

# *Loss Minimization of Distribution System Using Distributed Generation*

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## ABSTRACT

Modern utilities are continuously planning the expansion of their electrical networks to face the load growth and to properly supply their consumers. Distributed generation (DG) is a rapidly growing technology that helps to achieve this objective. This article presents computationally efficient and numerically robust distribution flow equations for the power flow solution of distribution system with distributed generation. The loss minimization problem is formulated as non-linear optimization programming, where the objective is to minimize the real power losses. The constraints are the power balance equations and voltage balance equations. The upper and lower limits of voltages are considered. The non-linear programming is solved by Newton's method. The effects of distributed generation on the system voltage profile and losses have been analyzed. The results show that the voltage profile is improved and losses are reduced, when DG is incorporated in the system. The methodology is applied to IEEE-13 bus distribution test system.

## INTRODUCTION

An electrical distribution system is a service of electrical circuits that delivers power in the proper proportion to homes, commercial businesses and industrial facilities. Regardless of the size and applications, the ultimate goal remains universal, i.e., the economic and safe delivery of adequate electric power to electrical equipment. The type

of distribution system used by the utility company depends on the service required, location and economy. Overhead distribution systems are generally configured in a radial manner. However, the configuration is changed during operation by changing the state of the sectionalizing switches. Changes in the topology of a distribution system is mainly aimed at diminishing the real power losses in the feeders, improving the consumers' voltage profile, increasing reliability levels and/or isolating faults to restore the power supply. The change in topology of the distribution system for the purpose of system loss reduction is termed network reconfiguration [1]. On the other hand, for many years, capacitor banks have been added to distribution system to reduce losses, to improve system capacity and also to improve the voltage profile [2]. To use the smallest number of capacitors for attaining the best benefits, it is necessary to determine the best location and sizes of capacitors [3].

The demand for electrical energy has increased many fold as a result of large-scale industrialization, which leads to many problems associated with operation and control of power systems. Therefore, the power utilities always need new generation technologies to solve their problems [4]. Distributed generation (DG) technology is one of the solutions that have received a lot of attention in the recent past.

The development of microturbines, renewable energy resources, solar cells, wind systems, bio-mass gasifiers, combined heat and power (CHP) cycle turbines forms a new category of power generation. These can be used at many load points within distribution systems in small capacities and are known as distributed generation. Supply security, energy efficiency and CO<sub>2</sub> emission reduction are widely quoted as the main drivers for this technology [5]. The World Alliance for Decentralized Energy (WADE) defines decentralized energy (DE) as electricity production at or near the point of use, irrespective of size, technology, or fuel used- both off grid and on-grid. The 4th annual survey of WADE concludes that 24% of all electricity generated from new plant added in 2005 was Decentralized Energy. The integration of distributed generation into an existing network can result in line loss reduction, reduced environmental impacts, peak shaving, increased overall energy efficiency, relieved transmission and distribution congestion, voltage support and deferred investments to upgrade existing generation, transmission and distribution systems [6, 7].

Load flow is a very important and fundamental tool for the analysis of a distribution system and is used in the operational as well

as planning stages [8]. Certain applications, particularly in distribution automation and optimization of a power system, require repeated load flow solutions. Newton-Raphson and fast decoupled power flow solution techniques have efficiently solved well-behaved power systems for more than two decades. However, these are, in general, unsuitable for solving load flow for distribution networks because of high R/X ratios and radial nature of distribution networks. Literature surveys show that the two most popularly used techniques for distribution load flow (DISTFLOW) are one based on a Newton-like method involving formation of Jacobians and computation of power mismatches at the end of the feeder and laterals, and the other based on backward and forward sweeps involving computation of current flows in the branches [8, 9, 10].

In the past, much literature related to performance of the distribution system has been published. The interaction between DGs and distribution networks is discussed and sensitivity indices are proposed that can be used to identify the size and location of DG with minimum losses in distribution system [11]. The contribution of DG on loss reduction is presented [12]. However, the DG rating, location, and operating power factor are important factors for line loss reduction. A distribution system graphic simulator is developed with reconfiguration functions that focus on loss allocation and the presence of distributed generation [13]. A power flow algorithm has been developed based on the current summation backward-forward technique. A reconfiguration problem is solved through a heuristic methodology and the losses allocation function based on the Z-bus method is presented. A technique for evaluation of optimal power flow for the connection of distributed generation is presented [14]. It performs negative load shedding that effectively maximizes capacity and identifies available headroom. The technique identifies available headroom within the imposed thermal and voltage constraints.

A new methodology to solve the optimal distributed generation (DG) sizing problem is proposed [15]. Its main feature is to utilize the radial power flow method to satisfy the power flow equality constraints as a substitute of the Newton method used in the conventional sequential quadratic programming (SQP). The improvement effect of DG on the distribution system voltage stability has been theoretically established, and a quantitative index is proposed to evaluate the voltage stability of load nodes [16]. This index is calculated by continuation power flow (CPF) method and then ranked to decide the optimal DG location. After

the selection of best location, the optimal penetration level of DG at selected buses is calculated by primal-dual interior point method.

A multi-objective performance index is formulated for distribution networks with distributed generation [17]. The issue of optimizing DG planning in terms of DG size and location to reduce the amount of line losses in the distribution network is presented [18]. The optimization methodology is based on the sequential quadratic programming. It assesses the compatibility of different generation schemes upon the level of power loss reduction and DG cost.

A technique that helps to identify the impact of grid-connected DG on the reliability of on-site electric power is discussed. Recognizing the increased need for a higher reliability energy system and a cleaner environment, a technique is proposed that helps to identify the impact of grid-connected DG on the reliability of on-site electric power [19]. The analysis shows the optimal DG mix at various facility outage costs with and without an emission restriction. An algorithm based on primal-dual interior point method has been developed for solving non-linear optimal power flow problems [20]. The objective is to optimize the location and sizing of DG on distribution system for solving the problem of line loss reduction.

In the present work, computationally efficient and numerically robust distribution flow equations are used for the power flow solution of distribution system. The concept of distributed generation is discussed and implemented. The problem is formulated as non-linear optimization programming, where the objective is to minimize the real power losses. The constraints are the power balance equations and voltage balance equations. The upper and lower limits of voltages are considered. The non-linear programming is solved by Newton's method. The effects of distributed generation on the system voltage profile and losses have been analyzed. The results show that the voltage profile is improved and losses are reduced, when DG is incorporated in the system. The methodology is applied to IEEE -13 bus distribution test system.

## BENEFITS OF DISTRIBUTED GENERATION

Distributed generation (DG) by itself is not a new concept. A small number of consumers have been installing their own generation on-site for decades. Recently, however, the creation of competitive retail electric

markets and the development of new generation technologies, including fuel cells and microturbines have sparked new and broader interest in distributed generation. Almost every participant in discussions about DG defines the term “distributed generation” differently. At one end, DG could include only small-scale environmentally friendly technologies, such as photovoltaics (PV), fuel cells, microturbines or small wind turbines—that are installed on and designed primarily to serve a single end user’s site. At the other end, DG could encompass any generation built near consumer’s load regardless of size or energy source.

In certain applications, some DG technologies can provide significant benefits, including reduced transmission and distribution costs, reduced emissions, and enhanced reliability. Generation located near customer load can reduce energy losses, permit utilities to deter upgrades to substations, distribution facilities and transmission facilities and provide back start capability and spinning reserves. Microturbines, turbines and combustion engine generators can provide voltage support and reduce reactive power losses. Some DG technologies including fuel cells, microturbines and internal combustion engines can gain increased efficiency by taking advantage of waste heat. DG powered by renewable resources or fuel cells can substitute for central station generation that could have greater emissions and land-use impacts. As the industry restructures, DG can also provide some consumers a “self help” alternative to volatile markets and market abuses. Finally, because they can be faster to build, easier to move, need less existing infrastructure, and require less up-front capital investment than large central station generations, some DG technologies could have a tremendous role to play internationally in less developed countries.

There is risk, however, that the immediate benefits of DG are being oversold to fit all cases. Not all DG technologies have yet proven to be cheap, clean and reliable for broad application. Some of the presumed benefits of DG are speculative. They rely, for example, on the presumption made by manufacturers of fuel cells and microturbines that their technologies will eventually prove to be inexpensive and reliable (as they are projected to be). In reality, it will take several years of further developments and testing before those projections can be evaluated objectively. Some of the presumed benefits also rely on generic assumptions about power delivery system needs and costs that may not reflect the realities of any particular system or DG site. Other presumed benefits are highly dependent on the manner in which DG facilities are planned,

installed and operated. Policies that encourage DG without taking those factors into account could not only fail to capture any of the presumed benefits but instead could be extremely costly.

PROPOSED METHODOLOGY

**Distribution System Power Flow**

Power flows in a distribution system obey physical laws (Kirchoff’s law and Ohm’s law), which become part of the constraints in the DG placement problem. In the proposed solution algorithm for the DG placement problem, the distribution system power flow solution is used. In this analysis, a balanced 3-phase radial distribution is considered, which is modeled by a set of n buses or nodes interconnected by n branches.

**Special Case: Radial Main Feeder**

Figure 1 illustrates a 1-line diagram of a radial feeder. Where,  $V_0$  represents the constant station bus voltage magnitude. The equation,  $z_1 = r_1 + jx_1$ , represents the series impedance of lines and the equation,  $S_L = P_L + jQ_L$ , represents the loads. Distributed Generators are placed at the nodes where real and reactive power injections are required.

If the power supplied from the substation,  $S_0 = P_0 + jQ_0$ , is known, then the power and the voltage at the receiving end of the first branch is calculated as

$$S_1 = S_0 - S_{loss1} - S_{L1} = S_0 - z_1 |S_0|^2 / V_0^2 - S_{L1} \tag{eq 1}$$

$$V_1 \angle \theta_1 = V_0 - z_1 I_0 = V_0 - z_1 S_0^* / V_0 \tag{eq 2}$$

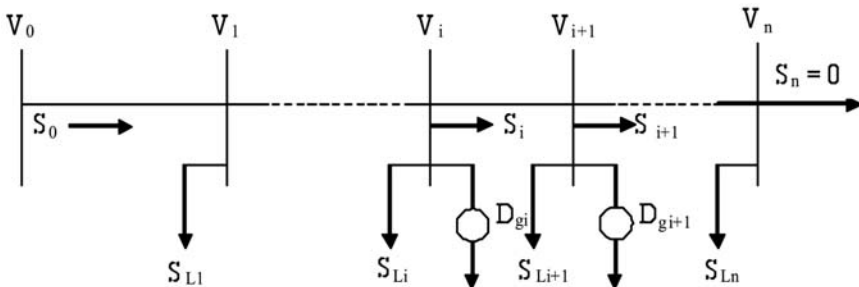
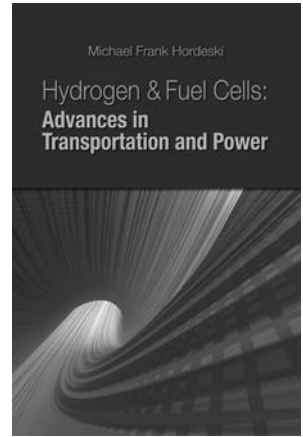


Figure 1. One-line Diagram of a Radial Feeder.

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Michael F. Hordeski

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Repeating the same process yields the following recursive formula for each branch on the feeder.

$$P_{i+1} = P_i - r_{i+1} (P_i^2 + Q_i^2) V_i^2 - P_{Li+1} + P_{Dgi+1} \quad (\text{eq 3.i})$$

$$Q_{i+1} = Q_i - x_{i+1} (P_i^2 + Q_i^2) V_i^2 - Q_{Li+1} + Q_{Dgi+1} \quad (\text{eq 3.ii})$$

$$V_{i+1}^2 = V_i^2 - 2(r_{i+1} P_i + x_{i+1} Q_i) + (r_{i+1}^2 + x_{i+1}^2) (P_i^2 + Q_i^2) V_i^2 \quad (\text{eq 3.iii})$$

Where,

$P_i, Q_i$  real and reactive power flows into the sending end of branch  $i + 1$  connecting node  $i$  and node  $i + 1$ ,

$V_i$  = bus voltage magnitude at node  $i$

$P_{Dgi}$  = real power injection from DG at node  $i$ .

$Q_{Dgi}$  = reactive power injection from DG at node  $i$

Equation 3 is called the "branch flow equations" has the following form

$$\mathbf{x}_{0i+1} = \mathbf{f}_{0i+1}(\mathbf{x}_{0i}, \mathbf{u}_{i+1}) \quad (\text{eq 4})$$

Where,  $\mathbf{x}_{0i} = [P_i \ Q_i \ V_i^2]^T$  and  $\mathbf{u}_{i+1} = [P_{Dgi+1}, Q_{Dgi+1}]$

The following terminal conditions are satisfied:

(i) at the substation; let the given substation voltage be  $V^{SP}$ , then

$$\mathbf{x}_{00_3} = V_0^2 = V^{SP^2} \quad (\text{eq 5.i})$$

(ii) at the end of the main feeder,

$$\mathbf{x}_{0n_1} = P_n = 0, \quad \mathbf{x}_{0n_2} = Q_n = 0 \quad (\text{eq 5.ii})$$

The  $3n$  branch flow equations of (eq 4) together with boundary conditions of (eq 5) constitute the system equations and will be referred to as DistFlow equations.

They are of the form

$$\mathbf{G}(\mathbf{x}_0, \mathbf{u}) = 0 \quad (\text{eq 6})$$

Where,  $\mathbf{x}_0 = [\mathbf{x}_0^T \dots \mathbf{x}_n^T]^T$  is the branch variables and  $\mathbf{u}$  is the DG sizes. For a given load profile (i.e., set of demands  $P_{Li}, Q_{Li}; i = 1 \dots n$ ) and DG sizes (control variables),  $\mathbf{u}$ ,  $3(n + 1)$ . DistFlow equations can be used to determine the operating point,  $x_{op}$  of the system.

**General Case: Main Feeder with Laterals**

The DistFlow equations can be generalized to include laterals as illustrated in Figure 2.

Figure 2 represents a distribution system comprising the main feeder as well as laterals. The lateral branching out of node  $k$  is referred to as the lateral  $k$  and the node  $k$  is referred to as the branching node. For lateral  $k$  with  $nk$  branches,  $3(nk+1)$  branch flow equations can be of the following form

$$\mathbf{x}_{ki} = \mathbf{f}_{ki+1}(\mathbf{x}_{ki}, \mathbf{u}_{ki+1}) \quad i = 0, \dots, nk - 1 \tag{eq 7.i}$$

$$\mathbf{x}_{ki} = V_{k0}^2 = V_k^2 = \mathbf{x}_{0k3} \tag{eq 7.ii}$$

$$\mathbf{x}_{kn1} = P_{kn} = 0; \mathbf{x}_{kn2} = Q_{kn} = 0 \tag{eq 7.iii}$$

Hence, in general, for a distribution network of  $n$  branches and  $l$  laterals, there are  $3(n + 1 + l)$  DistFlow equations. They are of the form

$$\mathbf{G}(\mathbf{x}, \mathbf{u}) = 0 \tag{eq 8}$$

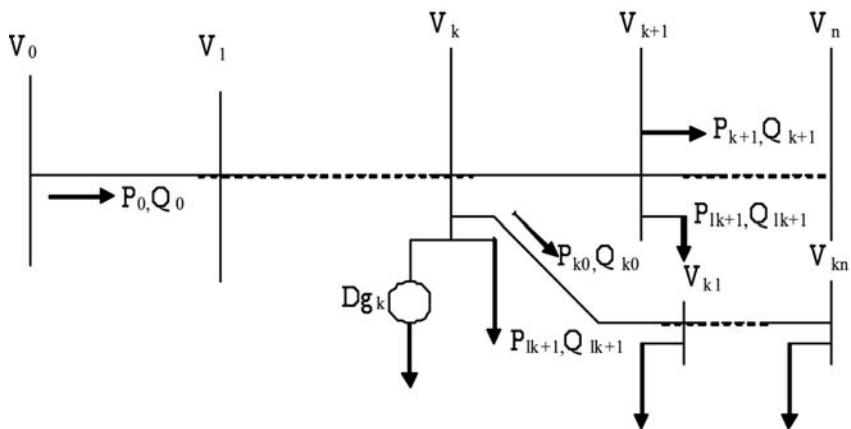


Figure 2. One line diagram of radial feeder with laterals.

Where  $\mathbf{x} = [\mathbf{x}_1^T \dots \mathbf{x}_1^T \mathbf{x}_0^T]^T$ ,  $\mathbf{x}_k = [\mathbf{x}_{k0}^T \dots \mathbf{x}_{kn}^T]^T$

DistFlow equations can be used to determine the operating point “ $\mathbf{x}$ ” of the system if the DG sizes  $\mathbf{u}$  are given. These equations can be utilized to develop a computationally efficient and numerically robust solution algorithm.

PROBLEM FORMULATION FOR DG SIZING

The DG placement problem is to determine the location, type and size of the DGs to be placed on a distribution system. The objectives are to reduce the losses on the system and to maintain the desired voltage profile. In the sizing problem, it is assumed that:

- The DGs are placed
- There is only one load profile.

Therefore, the sizing problem determines the optimal sizes of the DGs once they are placed. However, in this proposed formulation, the voltage profile of the system (voltages at all nodes) is required to lie within the acceptable limits.

To formulate the sizing problem as a nonlinear programming problem, a radial distribution system with  $n$  branches,  $l$  laterals, and  $nDg$  DGs placed at the nodes of the system and a load profile,  $P_{Li}, Q_{Li}, i = 1, \dots, n$  is considered. The objective comprises real power loss reduction in the system as a result of DG placement. The real power losses in the network are calculated as the sum of the  $i^2r$  loss on each branch.

$$p(x) = \sum_{k=0}^l \sum_{i=0}^{kn-1} r_{ki+1} \frac{P_{ki}^2 + Q_{ki}^2}{V_{ki}^2} \tag{eq 9}$$

There are 3 sets of constraints.

- (i) The power flow equations:  $\mathbf{G}(\mathbf{x}, \mathbf{u}) = 0$
- (ii) Voltage limits:  $V_{kl}^{\min 2} \leq \mathbf{x}_{ki3} = V_{k1}^2 \leq V_{ki}^{\max 2}$
- (iii) DG limits:  $0 \leq \mathbf{u} \leq \mathbf{u}^{\max}$

To summarize, the sizing problem in DG placement is

$$\begin{aligned} \min f_0 &= k_p p(x) \\ \text{S.t } x_{ki+l} &= f_{ki+l}(x_{ki}, u_{ki+l}) \quad k = 0 \dots l \\ x_{k0_3} &= x_{0k_3} \\ x_{kn_1} &= x_{kn_2} = 0 \quad i = 0 \dots nk - 1 \\ V_{ki}^{\min^2} &\leq x_{ki_3} = V_{ki}^2 \leq V_{ki}^{\max^2} \\ 0 &\leq u \leq u^{\max} \end{aligned}$$

## RESULTS AND DISCUSSIONS

An IEEE 13-bus test feeder, as shown in Figure 3, is considered for study. A number of simulations are conducted with different load profiles, but the results for only the base case load profile are given here. The study is done for different cases of distributed generation as follows:

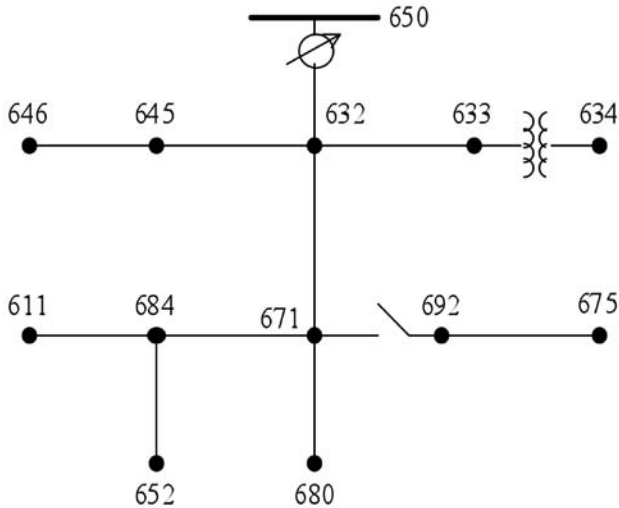


Figure 3. IEEE 13 Node Test Feeder

- System without DG
- System with DG at bus no. 675
- System with DG at bus no. 680

The maximum size of the DG considered is 1000 kW. The voltage profile and the load flow summary for the system without DG showing only the magnitude is given in Table 1 and Table 2. The voltage profile and the load flow summary for the system with DG at node 680 showing only the magnitude is given in Table 3 and Table 4. The voltage profile and the load flow summary for the system with DG at node 675 showing only the magnitude is given in Table 5 and Table 6.

The voltage profile of the system without DG is given in Figure 4. The voltage profiles of the system with DG at node 680 and node 675 are given in Figure 5 and Figure 7, respectively. A comparison of the voltage magnitude for the system without DG and with DG at node 680 and node 675 is shown in Figure 6 and Figure 8, respectively. From Figure 6 and Figure 8, it is found that because of the incorporation of DG at node 680 and node 675, the voltage profile has been improved by 1.01%. From Table 2, the total input to the system without DG is 35077.191 kW, and the total losses without DG in the system are 111.063 kW. This is illustrated in Figure 9. Similarly, from Table 4, the total input to the

**Table 1. Voltage Profile of the System without Distributed Generation**

Node No.	Node Name	Phase A Magnitude	Phase B Magnitude	Phase C Magnitude
1	650	1	1	1
2	RG60	1.0625	1.05	1.0687
3	632	1.021	1.042	1.0174
4	633	1.018	1.0401	1.0148
5	XFXFM1	0.9941	1.0218	0.996
6	634	0.994	1.0218	0.996
7	645		1.0329	1.0155
8	646		1.0311	1.0134
9	671	0.99	1.0529	0.9778
10	680	0.99	1.0529	0.9778
11	684	0.9881		0.9758
12	611			0.9738
13	652	0.9825		
14	692	0.99	1.0529	0.9777
15	675	0.9835	1.0553	0.9758

**Table 2. Radial Flow Summary of the System without Distributed Generation**

<b>System Input</b>	<b>Phase A</b>	<b>Phase B</b>	<b>Phase C</b>	<b>TOTAL</b>
kW	1251.398	977.332	1348.461	3577.191
kVAr	681.57	373.418	669.784	1724.772
kVA	1424.968	1046.241	1505.642	3971.289
PF	0.8782	0.9341	0.8956	0.9008
<b>System Losses</b>	<b>Phase A</b>	<b>Phase B</b>	<b>Phase C</b>	<b>TOTAL</b>
kW	39.107	-4.697	76.653	111.063
kVAr	152.585	42.217	129.85	324.653
kVA	157.517	42.478	150.787	343.124

**Table 3. Voltage Profile of the System with Distributed Generation at 680**

<b>Node No.</b>	<b>Node Name</b>	<b>Phase A Magnitude</b>	<b>Phase B Magnitude</b>	<b>Phase C Magnitude</b>
1	650	1.0067	1.0015	1.0053
2	RG60	1.0709	1.057	1.076
3	632	1.0212	1.0458	1.0205
4	633	1.0248	1.0487	1.0232
5	XFXFM1	0.9979	1.0303	1.0017
6	634	0.9978	1.0277	0.9997
7	645		1.0379	1.0225
8	646		1.0401	1.0189
9	671	0.9943	1.0611	0.9922
10	680	1	1	1
11	684	0.99		0.982
12	611			0.9817
13	652	0.9893		
14	692	0.993	1.0558	0.9829
15	675	0.9889	1.0587	0.9846

system with DG at node 680 is 2969.069 kW, and the total loss incurred is 92.18229 kW. This is illustrated in Figure 10. Hence, the reduction in loss because of the incorporation of DG at node 680 is 17%. Similarly, considering Table 6, it can be calculated that the induction of DG at node 675 causes a total 14% reduction in line loss, which is illustrated in Figure 11. This is because DG supplies a portion of real and reactive power to the load. Thus, the feeder current reduces from the source to

**Table 4. Radial Flow Summary of the System with Distributed Generation at 680**

<b>System Input</b>	<b>Phase A</b>	<b>Phase B</b>	<b>Phase C</b>	<b>TOTAL</b>
kW	1038.66	811.1856	1119.223	2969.069
kVAr	565.7031	309.9369	555.9207	1431.561
kVA	1182.723	868.38	1249.683	3296.17
PF	0.8884	0.9541	0.9195	0.92
<b>System Losses</b>	<b>Phase A</b>	<b>Phase B</b>	<b>Phase C</b>	<b>TOTAL</b>
kW	32.45881	-3.89851	63.62199	92.18229
kVAr	126.6456	35.04011	107.7755	269.462
kVA	130.7391	35.25674	125.1532	284.7929

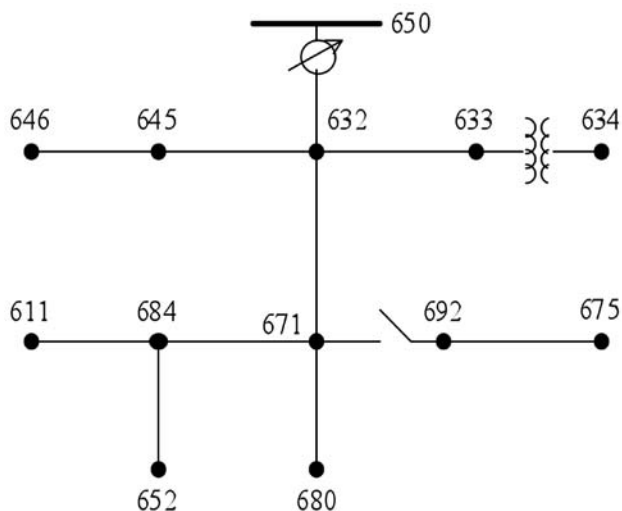
**Table 5. Voltage Profile of the System with Distributed Generation at 675**

		<b>Phase A</b>	<b>Phase B</b>	<b>Phase C</b>
<b>Node No.</b>	<b>Node Name</b>	<b>Magnitude</b>	<b>Magnitude</b>	<b>Magnitude</b>
1	650	1.0017	1.0099	1.0046
2	RG60	1.0723	1.0558	1.0744
3	632	1.0237	1.0462	1.0253
4	633	1.0205	1.0453	1.0154
5	XFXFM1	1.0029	1.0251	1.002
6	634	1.0014	1.0261	0.9965
7	645		1.0352	1.0197
8	646		1.0369	1.0164
9	671	0.9989	1.0605	0.9865
10	680	0.992	1.0582	0.978
11	684	0.9911		0.9835
12	611			0.9835
13	652	0.9853		
14	692	0.9947	0.9976	0.9965
15	675	1	1	1

the DG location, resulting in lower electrical line loss. Figure 12 shows the real power losses with respect to the system without DG and with DG at node 680. Similarly Figure 13 shows the real power losses with respect to the system without DG and with DG at node 675. Figure 12 and Figure 13 show that, by injecting DG into the distribution system, we can reduce the distribution line loss.

**Table 6. Radial Flow Summary of the System with Distributed Generation at 675**

<b>System Input</b>	<b>Phase A</b>	<b>Phase B</b>	<b>Phase C</b>	<b>TOTAL</b>
kW	1076.202	840.5055	1159.676	3076.384
kVAr	586.1502	321.1395	576.0142	1483.304
kVA	1225.472	899.7673	1294.852	3415.309
PF	0.8884	0.9541	0.9195	0.92
<b>System Lossess</b>	<b>Phase A</b>	<b>Phase B</b>	<b>Phase C</b>	<b>TOTAL</b>
kW	33.63202	-4.03942	65.92158	95.51418
kVAr	131.2231	36.30662	111.671	279.2016
kVA	135.4646	36.53108	129.6768	295.0866



**Figure 3. IEEE 13 Node Test Feeder**

## CONCLUSION

In the present work, computationally efficient and numerically robust distribution flow equations are used for the power flow solution of distribution system with distributed generation. The problem is formulated as non-linear optimization programming, where the objective is to minimize the real power losses. The constraints are the power balance equations and voltage balance equations.

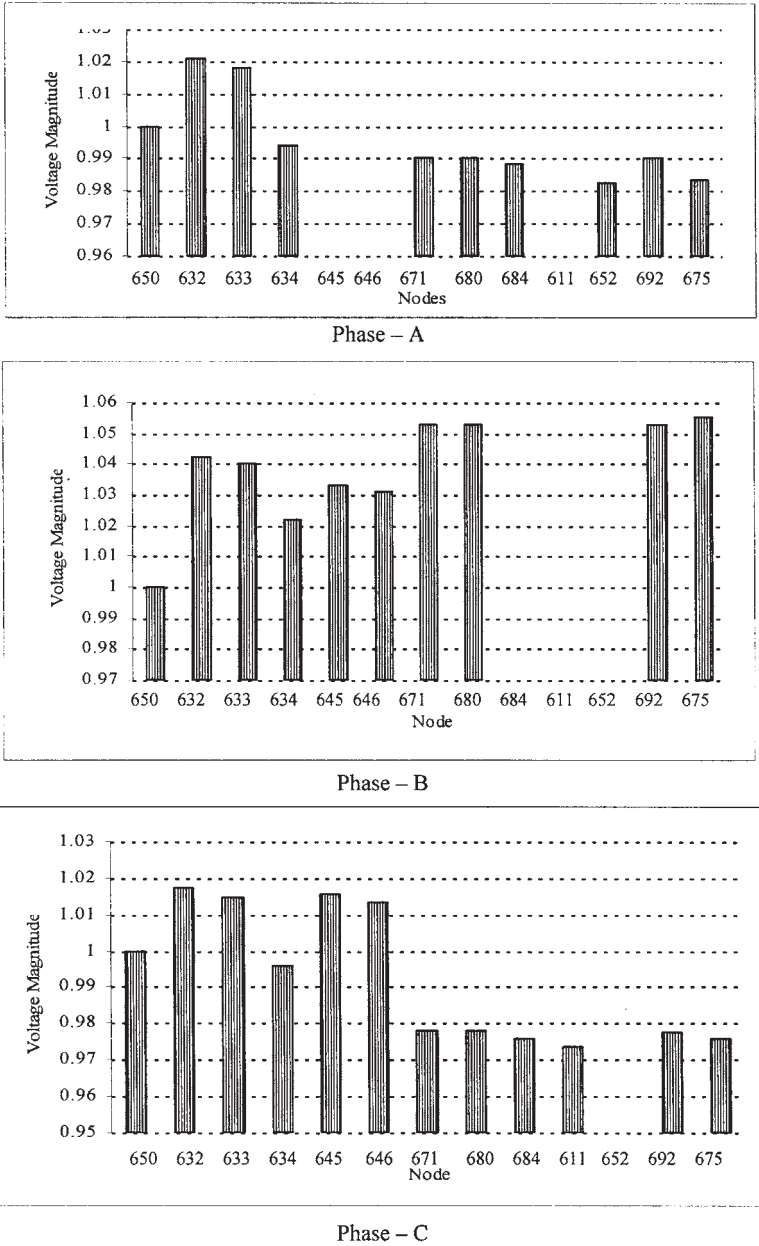


Figure 4. Voltage profile of the system without DG

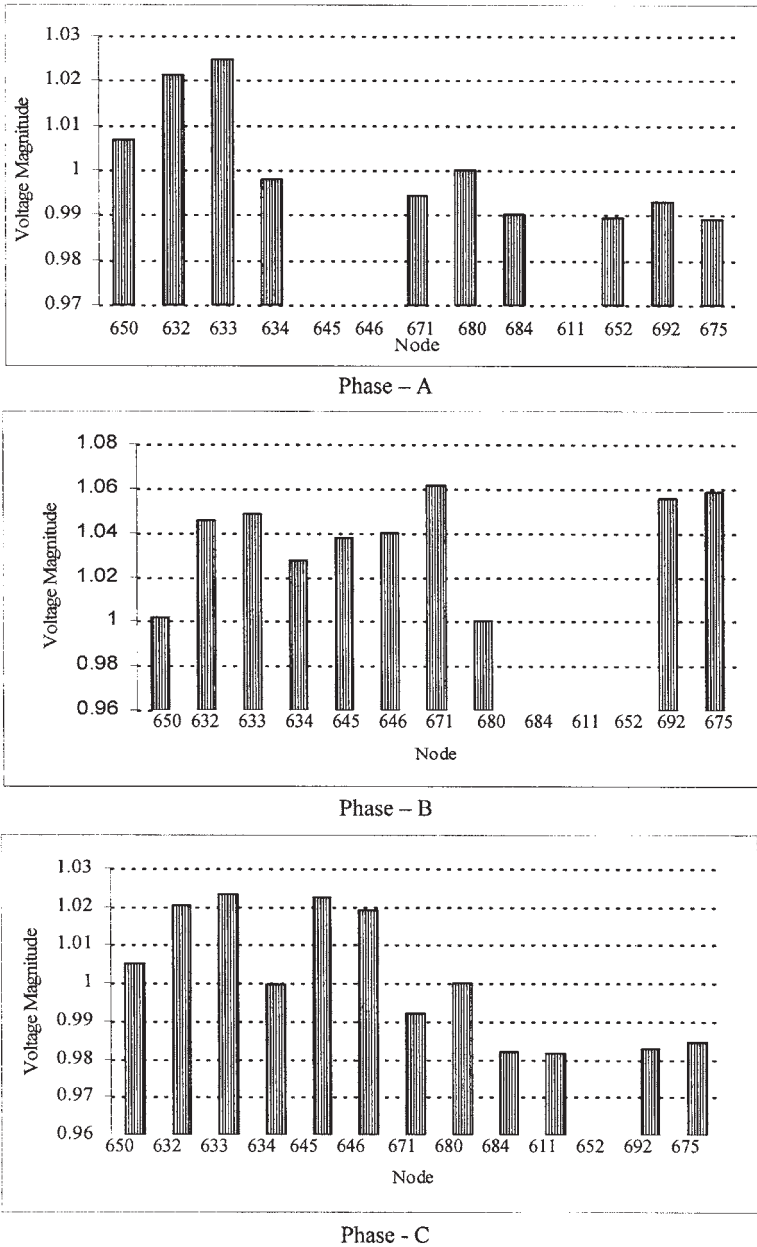
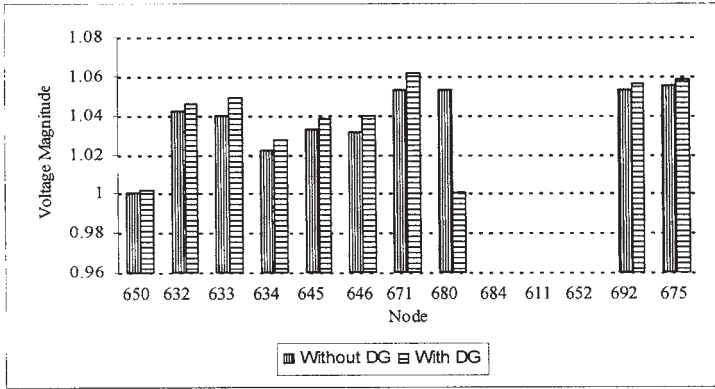
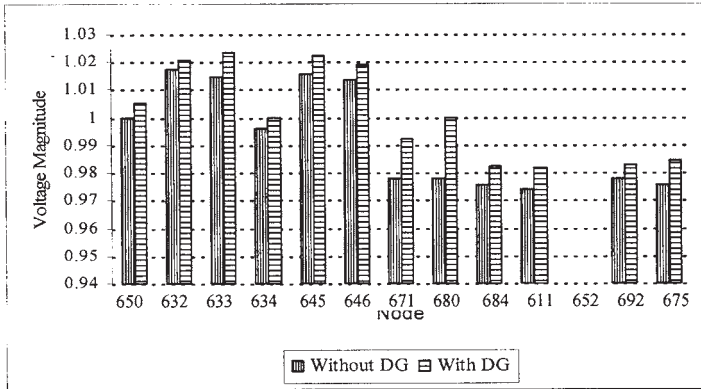


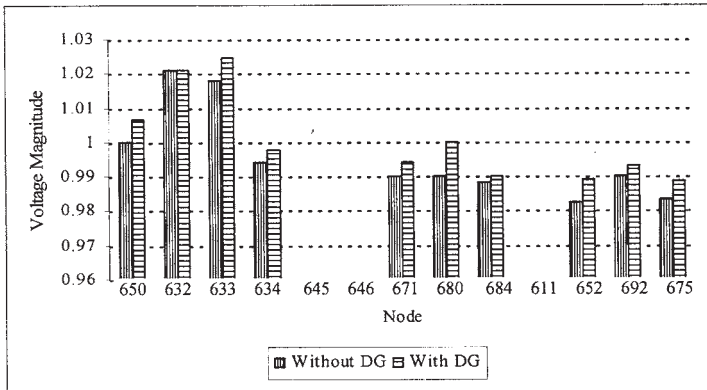
Figure 5. Voltage profile of the system with DG at Node - 680



Phase - A

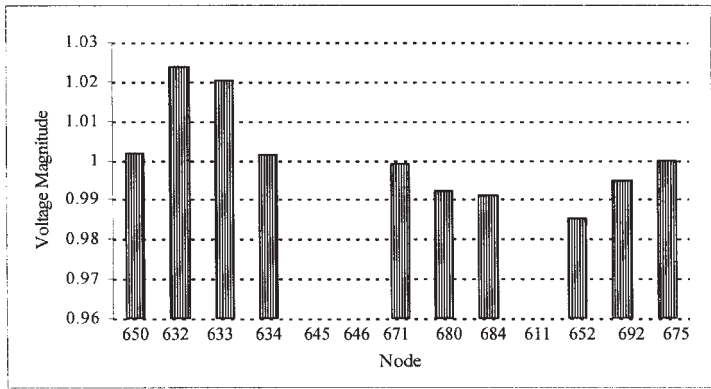


Phase - B

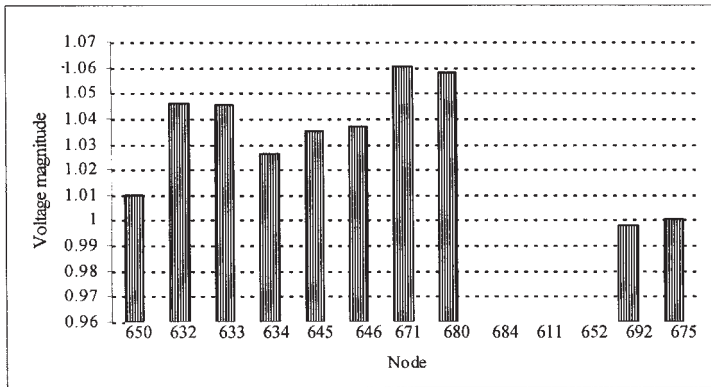


Phase - C

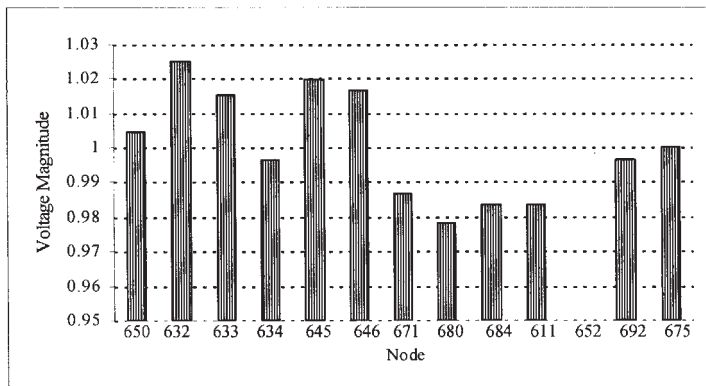
Figure 6. Comparison of Voltage Profile of the system without DG and with DG (At Node 680)



Phase - A

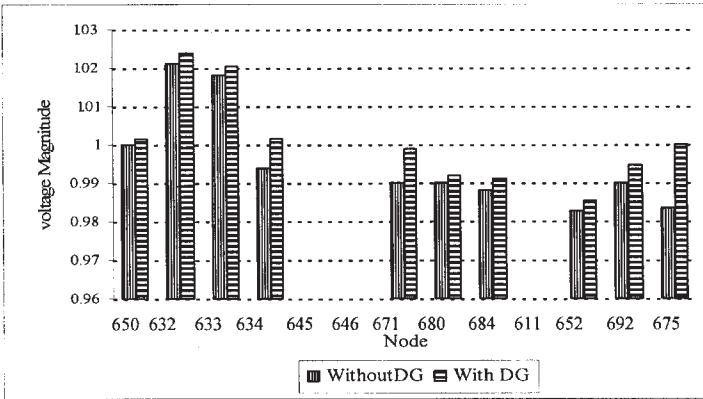


Phase - B

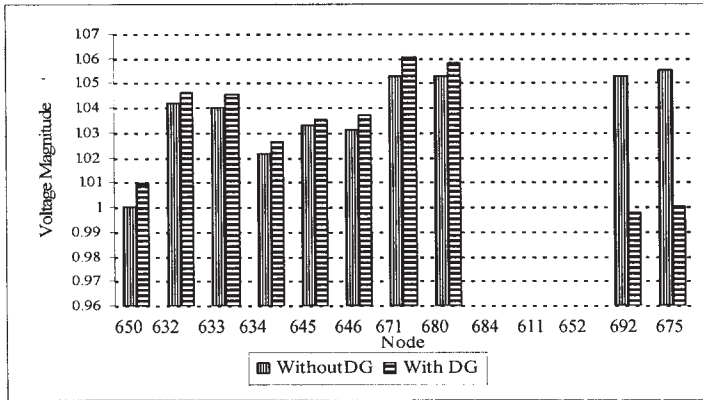


Phase - C

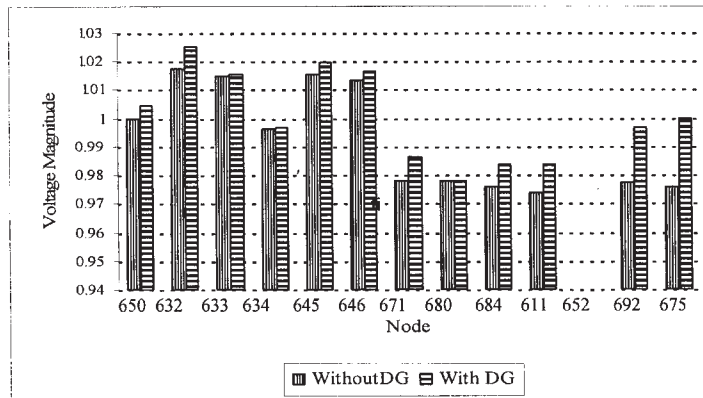
**Figure 7.**  
Voltage  
profile of  
the system  
with DG at  
Node - 675



Phase - A



Phase - B



Phase - C

Figure 8. Comparison of Voltage Profile of the system without DG and with DG (At Node 675)

Figure 9. Losses of the system without DG

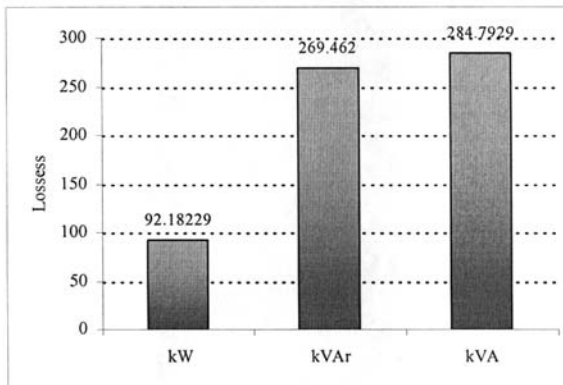
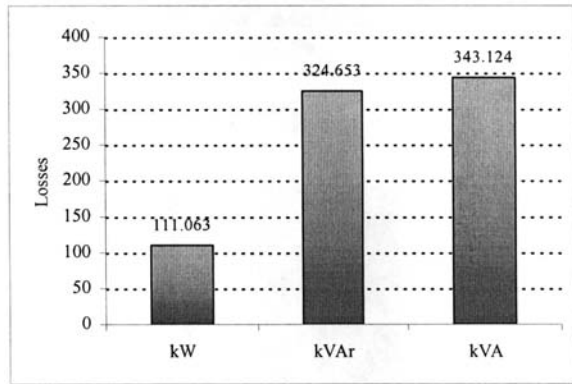


Figure 10. Losses of the system with DG (At Node 680)

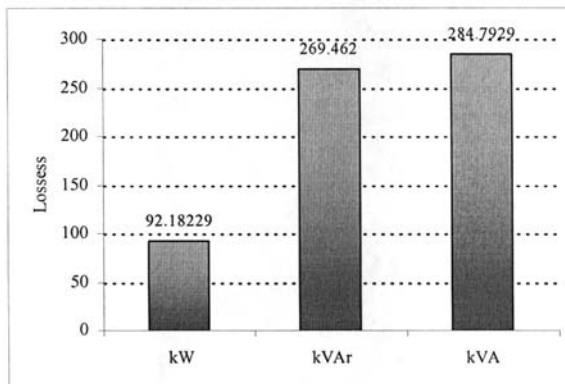


Figure 11. Losses of the system with DG (At Node 675)

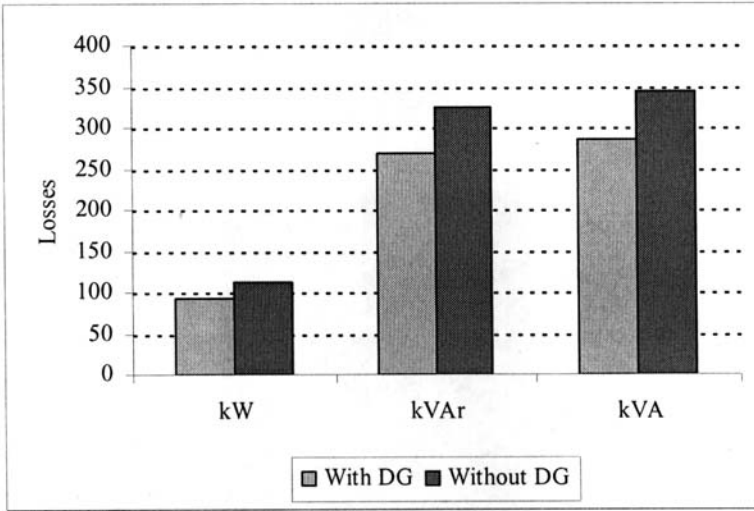


Figure 12. Comparison of System Losses without DG and with DG at Node 680

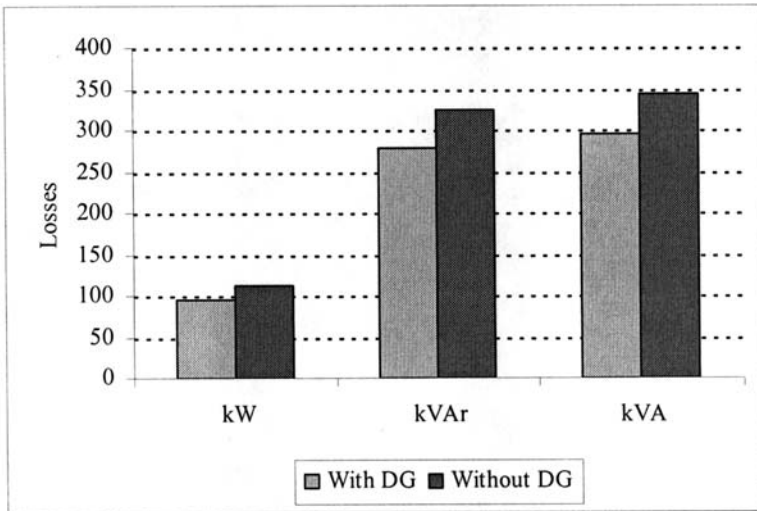


Figure 13. Comparison of System Losses without DG and with DG at Node 675

The upper and lower limits of voltages are considered. DG is considered to be connected at some of the busses. The non-linear programming is solved by Newton's method. The effects of distributed generation on the system voltage profile and losses have been analyzed. The system is simulated for different cases of distributed generation and a comparative study of the system with DG and without DG is carried out. The study reveals that, with the incorporation of DG, the system voltage profile improves to a greater extent and also the system loss is minimized extensively. The results show that the voltage profile is improved and losses are reduced when DG is incorporated in the system. This is because DG supplies a portion of real and reactive power to the load. Thus, the feeder current reduces from the source to the DG location, resulting in lower electrical line loss. The methodology is applied to the IEEE-13 bus distribution test system.

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