Optimal Location and Sizing of Distributed Generation In a Power Distribution System

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ABSTRACT

Modern electric power distribution utilities are continuously under pressure for expansion of their networks in order to face the load growth and to properly supply their consumers. To meet these objectives, there is a need to provide acceptable climate for the entry of distributed resources and innovative operating practices. This article focuses on determining the effect of inserting a Distributed Generation (DG) unit in a power distribution system in India. The effect on the system voltage profile and line losses is evaluated. This has been accomplished by modeling the connection of a DG unit to different distribution buses and varying the DG unit size in a 13-bus test feeder. A financial evaluation has been carried out to examine implementation viability. The results show that the voltage profile is improved, losses are reduced and consequently the utility can obtain financial benefits when DG is incorporated into the system.

Keywords: distributed generation, optimal location, optimal sizing, load growth, cost benefit analysis, voltage profile, line losses

INTRODUCTION

The recent deregulated environment faced by electric utilities in India and other developing countries, particularly by distribution companies, is a challenge as well as an opportunity for adoption of a variety of new technologies and operating scenarios. Distributed generation (DG) is one such rapidly growing technology [1]. Distributed resources or more commonly known as Distributed Generation (DG) can be defined as electric power generation within distribution networks or on the customer side of the network. A number of technologies of DG have reached in a developed stage allowing for a large scale implementation within existing electric utility system [2]. The development and growing interest in renewable sources of energy such as wind, solar, geothermal, biomass, ocean and even small hydro, all over the world, make these technologies suitable for integration into distribution network [3].

In recent years, research for assessing the performance of distribution system having distributed generation has accelerated and various methodologies have been proposed. A general formulation of the feeder reconfiguration problem for loss reduction and load balancing has been proposed [4]. This formulation employs a search over different radial configurations created by considering branch exchange type switching. The voltage profile improvement in a distribution system has been highlighted [5].

The contribution of DG on loss reduction is presented in relation with the DG rating, location, and operating power factor [6]. A non linear programming method for loss minimization is presented in [7]. A power flow algorithm has been developed based on the current summation backward-forward technique. 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 in [8].

A new heuristic approach for DG capacity investment planning from the perspective of a distribution company is presented [9]. Optimal sizing and sitting decisions for DG capacity is obtained through a cost-benefit analysis approach based on a new optimization model. The model aims to minimize the distribution companies investment and operating costs as well as payment towards loss compensation. Taking account of the mutual impacts of distribution generation, reactive power and network—configuration planning, a new and more comprehensive distributed—generation—planning problem is defined [10]. By solving this problem the amount of distributed—generation resources (DGR_S) and reactive—power sources (RPS_S) in selected buses of a distribution system are determined taking account of their output and different load level. Analytical methods to determine the optimal location, to place a DG in radial as well as networked systems are proposed to minimize the power loss of the system [11]. The proposed approaches are not iterative algorithms, like power flow programs. Therefore, there is no convergence problems involved.

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 has been proposed to identify the impact of grid—connected DG on the reliability of on—site electric power [12]. The analysis shows the optimal DG mix at various facility outage costs with and without an emission restriction. An algorithm using *evolutionary programming* for the allocation and sizing of generators in radial distribution network is presented to maximize the reduction on load supply costs [13]. The algorithm helps improve the voltage profile and reducing losses through optimal placement and sizing of DG units. The above methodologies either employ a sophisticated procedure which needs more computation time or suffer lack of convergence.

In this work, a simple method has been presented to assess the loss in a typical radial distribution line and the drop in voltage at remote end load points calculated. A radial 13-bus distribution test feeder is used. The line loss and improvement in voltage has been calculated in all the buses of the above feeder with a standard load and the same has been calculated after connecting a suitable distributed generator in a bus towards the middle-end of the line by trial and error method for optimal benefit. The effect of DG on the system voltage profile and loss has been analyzed, financial benefits have been assessed. Cost-benefit analysis has been carried out and payback period of capital investments in DG project has been estimated.

SYSTEM UNDER STUDY

A 13-bus 11kv radial distribution feeder is used as a test network to analyze the loss of power in distribution network due to line resistance and effects of addition of DG, on voltage profile improvement on buses and reduction of line loss. Figure 1 shows a 13-bus, 11kv three-phase network of radial feeder typical to that used by a distribution company of India. The buses on the main feeder are numbered as 1, 2, 3 ...12, 13. From each bus all the outgoing sub feeders are represented as single equivalent feeder and those are shown as A, B, C… M.

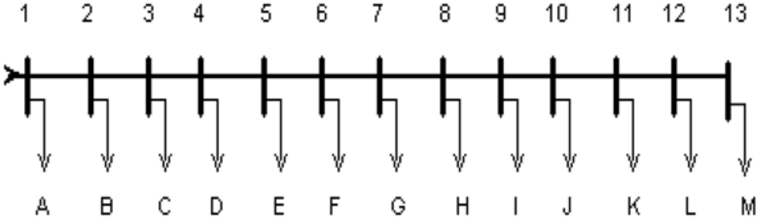
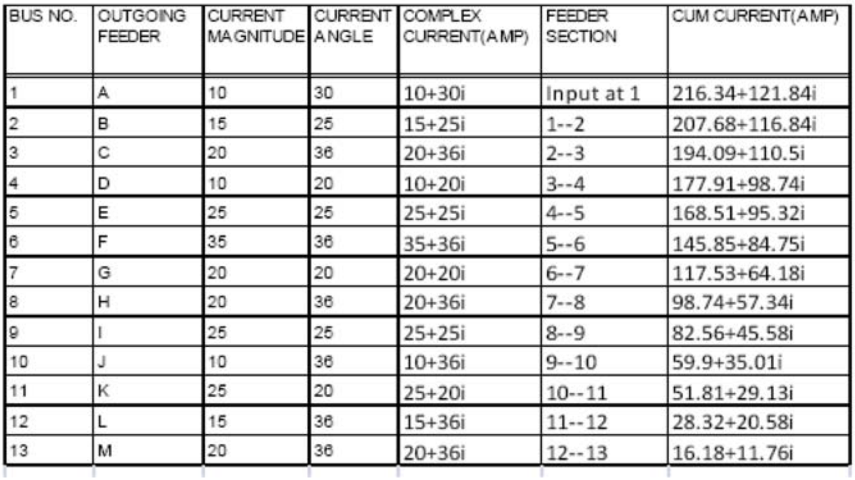


Figure 1. 13-bus 11kv radial distribution test feeder

The current drawn by each feeder depends on the load of the locality to which it feeds. Total current is fed from starting end i.e. bus '1' to end. The current in each feeder in its magnitude, phase angle with respect to the voltage and in its complex form are shown in Table 1. The current in each section of main feeder is the summation of currents in all feeders succeeding that section e.g. in Figure 1 current in section 8-9 is the summation of the currents in feeders 9, 10, 11, 12 and 13. The value of cumulative current in each feeder section is also shown in Table 1. As a practical field representation, a three phase radial distribution line of length 34 km (1 to 13) using 'RABBIT' type conductor is taken in to

Table 1. Current in 13-bus 11kv radial distribution test feeder



BUS NO.	OUTGOING FEEDER	CURRENT MAGNITUDE	CURRENT ANGLE	COMPLEX CURRENT(AMP)	FEEDER SECTION	CUM CURRENT(AMP)
1	A	10	30	10+30i	Input at 1	216.34+121.84i
2	B	15	25	15+25i	1--2	207.68+116.84i
3	C	20	36	20+36i	2--3	194.09+110.5i
4	D	10	20	10+20i	3--4	177.91+98.74i
5	E	25	25	25+25i	4--5	168.51+95.32i
6	F	35	36	35+36i	5--6	145.85+84.75i
7	G	20	20	20+20i	6--7	117.53+64.18i
8	H	20	36	20+36i	7--8	98.74+57.34i
9	I	25	25	25+25i	8--9	82.56+45.58i
10	J	10	36	10+36i	9--10	59.9+35.01i
11	K	25	20	25+20i	10--11	51.81+29.13i
12	L	15	36	15+36i	11--12	28.32+20.58i
13	M	20	36	20+36i	12--13	16.18+11.76i

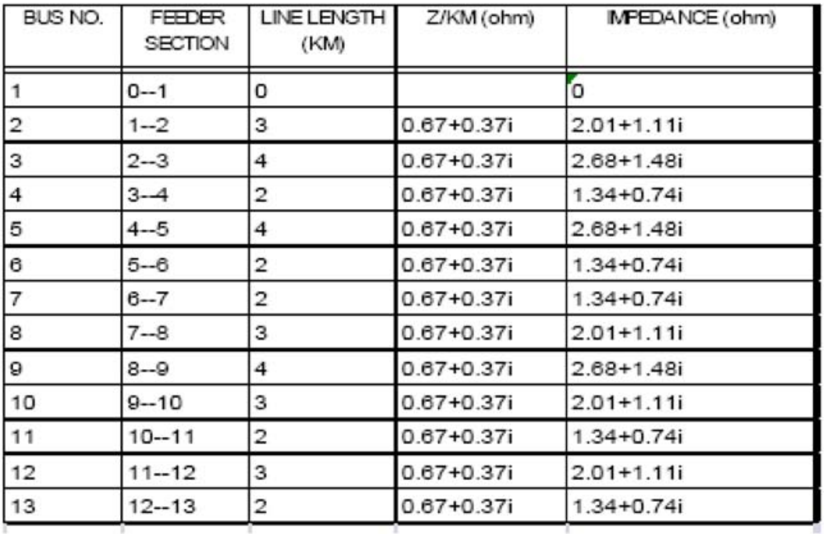
consideration.

Resistance and reactance per km are 0.67 Ohms and 0.37 Ohms respectively for such type of conductor. The impedance per km in complex form is determined by (1)

$$z = r + xi \text{ Ohm} = 0.67 + 0.37i \text{ Ohm} \tag{1}$$

Length of feeder section is multiplied by per unit impedance of the line to find out the impedance of that section of the line. The sectional length of the feeder and their impedance for sections 1-2 to 12-13 are given in Table 2. Figure 2 shows a suitable DG that can be connected at any one of the buses from bus 2 to bus 13.

Table 2. Length of feeder sections and their impedance



BUS NO.	FEEDER SECTION	LINE LENGTH (KM)	Z/KM (ohm)	IMPEDANCE (ohm)
1	0--1	0		0
2	1--2	3	0.67+0.37i	2.01+1.11i
3	2--3	4	0.67+0.37i	2.68+1.48i
4	3--4	2	0.67+0.37i	1.34+0.74i
5	4--5	4	0.67+0.37i	2.68+1.48i
6	5--6	2	0.67+0.37i	1.34+0.74i
7	6--7	2	0.67+0.37i	1.34+0.74i
8	7--8	3	0.67+0.37i	2.01+1.11i
9	8--9	4	0.67+0.37i	2.68+1.48i
10	9--10	3	0.67+0.37i	2.01+1.11i
11	10--11	2	0.67+0.37i	1.34+0.74i
12	11--12	3	0.67+0.37i	2.01+1.11i
13	12--13	2	0.67+0.37i	1.34+0.74i

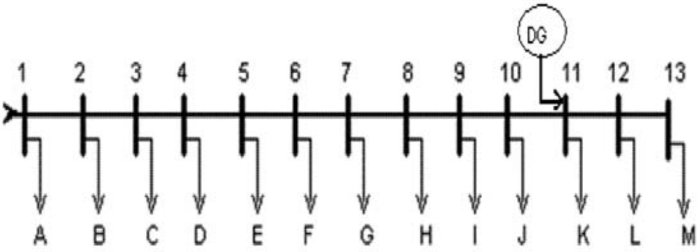


Figure 2. Radial distribution feeder with DG connected at bus no. 11

PROPOSED METHODOLOGY AND CALCULATION

In a radial distribution feeder such as the one under consideration, the line voltage decreases as we move from bus 1 to bus 13. The voltage drop is due to the impedance in the line and is equal to the multiplication of current and impedance of that section of feeder. The voltage drop is calculated by (2).

$$Vdrop = I \times Z \tag{2}$$

where I = line current and Z = R + jX, line impedance

The voltage at bus 1 is taken as 11kv, voltage at bus 2 is found out by subtracting voltage drop in feeder section 1-2 from bus 1 voltage. Subsequent bus voltage is found out by subtracting the voltage drop from the voltage of the previous bus. In this iterative process, the voltages of all the buses from 1to 13 are calculated.

Resistance of a conductor is the cause of power loss in the feeder mainly in the form of heat. The line loss in a three phase feeder is given by (3)

$$\text{Line loss} = 3 \times I^2 \times R \tag{3}$$

The total line loss is determined in terms of percentage of total power.

To find out the impact of DG, the DG unit is connected to one of the buses at a time and the effect on bus voltage and line losses are studied. Keeping the output capacity of DG constant, the position of the DG is changed from bus 1 to bus 13 and the effects on the above parameters are found out. Then the capacity of DG is changed and the same procedure is carried out for each variation of the capacity. The optimal position of DG in terms of the bus number is determined by the bus that yields minimum line loss. That is line loss reduction is maximum for each variation of capacity of the DG. Out of the above permutations and combinations of the size and location of DG tests, the one that is optimal and practically feasible is chosen as the solution. Cost benefit analysis is carried out considering present market value of the equipment, tariff, interest rate etc.

VOLTAGE DROP CALCULATION

From the equation (2) and from Table 1, current in feeder section 1-2 is calculated as

I = ∑ currents in feeders B to M
= (13.59+6.34i)+(16.18+11.76i)+(9.4+3.42i)+(22.66+10.57i)
+(28.32+20.57i)+(18.79+6.84i)+(16.18+11.76i)+(22.66+10.57i)
+(8.09+5.88i)+(23.49+8.55i)+ (12.14+8.82i)+ (16.18+11.76i)
=207.68+116.84i Amps

From Table 2, for the feeder section 1-2, impedance is calculated as

Impedance, Z =impedance/km X line length in km
= (0.67+0.37i) X3 = (2.01+1.11i) Ohm
Vdrop in line 1-2 = I x Z
= (207.68+116.84i) X (2.01+1.11i)
=287.74+465.37i Volt
Voltage in bus 2 = Voltage in bus 1– voltage drop
= (11000+0i) – (287.74+465.37i)
= 10712.25-465.37i

which is found to be 0.97 per unit (pu) of 11 kv i.e. bus 1 voltage.

In this manner, voltage in all the buses up to bus 13 has been calculated and found to be 0.95 pu, 0.93 pu, 0.91 pu, 0.91 pu, 0.90 pu, 0.89 pu,0.88 pu, 0.88 pu, 0.88 pu, 0.88 pu and 0.88 pu, respectively. The results for the system without DG are given in Table 3 and the voltage profile is plotted in Figure 3.

LINE LOSS CALCULATION

From eq. (3), and value of I and Z calculated above loss due to resistance in three phase line 1-2 = $3 \times I^2 \times R = 3$ X $(207.68 +116.841)^2$ X 2.01 = 342399 W. Similarly line losses are calculated in lines 2-3, 3-4, 4-5,…12-13 and all the losses are summated to get the total line loss which is equal to 1600054 W.

To measure the loss in terms of percentage of the total load i.e. total power supplied by the feeder, we calculate the power in each feeder as follows:

Load in feeder A = √3 × V × I × cosΘ
= real part of √3 × (11000+0i) (8.66+5i)
= 164,990 W

Load in rest of the feeders, B to M are calculated in the above manner and summed up to get the total load = 4,084,031 Watt = 4.08 MW.

Percentage of line loss is calculated as ratio of total line loss to the total load i.e. 1600054/4084031 X100 = 39.18%. The line losses for the system without DG are given in Table 3. The effects of addition of DG are now carried out as follows in the next section.

ADDITION OF DG

The location of DG is varied from bus 2 to bus 13 skipping bus 1, since it is the source bus. Note the addition of DG at bus 1 has no change of current in feeder sections. This is consistent with the "on-site" definition of DG. For each location from bus 2 to bus 13 the rated MW capacity of DG is varied from 10% to 80% of the total load in steps of 10%. For each case the total line loss (in terms of percentage of total load) and improvement in bus voltages are calculated. The results such as line losses, voltage profile for the system with DG capacity of 50% of total load at bus 5 and bus 10 is given in Table 4 and Table 5 respectively. The voltage profile for the system with DG capacity of 50% of total load at bus 5 and bus 10 is plotted in Figure 4 and Figure 5 respectively for illustration. The line losses for each case as mentioned above are summarized in Table 6.

Further, from Table 6 it is found that without DG, loss is 39.18% where as DG of 10% capacity produces minimal losses of 30.61% when connected at bus 13, similarly DG of 20% capacity produces minimal losses of 22.81% when connected at bus 12. All such results of optimal output are summarized in Table 7.

COST-BENEFIT ANALYSIS

The daily load curve of the test feeder is given in Figure 6. The load curve shows the amount of load in MW that the feeder supplies throughout a day and is plotted in MW versus hours. From the curve

Table 3. Line losses and voltage profile for the system without DG

SL NO.	LINE	COMPLEX CURRENT (Amps)	CUM CURRENT (Amps)	LINE LENGTH (km)	IMPEDANCE (Ohm)	DG CURRENT (Amps)	RESULTANT CURRENT (Amps)	V DROP	ABS VOLT	% VOLT	LINE LOSS (Watt)	POWER (Watt)
1	A	8.66+5i	216.34+121.84i	0	0	0	216.34+121.84i	0	11000	100%	0	164990.32
2	B	13.59+6.34i	207.68+116.84i	3	2.01+1.11i	0	207.68+116.84i	287.7444+465.3732i	10722.35945	97%	342398.89	257253.9941
3	C	16.18+11.76i	194.09+110.5i	4	2.68+1.48i	0	194.09+110.5i	356.6212+583.3932i	10408.6058	95%	401044.67	311565.4227
4	D	9.4+3.42i	177.91+98.74i	2	1.34+0.74i	0	177.91+98.74i	165.3318+263.965i	10274.50879	93%	166434.25	173682.1643
5	E	22.66+10.57i	168.51+95.32i	4	2.68+1.48i	0	168.51+95.32i	310.5332+504.8524i	10045.56889	91%	301351.44	421027.4381
6	F	28.32+20.57i	145.85+84.75i	2	1.34+0.74i	0	145.85+84.75i	132.724+221.494i	9958.048619	91%	114388.24	550741.6303
7	G	18.79+6.84i	117.53+64.18i	2	1.34+0.74i	0	117.53+64.18i	109.997+172.9734i	9887.662635	90%	72088.141	339836.7066
8	H	16.18+11.76i	98.74+57.34i	3	2.01+1.11i	0	98.74+57.34i	134.82+224.8548i	9809.732688	89%	78615.903	315923.8494
9	I	22.66+10.57i	82.56+45.58i	4	2.68+1.48i	0	82.56+45.58i	153.8024+244.3432i	9725.33629	88%	71505.268	415985.0696
10	J	8.09+5.88i	59.9+35.01i	3	2.01+1.11i	0	59.9+35.01i	81.5379+136.8591i	9685.915003	88%	29026.672	158546.5899
11	K	23.49+8.55i	51.81+29.13i	2	1.34+0.74i	0	51.81+29.13i	47.8692+77.3736i	9663.028765	88%	14201.989	417950.8671
12	L	12.14+8.82i	28.32+20.58i	3	2.01+1.11i	0	28.32+20.58i	34.0794+72.801i	9652.658545	88%	7390.1196	238471.1487
13	M	16.18+11.76i	16.18+11.76i	2	1.34+0.74i	0	16.18+11.76i	12.9788+27.7316i	9648.884182	88%	1608.3618	318056.6074
									TOTAL -		1600053.9	4084031.808

VOLTAGE CHANGE -88% TO 88%,NO IMPROVEMENT. LINE LOSS/TOTAL POWER----- 39.18%

CAPACITY OF DG/TOTAL POWER- 0%

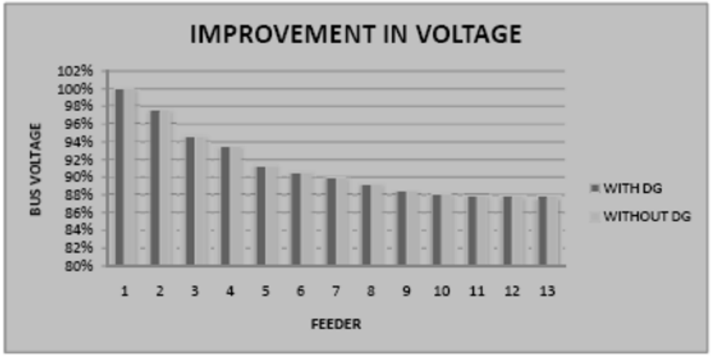


Figure 3. Voltage Profile for the System without DG

the demand of load varies from 2.5 MW during midnight hours, 5 MW during day time to 6 MW during evening hours. The average demand of load found out to be 4.08 MW.

Taking into consideration the discussion in "Addition of DG," we next consider the effect of variation of size of DG. It is observed that there is an appreciable reduction of line loss at the initial stages of DG addition, i.e. at 10% and 20% range and that the loss reduction decreases as the size reaches beyond 50%. Hence for optimal utilization, *a DG should be so chosen that it has to operate within the range below 50% of total load*.

A DG capacity of 30% of average load may be judiciously selected because when there is variation of total load in the feeder throughout the day, the DG will operate within the range of 20% to 50% of total load. The same is determined from the load duration curve of Figure 6 as follows.

Average load of the feeder = $\sum$ load in MW in each hour/24
=(3+2.5+2.5+2.5+2.5+3+3+3+4+4+5+5+5+5+5+5+4+4.5+5.5+6+6+5+4+3)/24
=98/24 = 4.08 MW
Capacity of DG selected = 4.08 MW X 30%
= 1.224 MW or say 1.25 MW.

From section 3.3, it is found that 30% DG capacity i.e. 1.25 MW (current rating of 67+15i) provides minimum line loss at bus 11. From Table 6 the line loss is found to be 17.18% (701.756 kW) when 30%DG capacity is connected to bus 11 and the line loss without DG is 39.18% (1600.054 kW). Hence the cost benefit analysis is carried out for the above selected DG capacity of 1.25MW being connected to bus 11.

Cost of 1.25 MW wind turbine-generator, fuel cell or reciprocating engine DG plant is assumed @ 20crore/MW = Rs. 25 crore. (This article refers to the Indian Currency: Rupees or Rs. A crore is a unit in the Indian numbering system that is equivalent to ten million or 107). When connected to bus the DG is not run at 100% of rated capacity throughout the day. The hourly loading pattern for 24 hours of a day on DG may be scheduled as

22-24hr and 00-04hr	(06hrs)	25% of rated capacity
04-08hr and 12-17hr	(09hrs)	50% of rated capacity
08-12hr and 17-22	(09hrs)	100% of rated capacity

Table 4. Line losses and voltage profile for the system with DG having capacity of 50% of total load at bus 5

SL NO.	LINE	COMPLEX CURRENT (Amps)	CUM CURRENT (Amps)	LINE LENGTH (km)	IMPEDANCE (Ohm)	DG CURRENT (Amps)	RESULTANT CURRENT (Amps)	V DROP	ABS VOLT	% VOLT	LINE LOSS (Watt)	POWER (Watt)
1	A	8.66+5i	216.34+121.84i	0	0	100+50i	116.34+71.84i	0	11000	100%	0	164990.32
2	B	13.59+6.34i	207.68+116.84i	3	2.01+1.11i	100+50i	107.68+66.84i	142.2444+253.8732i	10860.72319	99%	96857.285	257253.9941
3	C	16.18+11.76i	194.09+110.5i	4	2.68+1.48i	100+50i	94.09+60.5i	162.6212+301.3932i	10709.53877	97%	100605.95	311565.4227
4	D	9.4+3.42i	177.91+98.74i	2	1.34+0.74i	100+50i	77.91+48.74i	68.3318+122.965i	10648.42389	97%	33951.134	173682.1643
5	E	22.66+10.57i	168.51+95.32i	4	2.68+1.48i	100+50i	68.51+45.32i	116.5332+222.8524i	10548.82528	96%	54250.081	421027.4381
6	F	28.32+20.57i	145.85+84.75i	2	1.34+0.74i		145.85+84.75i	132.724+221.494i	10438.08553	95%	114388.24	550741.6303
7	G	18.79+6.84i	117.53+64.18i	2	1.34+0.74i		117.53+64.18i	109.997+172.9734i	10348.96145	94%	72088.141	339836.7066
8	H	16.18+11.76i	98.74+57.34i	3	2.01+1.11i		98.74+57.34i	134.82+224.8548i	10246.16119	93%	78615.903	315923.8494
9	I	22.66+10.57i	82.56+45.58i	4	2.68+1.48i		82.56+45.58i	153.8024+244.3432i	10133.77047	92%	71505.268	415985.0696
10	J	8.09+5.88i	59.9+35.01i	3	2.01+1.11i		59.9+35.01i	81.5379+136.8591i	10078.41284	92%	29026.672	158546.5899
11	K	23.49+8.55i	51.81+29.13i	2	1.34+0.74i		51.81+29.13i	47.8692+77.3736i	10046.36212	91%	14201.989	417950.8671
12	L	12.14+8.82i	28.32+20.58i	3	2.01+1.11i		28.32+20.58i	34.0794+72.801i	10027.59521	91%	7390.1196	238471.1487
13	M	16.18+11.76i	16.18+11.76i	2	1.34+0.74i		16.18+11.76i	12.9788+27.7316i	10020.60958	91%	1608.3618	318056.6074
									TOTAL -		674489.14	4084031.808

VOLTAGE IMPROVEMENT-88% TO 91% TOWARDS END BUSES

LINE LOSS/TOTAL POWER = 16.52%

DG IS CONNECTED IN BUS NO.-5

CAPACITY OF DG/TOTAL POWER = 50%

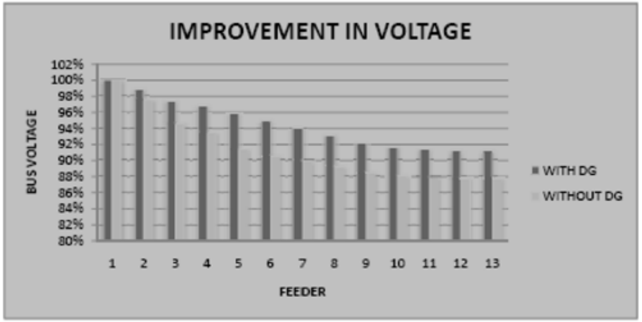


Figure 4. Voltage profile for the system with DG having capacity of 50% of total load at bus 5

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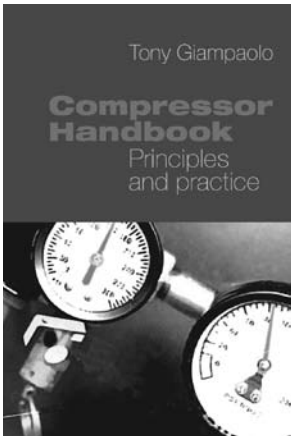

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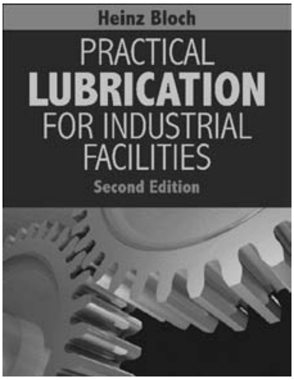

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Table 5. Line losses and voltage profile for the system with DG having capacity of 50% of total load at bus 10

SL NO.	LINE	COMPLEX CURRENT (Amps)	CUM CURRENT (Amps)	LINE LENGTH (km)	IMPEDANCE (Ohm)	DG CURRENT (Amps)	RESULTANT CURRENT (Amps)	V DROP	ABS VOLT	% VOLT	LINE LOSS (Watt)	POWER (Watt)
1	A	8.66+5i	216.34+121.84i	0	0	100+50i	116.34+71.84i	0	11000	100%	0	164990.32
2	B	13.59+6.34i	207.68+116.84i	3	2.01+1.11i	100+50i	107.68+66.84i	142.2444+253.8732i	10860.72319	99%	96857.285	257253.9941
3	C	16.18+11.76i	194.09+110.5i	4	2.68+1.48i	100+50i	94.09+60.5i	162.6212+301.3932i	10709.53877	97%	100605.95	311565.4227
4	D	9.4+3.42i	177.91+98.74i	2	1.34+0.74i	100+50i	77.91+48.74i	68.3318+122.965i	10648.42389	97%	33951.134	173682.1643
5	E	22.66+10.57i	168.51+95.32i	4	2.68+1.48i	100+50i	68.51+45.32i	116.5332+222.8524i	10548.82528	96%	54250.081	421027.4381
6	F	28.32+20.57i	145.85+84.75i	2	1.34+0.74i	100+50i	45.85+34.75i	35.724+80.494i	10520.43708	96%	13305.336	550741.6303
7	G	18.79+6.84i	117.53+64.18i	2	1.34+0.74i	100+50i	17.53+14.18i	12.997+31.9734i	10510.53191	96%	2043.6607	339836.7066
8	H	16.18+11.76i	98.74+57.34i	3	2.01+1.11i	100+50i	-1.260000000000	-10.68+13.3548i	10522.45711	96%	334.4431	315923.8494
9	I	22.66+10.57i	82.56+45.58i	4	2.68+1.48i	100+50i	-17.44-4.42i	-40.1976-37.6568i	10558.86899	96%	2602.4676	415985.0696
10	J	8.09+5.88i	59.9+35.01i	3	2.01+1.11i	100+50i	-40.1-14.99i	-63.9621-74.6409i	10615.86047	97%	11051.242	158546.5899
11	K	23.49+8.55i	51.81+29.13i	2	1.34+0.74i		51.81+29.13i	47.8692+77.3736i	10575.1472	96%	14201.989	417950.8671
12	L	12.14+8.82i	28.32+20.58i	3	2.01+1.11i		28.32+20.58i	34.0794+72.801i	10548.31849	96%	7390.1196	238471.1487
13	M	16.18+11.76i	16.18+11.76i	2	1.34+0.74i		16.18+11.76i	12.9788+27.7316i	10538.24494	96%	1608.3618	318056.6074
										TOTAL -	338202.07	4084031.808

VOLTAGE IMPROVEMENT-88% TO 95% IN LAST BUS.

DG IS CONNECTED IN BUS NO.-10

LINE LOSS/TOTAL POWER = 8.28%

CAPACITY OF DG/TOTAL POWER = 50%

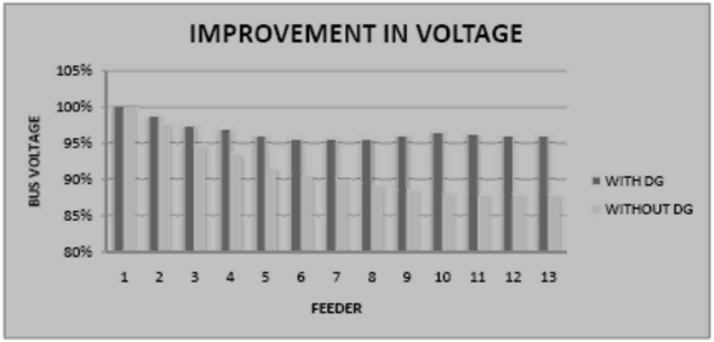


Table 6. Line losses for variation of DG capacity and DG position

BUS No. at which DG Connected	Rated capacity of DG in percentage of total load								
	0%	10%	20%	30%	40%	50%	60%	70%	80%
2	39.18	37.78	36.39	35.25	34.13	33.17	32.49	31.91	31.46
3	39.18	36.04	32.93	30.4	27.93	25.81	24.36	23.12	22.19
4	39.18	35.25	31.37	28.23	25.17	22.57	20.8	19.31	18.22
5	39.18	33.75	28.43	24.15	20	16.52	14.21	12.29	10.96
6	39.18	33.11	27.18	22.44	17.86	14.04	11.56	9.54	8.18
7	39.18	32.6	26.22	21.16	16.23	12.33	9.8	7.81	6.56
8	39.18	31.98	25.05	19.65	14.53	10.41	7.95	6.13	5.15
9	39.18	31.3	23.83	18.13	12.83	8.72	6.49	5.05	4.6
10	39.18	30.95	23.24	17.49	12.21	8.28	6.37	5.38	5.47
11	39.18	30.76	22.94	17.18	11.97	8.2	6.55	5.81	6.37
12	39.18	30.63	22.81	17.23	12.28	8.91	7.78	7.77	9
13	39.18	30.61	22.85	17.44	12.74	9.71	8.99	9.47	11.25

Table 7. Summary of minimal line losses for variation of DG capacity and DG position

SL.NO.	DG CAPACITY	DG IN BUS NO.	LINE LOSS	BUS VOLT (PU)
1	**0%**		**39.18%**	**0.88**
2	10%	13	30.61%	0.91
3	20%	12	22.81%	0.93
4	30%	11	17.18%	0.95
5	40%	11	11.97%	0.96
6	50%	11	8.20%	0.97
7	60%	10	6.37%	0.97
8	70%	9	5.05%	0.98
9	80%	9	4.60%	1

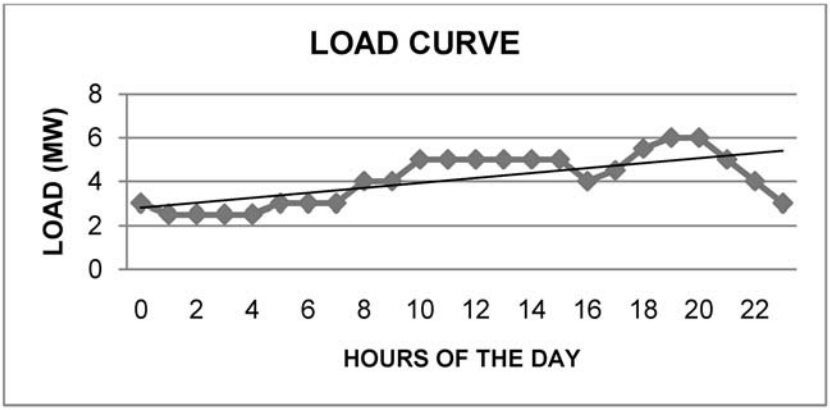


Figure 6. Daily load curve of test feeder

(i) Plant load factor for a day = capacity utilization of DG throughout the day =∑(Duration in hours X % of rated capacity utilization)/24 = (6X0.25+9X0.5+9X1)/24= 0.625= 62.5%

(ii) The loading pattern may vary but we will consider the plant load factor as 62.5 % for all our calculation purposes.

(iii) kW hr loading of DG = rating of DG in kW X hours of a day X plant load factor = 1250X24X0.625=18750 kWhr=18750 units per day

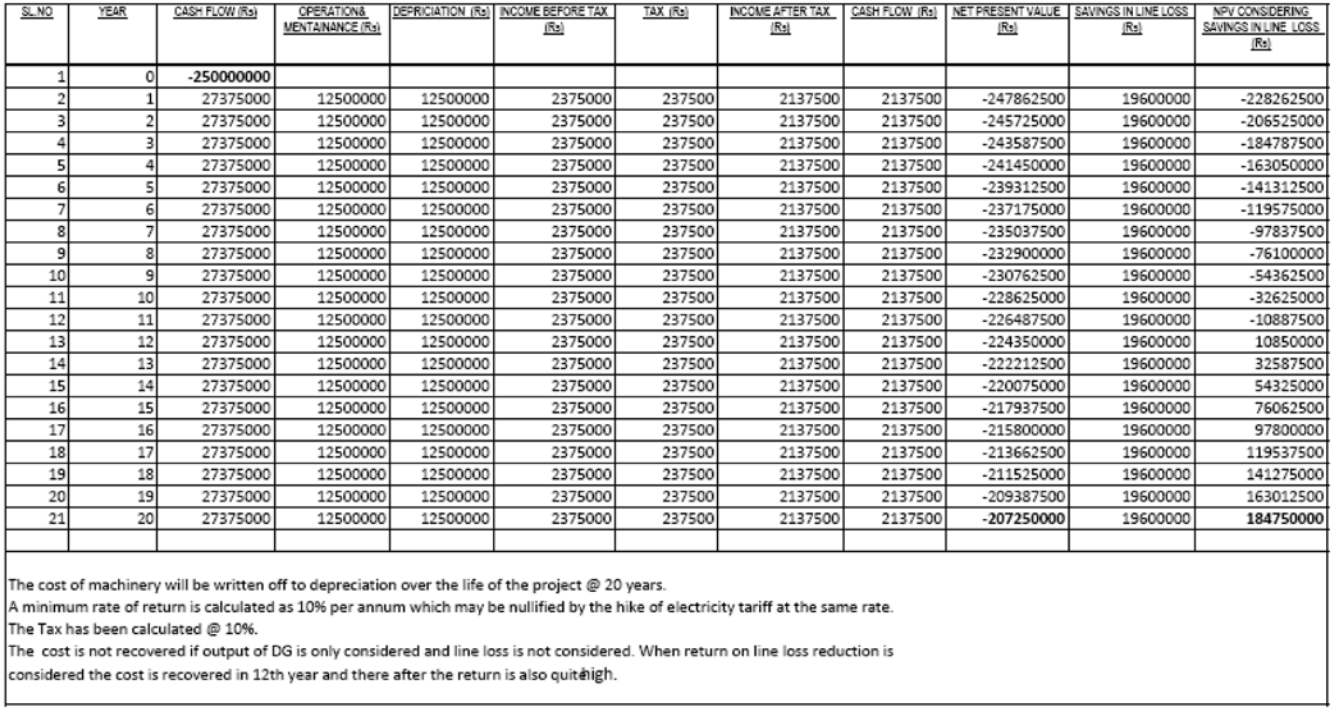
Income from the DG has two aspects, one is income from energy generated and the other is from energy saving due to reduction of line loss. These two incomes are calculated as follows:

(i) From above, 18750 units per day, calculated @4.00/unit which is the tariff at prevailing rate of distribution company for domestic consumers for a year,
= Rs.4X18750 units per dayX365 days = Rs27,375,000

(ii) Due to the improvement in line loss, saving in power may be calculated from line loss without DG calculated in section 3.2 and loss with DG calculated in section 3.3 and 3.4.
Reduction in line loss =line loss without DG line loss using DG =1600054-701756 =898.298 kW

Above kW saving is when the DG runs at full load

Table 8. Cost benefit analysis for the system having DG capacity of 30% of total load at bus 11



SL.NO	YEAR	CASH FLOW (Rs)	OPERATION& MENTAINANCE (Rs)	DEPRICIATION (Rs)	INCOME BEFORE TAX (Rs)	TAX (Rs)	INCOME AFTER TAX (Rs)	CASH FLOW (Rs)	NET PRESENT VALUE (Rs)	SAVINGS IN LINE LOSS (Rs)	NPV CONSIDERING SAVINGS IN LINE LOSS (Rs)
1	0	**-250000000**									
2	1	27375000	12500000	12500000	2375000	237500	2137500	2137500	-247862500	19600000	-228262500
3	2	27375000	12500000	12500000	2375000	237500	2137500	2137500	-245725000	19600000	-206525000
4	3	27375000	12500000	12500000	2375000	237500	2137500	2137500	-243587500	19600000	-184787500
5	4	27375000	12500000	12500000	2375000	237500	2137500	2137500	-241450000	19600000	-163050000
6	5	27375000	12500000	12500000	2375000	237500	2137500	2137500	-239312500	19600000	-141312500
7	6	27375000	12500000	12500000	2375000	237500	2137500	2137500	-237175000	19600000	-119575000
8	7	27375000	12500000	12500000	2375000	237500	2137500	2137500	-235037500	19600000	-97837500
9	8	27375000	12500000	12500000	2375000	237500	2137500	2137500	-232900000	19600000	-76100000
10	9	27375000	12500000	12500000	2375000	237500	2137500	2137500	-230762500	19600000	-54362500
11	10	27375000	12500000	12500000	2375000	237500	2137500	2137500	-228625000	19600000	-32625000
12	11	27375000	12500000	12500000	2375000	237500	2137500	2137500	-226487500	19600000	-10887500
13	12	27375000	12500000	12500000	2375000	237500	2137500	2137500	-224350000	19600000	10850000
14	13	27375000	12500000	12500000	2375000	237500	2137500	2137500	-222212500	19600000	32587500
15	14	27375000	12500000	12500000	2375000	237500	2137500	2137500	-220075000	19600000	54325000
16	15	27375000	12500000	12500000	2375000	237500	2137500	2137500	-217937500	19600000	76062500
17	16	27375000	12500000	12500000	2375000	237500	2137500	2137500	-215800000	19600000	97800000
18	17	27375000	12500000	12500000	2375000	237500	2137500	2137500	-213662500	19600000	119537500
19	18	27375000	12500000	12500000	2375000	237500	2137500	2137500	-211525000	19600000	141275000
20	19	27375000	12500000	12500000	2375000	237500	2137500	2137500	-209387500	19600000	163012500
21	20	27375000	12500000	12500000	2375000	237500	2137500	2137500	**-207250000**	19600000	**184750000**

The cost of machinery will be written off to depreciation over the life of the project @ 20 years.
A minimum rate of return is calculated as 10% per annum which may be nullified by the hike of electricity tariff at the same rate.
The Tax has been calculated @ 10%.
The cost is not recovered if output of DG is only considered and line loss is not considered. When return on line loss reduction is considered the cost is recovered in 12th year and there after the return is also quite high.

Calculating the income in the same manner as in (i) for a day and then multiplying by 365 to find out for a year

= Rs.4 X 898.298 units X 0.625 (PLF) X 24 X 365 days

= Rs19672726 Rs19,600,000

The cost benefit analysis results are given in Table 8. It is assumed that the cost of equipment will be written off to depreciation over a project life of 20 years. A minimum rate of return is 10% per annum which may be nullified by the hike of electricity tariff at the same rate. The tax has been considered @ 10%. It is observed that the cost is not recovered if output of DG is only considered and the return on line loss improvement is not considered. At the end of 20th year n.p.v is Rs(-)207,250,000. when return on line loss reduction is considered, the cost is recovered in 12th year and there after the positive return at the end of 20th year is Rs 184,750,000 which represents a profitable operation.

DG LIMITATIONS

Not all the DG technologies are suitable for all purposes. For example wind turbines cannot be installed in areas where there is no steady wind or in hurricane or cyclone prone areas. 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 micro turbines that their technologies will eventually prove to be inexpensive and reliable as they have projected they will be. In reality it will require 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.

CONCLUSIONS

In this article the impact of DG on distribution system has been studied. Using a long radial feeder and a DG of 30% of total load, the voltage profile in the buses and loss due to line resistance has been analyzed. For optimal utilization, a DG should be so chosen that it has to operate within the range below 50% of total load. Profits have been estimated in financial terms by doing a cost-benefit analysis for a DG with 20 years of useful life. It was determined that a distribution company may not make profit by merely utilizing DG as an power generator and energy supplier. However, DG will yield a have huge financial gain if a suitable size DG plant is strategically placed in the distribution system and the resulting savings obtained from the line loss are considered. Other intangible or harder to quantify benefits are voltage stability improvement and reliability of the overall power system. IN this case, the cost will be recovered in 12th year when the organization will make a profit. Please note that while the underlying method for modeling and evaluating DG in a distribution system can be applied elsewhere, the financial results obtained herein can't be generalized and are mainly valid for the underlying case study in India.

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