhra Pradesh

ABSTRACT:
Distributed generation is expected to play an increasing role in emerging power systems. Recent developments in the electric power and power supply industries have raised a great deal of interest in distributed power generation (DG). Recently the number of distributed generators being integrated into the distribution system has increased. Such distributed generators can reduce distribution power loss if they are placed appropriately in the distribution system. This paper presents the three phase unbalanced power flow algorithm with the choice of DG modeling. The mathematical model of DG is developed and integrated into the proposed power flow method. This paper also includes modeling of lines, transformers, capacitors, and loads.DGs are introduced in the IEEE 13-node test case, 37 –node test case and the results demonstrate the effect the DGs have on power loss.

Keywords: Distributed generators, Transformer model, load model, power loss.

1. INTRODUCTION

Trends in power system planning and operation are being toward maximum utilization of existing infrastructures with tight operating margins due to the new constraints placed by economical, political, and environmental factors. The distributed generation (DG) system [1] is one of the most possible solutions to deal with the aforementioned problems.
The major technical benefits are:

- Reduced line losses
- Voltage profile improvement
- Improved power quality.
- Reduced emissions of pollutants
- Increased overall energy efficiency
- Enhanced system reliability and security
- Relieved T&D congestion

To achieve the above benefits, DG must be of appropriate size, and at suitable locations [2]. More important, DGs should be properly coordinated with protection systems.

This paper also includes the formulation and an efficient solution algorithm for the distribution power flow problem which takes into account the detailed and extensive modeling necessary for use in the distribution automation environment of a real world electric power system. The modeling includes unbalanced three-phase, two-phase, and single-phase branches [7, 10], constant power, constant current, and constant impedance loads connected in wye or delta formations, distributed generators [3], shunt capacitors, line charging capacitance, and three-phase transformers [4] of various connection types.
In this paper, the authors illustrate a power flow to investigate how much distribution loss can be reduced if DGs are optimally allocated at the demand side of the power system, under the conditions that number of DGs and total capacity of DGs are known.
In section-2, the basic model of unbalanced radial distribution network is presented. In section-3, the component models which include branch model, shunt admittance model, shunt capacitor model, load model, distributed generator model, transformer models are discussed. Section-4 shows the load flow calculations. In section-5 demonstration of power losses with multiple DGs is presented for IEEE-13 node test case and 37 node test case.

1.1 BASIC SYSTEM MODEL

For the purposes of power flow studies, a radial distribution system can be modeled as a network of buses connected by distribution lines, switches, or transformers to a voltage specified source bus [9].

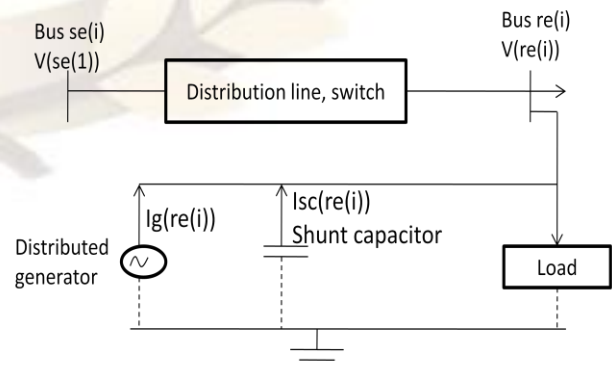


Fig. 1: Generic network branch diagram

Each bus may also have a corresponding load, shunt capacitor, and distributed generator connected to it. The model can be represented by a radial interconnection of copies of the basic building block shown in Fig.1. The dotted lines from distributed generator, shunt capacitor, and load to ground are to indicate that these elements may be connected in an ungrounded delta configuration.

2. COMPONENT MODELLING

The models used for loads, shunt capacitors, distributed generators [3], distribution lines, switches, and transformers [4]. These models provide relationships between the relevant voltages, currents, and power flows [6].

2.1 BRANCH MODEL

A simple circuit model is shown in Fig.2 and its parameters are shown in Fig.3 for a three-phase, four-wire grounded star system [7, 10].

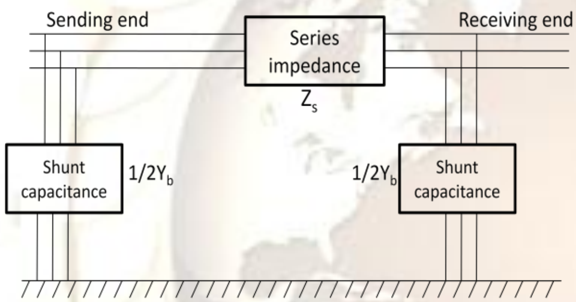


Fig. 2: Representation of distribution line

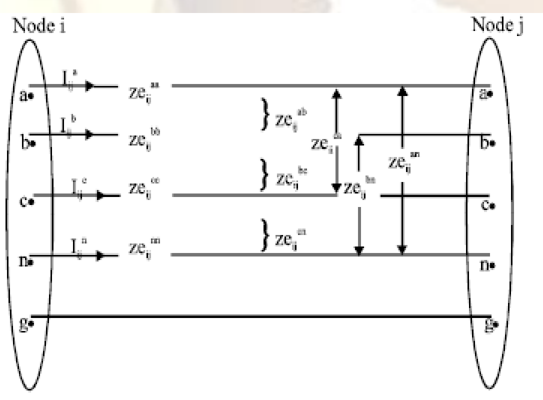


Fig. 3: Three-phase four-wire line model

Line charging admittance is neglected at the distribution voltage level. For this four-wire system, Carson's equations lead to the development of an impedance matrix of 4×4 dimension. This matrix is used to calculate conductor voltage drop as shown below. Using Kirchhoff's voltage law, one may write:

$$\begin{bmatrix} V_i^{ag} - V_j^{ag} \\ V_i^{ag} - V_j^{ag} \\ V_i^{ag} - V_j^{ag} \\ V_i^{ag} - V_j^{ag} \end{bmatrix} = \begin{bmatrix} ze_{ij}^{aa} & ze_{ij}^{ab} & ze_{ij}^{ac} & ze_{ij}^{an} \\ ze_{ij}^{ba} & ze_{ij}^{bb} & ze_{ij}^{bc} & ze_{ij}^{bn} \\ ze_{ij}^{ca} & ze_{ij}^{cb} & ze_{ij}^{cc} & ze_{ij}^{cn} \\ ze_{ij}^{na} & ze_{ij}^{nb} & ze_{ij}^{nc} & ze_{ij}^{nn} \end{bmatrix} \begin{bmatrix} I_{ij}^{a} \\ I_{ij}^{b} \\ I_{ij}^{c} \\ I_{ij}^{n} \end{bmatrix} \quad (1)$$

Therefore for phase a, one may write equation as below:

$$\begin{bmatrix} V_i^{a} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} V_i^{a} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} ze_{ij}^{aa} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_{ij}^{a} \\ 0 \\ 0 \end{bmatrix} \quad (2)$$

Similarly for phase's b and c, one may write expression as below:

$$\begin{bmatrix} 0 \\ V_{ij}^{b} \\ 0 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & Ze_{ij}^{b} & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} 0 \\ I_{ij}^{b} \\ 0 \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} 0 \\ 0 \\ V_{ij}^{c} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & Ze_{ij}^{b} \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ I_{ij}^{c} \end{bmatrix} \quad (4)$$

2.2 SHUNT ADMITTANCE MODEL

The fig.4 represents the shunt admittances connected to each phase and the admittances connected between the phase and ground. The directions of currents injected by the shunt admittances are represented in the Fig.5

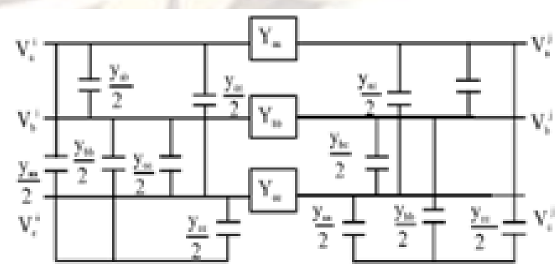


Fig. 4: Shunt capacitances of the line sections

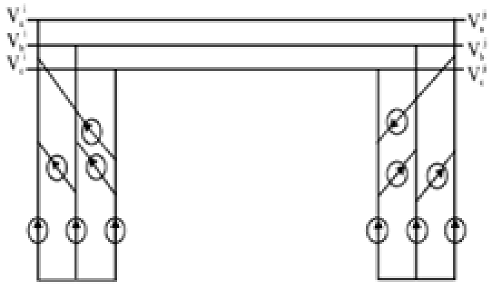


Fig. 5: Representation of the flow of currents due shunt capacitances

$$
\begin{aligned}
I_a &= (-y_{ab}(V_a - V_b) + y_{ca}(V_c - V_a) - y_{aa}V_a)/2 \\
I_b &= (-y_{ab}(V_a - V_b) - y_{bc}(V_b - V_c) - y_{bb}V_b)/2 \quad (5) \\
I_c &= (-y_{bc}(V_b - V_c) - y_{ca}(V_c - V_a) - y_{ca}V_c)/2
\end{aligned}
$$

2.3 SHUNT CAPACITOR MODEL

Shunt capacitors, often used for reactive power compensation in a distribution network, are modeled as constant capacitance devices. Capacitors are often placed in distribution networks to regulate voltage levels and to reduce real power loss. The Fig.6 & Fig.8 represents the capacitors placement in wye and delta connections and Fig.7 & Fig.9 represent the flow of currents due to these connections respectively.

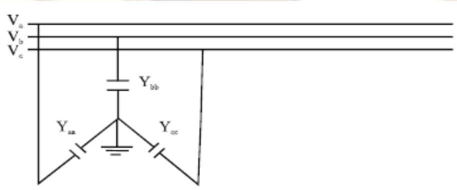


Fig. 6: Capacitors connected in wye connection

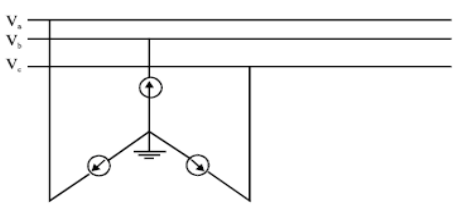


Fig. 7: Representation of flow of currents due to wye-connected capacitors

$$
\begin{aligned}
I_a &= -y^{aa}V_a \\
I_b &= -y^{bb}V_b \quad (6) \\
I_c &= -y^{cc}V_c
\end{aligned}
$$

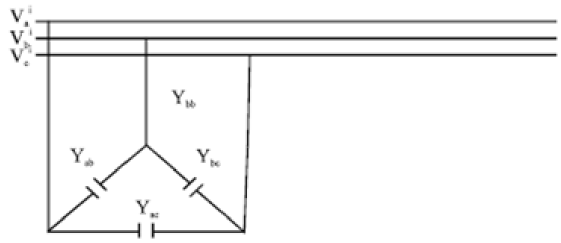


Fig. 8: Capacitors connected in delta connection

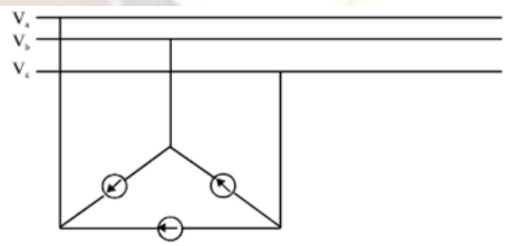


Fig. 9: Representation of flow of currents due to delta-connected capacitors

$$
\left.
\begin{aligned}
I_a &= \frac{y_{ab}}{3}(-2V_a + V_b + V_c) \\
I_b &= \frac{y_{bc}}{3}(-2V_b + V_a + V_c) \\
I_c &= \frac{y_{ac}}{3}(-2V_c + V_b + V_a)
\end{aligned}
\right\} \quad (7)
$$

2.4 LOAD MODEL

All the loads are assumed to draw constant complex power (S = P+jQ). A node in a radial system is connected to several other nodes. However, owing to the structure, in a radial system, it is obvious that a node is connected to the substation through only one line that feeds the node. All the other lines connecting the node to other nodes draw power from the node. Fig.5 shows phase a of a three-phase system where lines between nodes i and j feed the node j and all the other lines connecting node j draw power from node j. Following equations ($P_{ij}^{a}+jQ_{ij}^{a}$), ($P_{ij}^{b}+jQ_{ij}^{b}$), ($P_{ij}^{c}+jQ_{ij}^{c}$) refer to the power at the receiving end node j.

$$I_{ij}^{a} = \left[\frac{P_{ij}^{a} + jQ_{ij}^{a}}{V_{j}^{a}}\right]^{*} \qquad (8)$$

$$I_{ij}^{b} = \left[\frac{P_{ij}^{b} + jQ_{ij}^{b}}{V_{j}^{b}}\right]^{*} \qquad (9)$$

$$I_{ij}^{c} = \left[\frac{P_{ij}^{c} + jQ_{ij}^{c}}{V_{j}^{c}}\right]^{*} \qquad (10)$$

2.4.1 Wye-connected loads:

In the case of loads connected in wye are single phase loads connected line-to-neutral, the load current injections at the K^{th} bus can be given by

$Ia = (P_m \pm jQ_m) / V_m^*$ m= a, b, c (11)

Where P_m , Q_m and V_m^* denote real power, reactive power and complex conjugate of the voltage phasor of each phase, respectively.

2.4.2 Delta-connected loads:

The current injection at the K^{th} bus for three-phase load connected in Delta are single-phase load connected line-to-line can be expressed by

$$I_a = \frac{P_{ab} - jQ_{ab}}{V_a^* - V_b^*} - \frac{P_{ca} - jQ_{ca}}{V_c^* - V_a^*} \qquad (12)$$

$$I_b = \frac{P_{bc} - jQ_{bc}}{V_b^* - V_c^*} - \frac{P_{ab} - jQ_{ab}}{V_a^* - V_b^*} \qquad (13)$$

$$I_c = \frac{P_{ca} - jQ_{ca}}{V_c^* - V_a^*} - \frac{P_{bc} - jQ_{bc}}{V_b^* - V_c^*} \qquad (14)$$

All the loads, including shunt capacitors for reactive power compensation are represented by their active (P_{L0}) and reactive (Q_{L0}) components at 1.0.pu. The effect of voltage variation is represented as follows:

$$P_L = P_{L0}|V|^k \qquad (15)$$

$$Q_L = Q_{L0}|V|^k \qquad (16)$$

Where, $|V|$ is the voltage magnitude, K=0 for constant Power load, K=1 for Constant current load and K=2 for Constant Impedance load. The value of K may be different according to load characteristics.

2.5. DISTRIBUTED GENERATOR

Distributed generation [1] is an effective means of increasing energy efficiency and reduced energy costs. The distributed generation process puts wasted heat to work. It saves energy by using the reject heat of one process as an energy input to a subsequent process, effectively using the same fuel. When a request is made to generate electricity using distributed generators in parallel with a utility system, there is a need to study the impact of the proposed distributed generators will have upon existing system. There are different types of DGs from the constructional and technological points of view. These types of DGs must be compared to each other to help in taking the decision with regard to which kind is more suitable to be chosen in different situations. However, we are concerned with the location of distributed generation as the installation and operation of electric power generation modules connected directly to the distribution network or connected to the network on the customer site of the meter.

2.5.1 Distributed generator Model

A preliminary investigation of typical voltage control systems for synchronous distributed generators was done [2]. According to the investigation results, synchronous DGs are not controlled to maintain constant voltage; they are controlled to maintain constant power and constant power factor. The power factor controller must be capable of maintaining a power factor within plus or minus one percent at any set point. As a result, the synchronous DGs can be represented approximately as constant complex power devices in the power flow study, i.e. DGs can be represented as P-Q specified devices in the power flow calculation. As for induction DGs, their reactive power will vary with the terminal voltage change. Thus, the reactive power consumption of the induction DGs is not exactly constant.

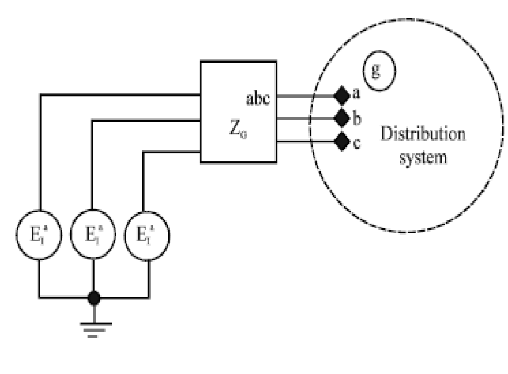


Fig. 10: Thevinen's equivalent circuit of cogenerator

E_i^{abc} are the voltages behind sub transient, Z_i^{abc} is the sub transient impedance matrix. Based on the assumptions discussed above, we have

Total real power $= \mathbf{P_T} = p^a+p^b+p^c$ = Constant

Total reactive power $=\mathbf{Q_T} = q^a+q^b+q^c$ = Constant

The internal voltage $\mathbf{E_i^{abc}}$ is a balanced three-phase voltage in both magnitude and angle, assuming a balanced design of the generator windings. A Norton equivalent circuit of Fig.10 is used to represent the distributed generator model shown in Fig.11.

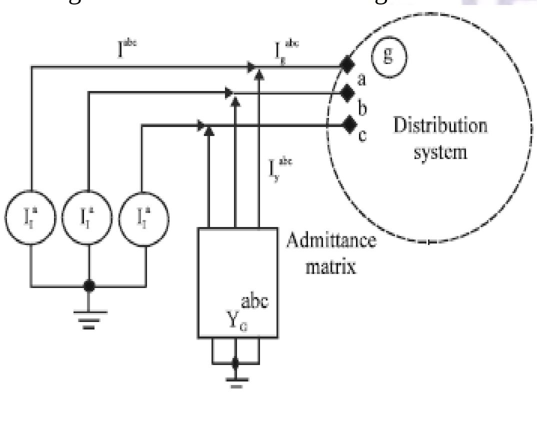


Fig. 11: Norton's equivalent circuit of cogenerator

2.6. TRANSFORMER MODEL

The impact of the numerous transformers in a distribution system is significant. Transformers affect system loss, zero sequence current, grounding method, and protection strategy.

The conventional transformer models [4] based on a balanced three phase assumption can no longer be considered suitable for unbalanced systems. Recent interest in unbalanced system phenomena has also produced a transformer model adaptable to the unbalanced problem which is well outlined in [13]. The model developed thus far can be applied directly to distribution power flow and short-circuit analysis. However, it is still not accurate for system loss analysis because the transformer core loss contribution to total system loss is significant [5]. To calculate total system loss, the core loss of the transformer must be included in the model. . To solve this problem, this paper introduces an implementation method in which artificial injection currents are used to make the system Y_{Bus} nonsingular.

2.6.1 Derivation of Transformer Models

A three-phase transformer is presented by two blocks shown in Fig. 12

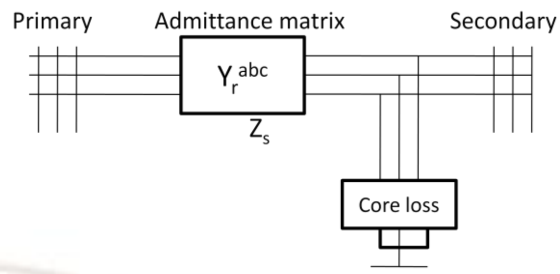


Fig. 12: Overall proposed transformer model

One block represents the per unit leakage admittance matrix Y_T^{abc}, and the other block models the core loss as a function of voltage on the secondary side of the transformer.

The presence of the admittance matrix block is the major distinction between the proposed model and the model used in [4, 8]. In the proposed model, Dillon's model is integrated with the admittance matrix part. As a result, the copper loss, core loss, system imbalance, and phase shift characteristics are taken into account. The implementation method is introduced in the following sections.

Impedance values:

$Z_1 = R_1 + j*L_1 \quad Z_2 = R_2 + j*L_2 \quad Z_m = j*M$

$Z_1 = Z_3 = Z_5 \quad Z_2 = Z_4 = Z_6$

2.6.2. Copper Loss and Core Loss of Transformer:

The total loss of the transformer consists of core and copper losses, which is the difference between input and output powers. It is well known that for any Y-(ungrounded) or Δ-connected three-phase windings, the two-wattmeter method is often used to measure the power based on the voltages and currents of any two phases. For a Y-grounded three-phase winding, an additional wattmeter is necessary for the voltage and current of the third phase, or those of the zero sequence. Therefore, for a transformer without grounding on any side (primary and secondary), power loss is measured with eight signals (voltages and currents of two phases for each side). If the primary or/and the secondary are grounded, the power loss can be measured with ten or twelve signals. If we know the primary and secondary quantities (i.e. signals) of specified configuration, we can calculate power loss (or powers) by using measurement formulae [4].

$I_p^{abc} = Ypp * V_p^{abc} + Yps*V_s^{abc}$

I_s^{abc} is calculating by the load on the transformer. The formulae for core and copper loss for various connections of transformer [5] is shown in table 1.

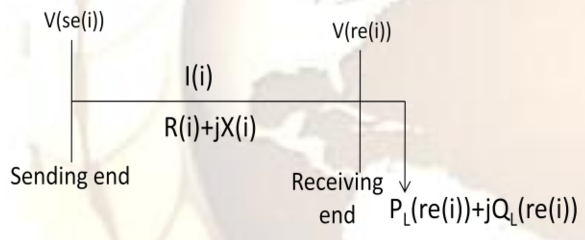
TABLE 1

IRON-CORE AND COPPER LOSSES OF THREE-PHASE TRANSFORMERS

	$p_{fe}(t)$	$p_{cu}(t)$
Y-Y (or Δ-Δ)	$v_{AC}(i_A - i_a') + v_{BC}(i_B - i_b')$	$(v_{AC} - v_{ac}')\, i_a' + (v_{BC} - v_{bc}')\, i_b'$
Δ-Y	$v_{AC}(i_{Al} - i_{al}') + v_{BC}(i_{Bl} - i_{bl}')$	$(v_{AC} - v_{an}')\, i_{al}' + (v_{BC} + v_{cn}')\, i_{bl}'$
$\Delta\text{-}Y_0$	$v_{AC}(i_{Al} - i_{al}') + v_{BC}(i_{Bl} - i_{bl}')$	$(v_{AC} - v_{an}')\, i_{al}' + (v_{BC} + v_{cn}')\, i_{bl}' - v_0'\, i_b'$
$Y\text{-}Y_0$	$v_{AC}(i_A - i_a') + v_{BC}(i_B - i_b') - v_{cn}'\, i_0'$	$(v_{AC} - v_{ac}')\, i_a' + (v_{BC} - v_{bc}')\, i_b'$
$Y_0\text{-}Y_0$	$v_{An}(i_A - i_a') + v_{Bn}(i_B - i_b') + v_{Cn}(i_C - i_c')$	$(v_{An} - v_{an}')\, i_a' + (v_{Bn} - v_{bn}')\, i_b' + (v_{Cn} - v_{cn}')\, i_c'$

3. LOAD FLOW CALCULATION

Consider the i^{th} branch of the network



The receiving-end node voltage can be written as

$$V\,re(i) = V\,se(i) + I(i)Z(i)$$

The equation is evaluated for

$$i = 1,2 \ldots\ldots\ldots l_n.$$

Where n is the total number of branches.

Current through branch i is equal to the sum of the load currents of all the nodes beyond branch i plus the sum of the charging currents of all the nodes beyond branch i plus the sum of all injected capacitor currents of all the nodes and the sum of distributed generator currents at all nodes , i.e.

$$I(i) = \sum_{j=1}^{ln} I_L(IE(i,j)) + \sum_{j=1}^{ln} I_C(IE(i,j)) - \sum_{j=1}^{ln} I_{CC}(IE(i,j)) - \sum_{j=1}^{ln} I_G(IE(i,j)) \quad (17)$$

The real and reactive power loss of I^{th} node is given by

$P_L(i) = \text{real}\,\{V(se(i)) - V(re(i))\}\,.I(i)$ (18)

$Q_L(i) = \text{imag}\,\{V(se(i)) - V(re(i))\}\,.I(i)$ (19)

Initially, a constant voltage of all the nodes is assumed and load currents, charging currents, capacitor currents, and DG currents are computed. After currents have been calculated, the voltage of each node is then calculated. The real and reactive power losses are calculated. Once the new values of voltages of all the nodes are computed, convergence of the solution is checked. If it does not converge, then the load and charging currents are computed using the recent values of the voltages and the whole process is repeated.

The convergence criterion of the proposed method is that if, in successive iterations the maximum difference in voltage magnitude (D_{vmax}) is less than 0.0001p.u, the solution has then converged. This solution method is known recursive voltage computation method. The flowchart of the method is represented below.

Algorithm for load flow:

1. Find the Z_{bus} (line impedance) and Y_{bus} (Branch charging admittance) for the system.
2. Consider the flat voltages at each node v(i).
3. Load current I_L is calculated through 11, 12, 13 and 14 for corresponding loads of Y or delta connected.
4. Calculate shunt admittance branch current $I_{C,}$ using 5.
5. Calculate the core losses of transformer using table.1.
6. Calculate capacitor currents I_{CC} using 7.
7. Calculate the Distributed currents I_g.
8. Now calculate total current I by combining all the above currents using 17.
9. Calculate receiving voltage as $V_{re}(i)$,
   V re(i) = V se(i) + I(i)Z(i)
   DV(i) = abs(V(re(i))-v(i))
   Dvmax = max(max(DV))
10. If Dvmax>accuracy goto step 3, repeate the steps until the converged solution is obtained.
11. Calculate power losses using 18 and 19.

4. RESULTS AND DISCUSSION

The problem is solved on IEEE 13 bus system [11] and IEEE 37 bus system [12] and the results are analyzed for three different cases.

Case 1(No DG): Power loss calculation without considering Distributed generator currents (I_g).

Case 2(single DG): Power loss calculation adding only one DG at appropriate place.
Case 3(Multiple DGs): Power loss calculation including multiple DGs.
The placement of DG depends on the load. Normally DG is place nearer to loads at which the load in maximum. When considering multiple DGs the size of total DGs should not exceed 20% of the total load. Placing of DGs at appropriate place with appropriate sizes gives us better results.

5.1. TEST RESULTS

The test system of IEEE 13-bus is considered and it has four load points, a transformer and two capacitor banks. Test system of 37-bus has 26 load points, one transformer and no capacitor banks. The systems are analyzed using MATLAB and the power losses are calculated.
In this section, using the proposed algorithm, performance is analyzed in three different approaches: no DG, single Dg and with multiple DGs.
The results represent exclusively the proposed formulation performance, without any additional errors, as due to measurement devices.

TABLE 2. Power losses for 13-bus test system

DG Node position	**P_{loss} (MW)**	**Q_{loss} (MVAR)**
No DG	47.2445	70.3552
3	38.3402	45.8922
5	40.2435	52.7097
8	170.1690	-28.3991
9	38.3402	45.8922
11	169.3725	-35.2106
13	299.6173	-114.1238
3rd and 10th	35.6386	37.8075

Analyzing the results from table.2, it can be seen the proposed load flow algorithm affected by the DG positions. DG position at node 3 where maximum load is present gives minimal values for the power loss. Also at the node 10 where the unbalance load is present the power losses are minimum. From the lower values of power losses it can be said that the DG position should be at maximum load. As well as the multiple DGs give better results than that of single DGs. Multiple DGs at 3rd and 10th node give losses lesser than to single DG at 3rd and 10th node. It is also observed that unnecessary placement of DG in inappropriate places such as no load and minimal load positions (8, 11 and 13th positions) may also lead to increase the power losses.

TABLE 3. Power losses for 37-bus test system

DG Node position	**P_{loss} (MW)**	**Q_{loss} (MVAR)**
No DG	19.9303	59.7969
3	18.1624	57.6073
7	15.2042	54.7712
8	18.7803	58.7743
10	18.0458	58.3738
15	17.1224	55.8426
20	18.0703	58.4069
24	18.5984	58.6268
30	17.5463	58.2327
35	15.6545	54.7731
37	14.8628	54.5119
7th and 29th	11.5563	51.0651
7th, 16th and 29th	10.4498	49.5579

For 37-bus system, from table.3, it is also observed that the power losses are minimum when placing DG at maximum load location i.e. at 29th node. Considering multiple DGs at 7th and 29th lead to much decrease in losses compared to single DGs. Also multiple DGs at 7th, 16th and 29th shows more decrease in power losses.

5. CONCLUSION

In this paper, a novel algorithm is presented to find the power losses using the mathematical modeling of the whole system components. The technique also can be used to find losses when distributed generators included.
The proposed technique consists of loads, capacitors, branches, transformer losses and distributed generators modeling. Test results show the benefits in placing of DG. Distributed generator plays a significant role on power losses of the unbalanced radial distribution systems. The placements of multiple DGs in appropriate places lead minimal losses compared to single DG. For several realistic distribution networks the effectiveness of the proposed method is explained with two different systems.

REFERENCES

[1]. W.El-Khattam, M.M.A.Salama , "Distributed generation Technologies, definitions and benefits", Electric Power Research 71 (2004) 119-128
[2]. R. K. Singh and S. K. Goswami, "Optimal Siting and Sizing of Distributed Generations in Radial

and Networked Systems Considering Different Voltage Dependent Static Load Models" 2nd IEEE International Conference on Power and Energy (PECon 08), December 1-3, 2008.
[3]. T.H.Chen, M.S.Chen, "Three Phase Co generator and Transformer Models for distribution system analysis" IEEE Transactions on Power Delivery, Oct 1991.
[4]. Peng Xiao, David C. Yu and Wei Yan, "A Unified Three-Phase Transformer Model for Distribution Load Flow Calculations", IEEE Transactions on Power Systems, 2006 Vol 21. Issue 1, pp 153-159
[5]. Dingsheng Lin and Ewald F.Fuchs, "Real-Time Monitoring of Iron-Core and Copper Losses of Transformers Under (Non) Sinusoidal Operation", IEEE Transactions on Power Delivery, 2006, Vol. 21, No 3, pp 1333-1341
[6]. R. Ranjan, B.Venkatesh, A.Chaturvedi, and D.Das, "Power flow solution of Three-phase unbalanced Radial Distribution Network.", Electric Power Components and Systems,32:421-432,2004.
[7]. Carol S. Cheng, and Dariush Shirmohammadi, "A Three-phase Power flow Method for Real-time Distribution system Analysis." IEEE Transactions on Power Systems, Vol 10 Issue 2 pp 671-679
[8]. G.D.Patil, S.V.Kulakarni, "Performance Assessment of load flow techniques for unbalanced distribution systems", NPSC 2004.
[9]. Carol S. Cheng, and Dariush Shirmohammadi, "A Three-phase Power flow Method for Real-time Distribution system Analysis."IEE/PES 1994 Summer Meeting, San Fransisco, July 1994, 94 SM 603-1 PWRS.
[10]. IEEE Distribution Planning Working Group Report, "Radial Distribution test feeders", IEEE Transactions on Power Systems, August1991, Volume 6, Number 3, pp 975-985.
[11]. IEEE Distribution Planning Working Group Report, "IEEE 37 node Test Feeder".
[12]. W. E. Dillon, "Modeling and Analysis of an Electrically Propelled Transportation System," The University of Texas at Arlington, May 1972.
[13]. D. I. Sun, "Distribution System Loss Analysis and Optimal planning," The University of Texas at Arlington, May 1980.
[14]. D. I. Sun, S. Abe, R. R. Shoults, M. S. Chen, P.Eichenberger, and D. Fanis, "Calculation of Energy Losses in a Distribution System"' IEEE Transactions on Power Apparatus and Systems, Vol. PAS-99, No.4, July/Aug 1980