Optimal Integration of Distributed Generation in Primary Distribution System and its Economics

Vani Bhargava, S K Sinha, M P Dave

Abstract*: The paper analyses four types of DG (distributed generators) for their optimal placement in primary distribution system. They are sited and sized optimally to obtain maximum loss reduction. The ultimate objective of the adopted work in this paper is to identify the size and location of distributed generators for their placement in primary distribution network and to justify the economics of these placements. To serve the purpose, an analytical method is used in this paper for determination of sizes and sites for four DG types. The analytical method is considered suitable for the analysis purpose in proposed work. The paper presented a comprehensive analysis for four types of DGs for their placement in primary distribution system. The type 1 DG is capable of delivering real power only whereas type 3 DG is capable of providing real as well as reactive power to the distribution network. Out of other two types, type 2 can deliver only the reactive power whereas type 4 supplies active power but at the same time it consumes reactive power. The paper compares the economic feasibility of placement of four DG types in primary distribution system.

***Index Terms*: Distributed Generation, Distribution System,Economics, Optimal Placement**

I. INTRODUCTION

In recent years, electricity market liberalization, constraints on erecting new transmission lines, carbon footprint reduction requirement due to environmental concerns, reduction of fossil fuel generation and motivating renewable energy generation, caused an increased penetration of distributed resources in distribution system [1].

Generating plant connected to the distribution system directly is termed as the distributed generation or dispersed generation [2]. The dispersed generation can supply consumer load directly as it is connected at the consumer's end. Distributed/dispersed generation improves the quality and reliability of power distribution network. As generation is placed nearer to its utilization point, line losses as well as line voltage drop are also reduced.

It is observed that about 75% of total system losses take place in distribution system. The reason of higher system losses in distribution system is lack of adequate investments in the same. Also the distribution system is overloaded and has insufficient reactive power support. And the distribution network contains almost 90% of total system length [3].

A distribution feeder is the part of distribution system tailored to supply the load locations and needs. There are three types of feeder systems: radial, loop feeder and ring feeder network. Radial feeders have lowest cost and they are easy to analyze although reliability of this system is low. Feeders can be constructed and operated to form a loop and they can be tapped to supply the consumers. There is a point in the loop where power flow is zero. Feeder network is made up of a group of interconnected feeders so connected that there is always more than single root between two points in the network. Loop feeders are designed with to accommodate sufficient capacity protection throughout the feeder length. The reliability provided to consumer by this system is very high but the cost of the system is also high [3].

Worldwide, more than 80% of electricity distribution is accomplished by the radial distributors having only one path between any consumer and substation. The effectiveness of the distribution system in fulfilling its function is measured by means of voltage regulation, reliability and upon cost.

To mitigate some of the problems associated with the distribution system, distributed generation could be considered as the most viable one and in addition to the same it can meet the ever-increasing electricity demand on the system.

The distributed generation involves smaller sized generators than the central power generating facilities [4].

A large number of definitions are given for distributed generation. Because of large variation in definitions it is better to consider some factors while defining DG. These factors may include purpose of connecting DG, its location, their ratings, the area in which power is delivered, the technology employed, its impact on environment, mode of their operation, ownership of DG plant, its penetration in the system etc. In terms of ratings or size of DG, various agencies define them in a variety of ways. For example EPRI (Electric Power Research Institute) defined DG as a source of generation extending from a few kW to 50 MW. As per GPI (Gas Research Institute) it is the generation between 25 kW to 25 MW capacity. Preston and Rastler defines the same as generation that ranges from few kW to 100 MW. As per another author Cardell, it is defined as the capacity that ranges between 500 kW upto 1 MW [5]. CIGRE gives its range as capacities smaller than 50-100 MW.

The paper has taken DG capacity and its location as the factors for optimization of DG placement cost. After defining DG based upon their power rating, let it be defined based upon the location. So based upon this criterion the DG is defined by some authors as a source of power connected to the distribution system network. Some authors define it as the source connected directly to the customer end and some include it even in the transmission system. But it is basically the local generation connected to the distribution network. So it can precisely be defined as the electric

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power generation units installed and operated directly in the distribution system which is the customer's side of electric power system.

These generators are distributed throughout the power system but in vicinity to the load. If defined loosely, they are the electricity generators involved in small scale electricity generation. They seem to be comparatively new technology, but the concept as applied to present system is only new. The earliest power stations were actually the generators to supply local load. They were connected to the system where load was also connected. After technology evolution, the concept of transmission grid came in and the generators later on became the central power generating facilities. Then it became possible to transmit the electricity over long distances. The generating facilities were placed near the resource site, electricity generation started in bulk and all this resulted in a reduction in per unit electricity price.

From last decade or so, a renewed interest, resulted from the newer version of electricity market and its changing regulations and economics, in small scale electricity generation or the distributed generation is evolved [6].

The performance of distribution lines is determined by line efficiency and line voltage regulation. The efficiency of line can be determined as

Power delivered at receiving end / (Power delivered at receiving end +line losses)

In the similar way voltage regulation is defined as change in receiving end voltage, expressed as a percentage of full load voltage, from no load value to full load value while sending end voltage is kept unchanged. About 75% of total losses occur along the distribution system. A reduction in distribution system loss can result in energy saving in a substantial amount and at the same time it will cause an increment in system power capacity, resulting from reduced system losses. Various ways for reducing system losses are :

1. Optimization of line capacity,
    a. selecting appropriate kVA-km
    b. selecting appropriate MW-km capacity
2. Optimizing transformer capacity location and use

The losses in distribution system can also be reduced by optimal placement of distributed generators [7]. Optimal placement of distributed generators in system acts as active and reactive power compensation in the system and relieves the substation capacity. As DGs are local generators in distribution system the length of power flow reduces causing an improvement in system voltage profile and a reduction in losses [20],[21],[22].

II. DISTRIBUTION SYSTEM AND DISTRIBUTED GENERATION

The number of electricity units generated is not same as the number of electricity units utilized. A percentage of these units are lost in the system connecting generation with the consumer, i.e. in transmission and distribution networks. The amount of units lost in the system is not paid by the consumers. Total percentage of T& D losses in the system is given as =[Feeder input energy (kWh)- Energy billed at consumer's end (kWh)]*100 / Feeder input energy (kWh)

Total T& D losses are categories as:

a. Technical losses
b. Commercial or non-technical losses

Technically losses amount to 22.5% and out of these losses the main contributors are the primary and secondary distribution system. Transmission and sub-transmission system contribute to approximately 30% of total technical loss.

Technical losses are further divided into two categories of fixed and variable losses. Fixed losses do not vary with current. They typically amount between 1/3 to ¼ of the losses.

They are due to corona losses, dielectric losses, losses due to continuous loading of measuring instruments, due to control elements load etc.

The variable losses are current dependent losses and hence they are dependent upon the amount of energy distributed. These losses amount between 2/3 and ¾ of total technical losses.

Fixed losses remain fixed but variable losses can be reduced by proper choice of distributed generator (DG) when placed in the distribution system. DGs are classified based upon the type of power they can deliver. They are categorized as type 1 to type 4.

III. TEST SYSTEM AND METHODOLOGY

An IEEE 33 bus test distribution system is taken into consideration for the analysis. This is a radial distribution system, with bus 1 as the slack bus. Total loading of the system is 3.7 MW and 2.3 MVAr.The voltage at bus 1 is 12.66 KV which is the base voltage and is taken as 1.0 per unit. The system is studied first in respect of total system losses and the voltage profile of the system. After running the load flow analysis total system losses are found to be 200.1512kW.

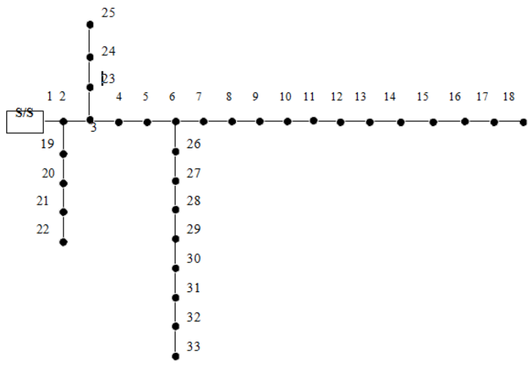

Fig.1. IEEE 33 bus radial distribution system

And voltage profile of the system is as shown below in figure 2:

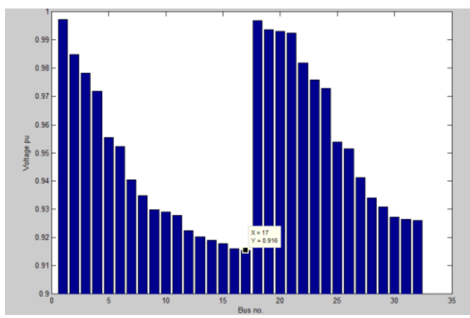

Fig.2. System voltage profile before DG placement

The minimum bus voltage is obtained at bus no. 17 and it is 0.916 pu.

A. Methodology: DG Size

For determination of optimal DG size the paper uses exact loss formula[8] and its solution for loss minimization is obtained by analytical method.Distribution network performance analysis requires repeated load flow analysis of the same. Load flow calculations are basically the line power flow calculations which provide the knowledge of steady state operating state of the system for a particular load level. Knowledge of steady state operating condition of the network with the help of load flow analysis provides continuous monitoring of the system and is helpful in stability studies, planning and optimization of the system. Applications like distribution network optimization require repeated load flows. With the help of load flow analysis various parameters of interest for system analysis, i.e. various node voltages, branch currents, and losses can be determined [9]. The traditional methods of Gauss-Seidel, Newton-Raphson etc. do not suit for load flow analysis of distribution system because of the radial/tee nature of distribution network and distribution system's ill conditioning due to the high R/X ratio as compared to the transmission system, which otherwise, follows meshed network structure and has a low R/X ratio. The load flow analysis is the backbone of the distribution system optimization [10]. As for analysis purpose, the load flow has to run many a times; it must be robust in nature and must consume minimum time. This work uses a method of load flow that uses topological structure and Kirchhoff's current law for load flow calculations. Initially following three steps are required: determination of equivalent current injection, formation of BIBC matrix, formation of BCBV matrix. BIBC matrix is formed by applying Kirchhoff's current law at various buses or nodes and the BCBV matrix is formed by applying Kirchhoff's voltage law at various buses/nodes. Once BIBC and BCBV matrices are known, bus current injection and bus voltages can be related as [11]

$$[\Delta V] = [BCBV][BIBC][I] = [DLF][I]$$

The solution to load flow can be determined as follows:

$$I_i^k = I_i^r(V_i^k) + j * I_i^i(V_i^k) = \left(\frac{P_i + j * Q_i}{V_i^k}\right)$$
$$[\Delta V^{k+1}] = [DLF][I^k]$$
$$[V^{k+1}] = [V^0] + [\Delta V^{k+1}]$$

The solution to load flow requires two matrices and their multiplication.

A large number of techniques are proposed for optimal location of DG, the analytical technique is one of them [12]. The paper uses analytical technique for determination of optimal DG size and a methodology based upon minimum real power losses in distribution system for optimal site/location determination. For this purpose exact loss formula [10] is used which is given as:

$$P_l = \sum_{i=1}^{N} \sum_{j=1}^{N} \left[\alpha_{ij}\left(P_i P_j + Q_i Q_j\right) + \beta_{ij}\left(Q_i P_j - P_i Q_j\right)\right] \quad (1)$$

in which

$$\alpha_{ij} = \frac{r_{ij}}{V_i V_j}\cos(\delta_i - \delta_j),$$
$$\beta_{ij} = \frac{r_{ij}}{V_i V_j}\sin(\delta_i - \delta_j),$$

and

$r_{ij} + jx_{ij} = Z_{ij}$, being ijth element of Z-bus matrix [Zbus] also

[Zbus]=[Ybus]$^{-1}$

P_i, P_j, Q_i and Q_j are the real and reactive power injected at ith bus and the jth bus respectively and N is the total number of buses.

Knowing the power factor of DG, the equation of DG reactive power in terms of DG active power can be written as [13]

$$Q_{DGi} = [\pm \tan\{\cos^{-1}(PF_{DG})\} P_{DGi}]$$
$$Q_{DGi} = a(P_{DGi}) \quad (2)$$
$$a = \pm \tan\{\cos^{-1}(PF_{DG})\}$$

If sign of 'a' is positive DG injects reactive power and if it is positive DG withdraws reactive power.

The sizing at various locations can be determined as

$$P_i = P_{DGi} - P_{Di} \quad (3)$$
$$Q_i = Q_{DGi} - Q_{Di} = aP_{DGi} - Q_{Di} \quad (4)$$

Where, P_i and Q_i are the net values of real and reactive power at ith bus. P_{Di} and Q_{Di} are the real and reactive load powers at ith bus. P_{DGi} and Q_{DGi} are the real and reactive power supplied by distributed generators at i_{th} bus [14]

The equations (1) and (3) can be combined to write down the system real power loss as [15]:

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}\Big[\ \alpha_{ij}\left[(P_{DGi} - P_{Di})P_j + (aP_{DGi} - Q_{Di})Q_j\right] + \beta_{ij}\left[(P_{DGi} - P_{Di})P_j + (aP_{DGi} - Q_{Di})Q_j\right]\ \Big] \quad (5)$$

Now if the partial derivative of this equation is taken with respect to the active power injection at bus 'i' and is equated to zero, the total active power loss of the system would be zero . Solving the partial derivative and rearranging

$$\frac{\partial P_L}{\partial P_{DGi}} = 2\sum_{j=1}^{N}\left[\alpha_{ij}\left(P_j + aQ_j\right) + \beta_{ij}(aP_j - Q_j)\right] = 0$$

The above equation is re-written as

$$\alpha_{ii}(P_i + aQ_i) + \beta_{ii}(aP_i - Q_i) + \sum_{\substack{j=1 \\ j\neq i}}^{N}\left(\alpha_{ij}P_j - \beta_{ij}Q_j\right) + a\sum_{\substack{j=1 \\ j\neq i}}^{N}\left(\alpha_{ij}Q_j + \beta_{ij}P_j\right) = 0 \quad (6)$$

In this equation, let

$$\sum_{\substack{j=1\\j\neq i}}^{N}\left(\alpha_{ij}P_j-\beta_{ij}Q_j\right) = X_i$$

and

$$a\sum_{\substack{j=1\\j\neq i}}^{N}\left(\alpha_{ij}Q_j+\beta_{ij}P_j\right) = Y_i \qquad (7)$$

From equation (3), (4), (6) and (7) following equation can be developed as

$$\alpha_{ii}\left(P_{DGi}-P_{Di}+a^2P_{DGi}-aQ_{Di}\right)+\beta_{ii}\left(Q_{Di}-aP_{Di}\right)+X_i+aY_i=0 \qquad (8)$$

From this equation, the optimal size of DG, at ith (where 'i' is varying from 1 to N) bus can be determined using following equation:

$$P_{DGi}=\frac{\alpha_{ii}\left(P_{Di}+aQ_{Di}\right)+\beta_{ii}(aP_{Di}-Q_{Di})-X_i-aY_i}{a^2\alpha_{ii}+\alpha_{ii}} \qquad (9)$$

A complex distribution system, in general, has a few generation sources and a number of buses, lines and many loads. Losses in the system are minimum if each load is locally supplied by a DG and the DG power factor is exactly equal to the load power factor. But it is an unrealistic approach for practical implementation as it will result in a huge investment in DG installation, also the transmission lines would become of no use. Literaturesshow that the optimal DG operating power factor is determined by the fast method and the repeated method. But it is found that the total real power losses are minimum if the power factor of DG is taken as equal to the average power factor of the combined load.

Once the DG power factor is known, optimal size of DG at each bus in the distribution system can be determined for all the four types of distributed generators, in the manner given below:

(a) DG type 1:Type 1 DG like solar photovoltaic (SPV) are capable of supplying only real power to the distribution network [15]. The optimal sizes for these real power sources can be found out by using equation (9) and assuming DG power factor PF_{DG} = 1, with this 'a' becomes zero and equation is reduced to [16]

$$P_{DGi}=P_{Di}-\frac{1}{\alpha_{ii}}\left[\beta_{ii}Q_{Di}+\sum_{\substack{j=1\\j\neq i}}\left(\alpha_{ij}P_j-\beta_{ij}Q_j\right)\right] \qquad (10)$$

(b) DG type 2: Their capacity can be obtained by using the same equation (9) but now the condition is PF_{DG} = 0 so 'a' becomes infinite. The condition is justified as type 2 DG is capable of supplying only the reactive power to the distribution system. They may be the synchronous condensers. With this the equation (9) reduces to the following form

$$Q_{DGi}=Q_{Di}+\frac{1}{\alpha_{ii}}\left[\beta_{ii}P_{Di}-\sum_{\substack{j=1\\j\neq i}}\left(\alpha_{ij}Q_j+\beta_{ij}P_j\right)\right] \qquad (11)$$

(c) DG type 3: Under this category come generation facilities like gas turbines which are based upon synchronous generators. The constant 'a' is positive for this case and its value lies between zero and one. Optimal size of DG at each bus can be determined by equation (9) and equation (4), for real power and reactive power respectively.

(d) DG type 4: For this type of DG as well the PF_{DG} lies between 0 and 1, but sign of constant 'a' is negative. They are the generators which supplies real power to the distribution system but at the same time withdraws reactive power fro the supply. The supply authorities do not encourage such withdrawal of reactive power, so, for the purpose capacitors are connected near the terminals of these DGs. Asynchronous/ Induction generators comes under this category of DG type. The optimal capacity can be determined using the equations (9) and (4) respectively, for real and reactive power, while taking negative sign for constant 'a' [16].

B. Methodology: DG Placement

Once optimal sizes of DG are known, the next step is the determination of optimal placement site for the optimally sized DG. For this a procedure employing determination of total real power losses with optimally sized DG placed at each bus, one at a time, is followed. The steps for the same can be summarized as follows [15],[16]:

1st step: Running the load flow for base case.
2nd step: Determination of total loss using equation (1).
3rd step: Determination of DG power factor by calculating average load power factor.
4th step: Finding optimal DG size at each bus using equations (9) and (4).
5th step: Placement of optimal DG sizes at each bus for total real power loss with DG at each bus one at a time.
6th step: Locating the bus at which placement of optimal DG causes total system losses to become minimum.
7th step: Running load flow after placement of optimal sized DG at optimal bus location. Observe the bus voltage profile as well.

C. Methodology: Economics of Optimal DG Placement

To obtain economical benefit of DG placement, benefit of reduced energy loss cost and benefit of cost due to reduced supply drawn from substation is compared to the installation and maintenance cost of distributed generator.

Cost of Energy Loss: The energy lost in a certain time can be determined as:

$$L_e=\sum_{i=1}^{n}Lei$$

Where,

$$Lei=I_i\times I_i\times R\times T$$

Knowing L_e,the cost of lost energy can be determined as

$$CEL = \mathrm{Re} \times L_e$$

R_e is rate of energy and L_e is the lost energy.

DG Cost : The total DG cost comprises of two parts which are the fixed installation cost and the variable cost .

$$CDG= C_{cv}*Q_{ck} \quad (10)$$

C_{cv}& Q_{ck} are rate of DG per MW/MVA and rating of DG at k-th bus respectively.

The objective function for cost minimization can now be framed as:

$F=CEL + C_{cv}*Q_{ck}$; where F is the cost function for minimization.

Second part of equation is dependent upon the DG technology used. Nothing can be done for DG installation cost reduction, but first par is representing the cost of energy lost and it can be minimized if DGs are placed optimally in respect of loss minimization.

For the foregoing analysis of given system, the system is studied with the peak power demand. For the purpose of economics of loss calculations the average loading per day is considered which is approximately 60% of the peak load demand. The power lost is dependent upon the current squared, so the reduction of power level from peak value to average value causes the losses to get reduced to 36%. Further it is assumed that type 1 to type 4 DG are supplying power for eight hours in a day. For rest of the time, i.e. for 16 hours all thepower is withdrawn from substation.

IV. RESULT

Optimal size and location for four type of DGs are determined using analytical method. Type one DG which injects only real power may be a solar PV system , type two that basically supplies only the reactive power may be a synchronous compensator or may be the static capacitors [17],[18],[19]. Type three DG which are capable of supplying active as well as reactive powers are basically the synchronous generator based DGs and may involve gas turbines. Type four DGs are the one which supplies active power but withdraws reactive power from supply. Induction generators used for wind power generation fall in this category. For system study a program is written in MATLAB environment.

A. Optimal Placement of DG

From table I it can be seen that minimum losses are obtained if optimal sized type 1 DG is placed at bus no.7, so from loss minimization point of view , bus no. 7 becomes the optimal placement site for type 1 DG.

After placing this DG, the system voltage profile is also observed and it is found that this placement causes an improvement in voltage profile as well.

Table I: Type 1 DG Optimal Sizes and corresponding losses

S. NO.	P_{DG}(MW)	P_i (MW)	P_{LOSS}(KW)
2	3.3334	3.2334	191.1538
3	3.5909	3.5009	152.8956
4	3.3866	3.2666	141.4717
5	3.0922	3.0322	130.1902
6	2.9315	2.8715	108.1198
7	**2.6646**	2.4646	**108.0375**
8	2.5925	2.3925	129.2028
9	1.9312	1.8712	120.5075
10	1.7191	1.6591	122.0745
11	1.5593	1.5143	120.029
12	1.534	1.474	121.4819
13	1.493	1.433	129.0271
14	1.3275	1.2075	129.0721
15	1.2736	1.2136	130.1355
16	1.2176	1.1576	133.6032
17	1.1525	1.0925	140.5815
18	1.0488	0.9588	142.0009
19	0.9057	0.8157	196.637
20	2.9578	2.8678	260.224
21	1.2529	1.1629	206.6889
22	1.0956	1.0056	207.8386
23	0.8996	0.8096	176.7704
24	2.7155	2.2955	177.0284
25	1.9324	1.5124	177.1937
26	1.4708	1.4108	121.9327
27	2.5336	2.4736	111.6375
28	2.4048	2.3448	122.9002
29	2.0078	1.8878	121.6295
30	1.793	1.593	121.6852
31	1.6772	1.5272	129.3372
32	1.471	1.261	128.7765
33	1.408	1.348	132.4148

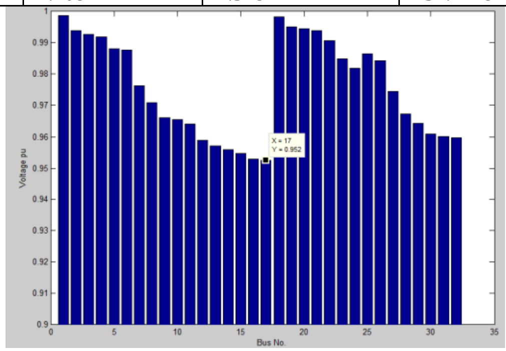

Fig.3. Voltage profile after type 1 DG placement at bus no.

Now considering type 2 DG placement, the problem with type 2 is they cannot supply active power they only supply the reactive power. Reactive power supply improves system's voltage profile and reduces the magnitude of current drawn from sub-station as it becomes a local supplier of reactive power.

The table of optimum size of Q-generator at different busses in system is given as table 2. It also contains the best location for the same by considering total minimum real power losses obtained by placing optimum DG sizes one at a time at respective buses. The best location is one that provides total minimum loss.

The improved voltage profile of the system with optimal DG placement, which is at bus no. 30, is shown in figure 4b. As seen the minimum voltage got improved to 0.928 pu at bus 17 counting from bus 2 (bus 1 being the substation bus), so it is actually the bus no.18 of the 33 bus system.

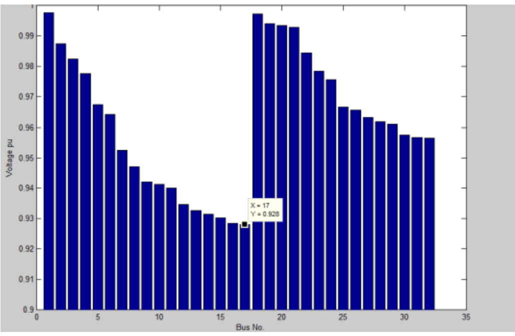

Fig.4. Voltage profile after optimum type 2 DG placement at bus no.30

Type 3 DGs are those which can supply real power as well as reactive power. Optimal sizes and the losses with them are given in table 3. The optimum site is found to be the bus no. 6 of the system as it is providing minimum real power losses in the system. After placing optimum sized DG at bus no. 6 the obtained system voltage profile is given in following fig.5

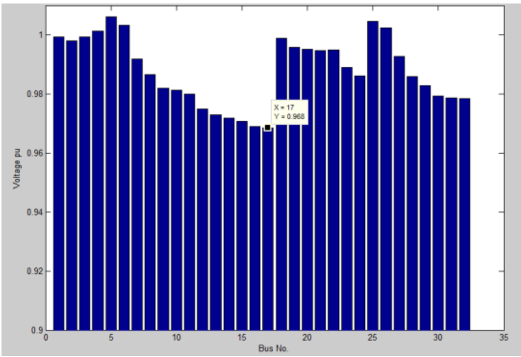

Fig.5. Voltage profile after optimum type 3 DG placement at bus no. 6

Table II: Type 2 DG Optimal Sizes and corresponding losses

S. NO.	**Q_{DG}(MVAr)**	**Q_i(MVAr)**	**P_{LOSS}(KW)**
2	2.0472	1.9872	196.6892
3	2.2035	2.1635	180.7433
4	2.1048	2.0248	174.0828
5	1.9612	1.9312	167.7434
6	1.8937	1.8737	154.1925
7	1.773	1.673	155.303
8	1.7167	1.6167	172.1124
9	1.2223	1.2023	168.8537
10	1.068	1.048	170.646
11	0.9549	0.9249	169.7585
12	0.9368	0.9018	170.7323
13	0.9088	0.8738	175.1796
14	0.7952	0.7152	174.5477
15	0.7584	0.7484	175.9225
16	0.7218	0.7018	177.5924
17	0.6812	0.6612	180.4953
18	0.6171	0.5771	180.9713
19	0.5242	0.4842	198.9234
20	1.8095	1.7695	224.8321
21	0.7445	0.7045	203.1403
22	0.6488	0.6088	203.905
23	0.5307	0.4807	191.6169
24	1.6555	1.4555	193.6902
25	1.1552	0.9552	193.6079
26	0.8735	0.8485	164.6318
27	1.7025	1.6775	152.8438
28	1.6461	1.6261	150.2158
29	1.4649	1.3949	146.3259
30	**1.3633**	0.7633	**144.4078**
31	1.2664	1.1964	151.3425
32	1.1014	1.0014	152.1337
33	1.0542	1.0142	154.8909

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Table III: Type 3 DG Optimal sizes and corresponding losses

S. NO.	P_{DG} (MW)	Q_{DG} (MVAr)	S (MVA)	P_{LOSS} (KW)
2	3.3334	2.0667	3.9216	187.7045
3	3.5909	2.2264	4.2246	134.3382
4	3.3866	2.0997	3.9842	116.9103
5	3.0922	1.9172	3.6379	100.0601
6	**2.9315**	**1.8175**	3.4488	**67.0901**
7	2.6646	1.652	3.1348	67.546
8	2.5925	1.6073	3.05	98.5458
9	1.9312	1.1974	2.272	90.1299
10	1.7191	1.0658	2.0224	93.4506
11	1.5593	0.9667	1.8344	91.2797
12	1.534	0.9511	1.8047	93.5017
13	1.493	0.9256	1.7564	103.9067
14	1.3275	0.8231	1.5618	102.5171
15	1.2736	0.7896	1.4984	106.0017
16	1.2176	0.7549	1.4325	110.6294
17	1.1525	0.7146	1.3559	118.9657
18	1.0488	0.6503	1.2339	121.0881
19	0.9057	0.5615	1.0655	195.3554
20	2.9578	1.8338	3.4797	281.9182
21	1.2529	0.7768	1.474	209.7521
22	1.0956	0.6793	1.2889	211.1912
23	0.8996	0.5577	1.0583	168.0226
24	2.7155	1.6836	3.1947	170.0453
25	1.9324	1.1981	2.2734	170.3551
26	1.4708	0.9119	1.7304	87.8553
27	2.5336	1.5708	2.9807	68.8874
28	2.4048	1.491	2.8292	75.9692
29	2.0078	1.2449	2.3622	71.7697
30	1.793	1.1117	2.1094	70.9852
31	1.6772	1.0399	1.9732	82.1802
32	1.471	0.912	1.7306	83.8927
33	1.408	0.873	1.6565	88.9162

Type 4 DGs are basically induction generators connected to the supply system. They supply real power to the system but at the same time they withdraw reactive power form supply. The optimal DG sizes are given in the following table and the corresponding losses are also mentioned.

The improvement in system voltage profile after placement of DG 4 at bus number 25 results 0.926 pu voltage at bus 17. This type of DG installation increases the substation capacity which is not permitted. So this placement is not possible without capacitor placement to support DG4 reactive power requirement

Table IV: Type 4 DG Optimal sizes and corresponding losses

S. NO.	P_{DG} (MW)	Q_{DG} (MVAr)	S (MVA)	P_{LOSS} (KW)
1	3.3334	-2.0667	3.9216	199.3776
2	3.5909	-2.2264	4.2246	207.3288
3	3.3866	-2.0997	3.9842	218.4699
4	3.0922	-1.9172	3.6379	222.2997
5	2.9315	-1.8175	3.4488	242.5286
6	2.6646	-1.652	3.1348	234.4628
7	2.5925	-1.6073	3.05	300.6461
8	1.9312	-1.1974	2.272	251.2425
9	1.7191	-1.0658	2.0224	246.925
10	1.5593	-0.9667	1.8344	231.1012
11	1.534	-0.9511	1.8047	233.795
12	1.493	-0.9256	1.7564	251.9742
13	1.3275	-0.8231	1.5618	236.5905
14	1.2736	-0.7896	1.4984	237.0257
15	1.2176	-0.7549	1.4325	238.5434
16	1.1525	-0.7146	1.3559	236.1743
17	1.0488	-0.6503	1.2339	237.4895
18	0.9057	-0.5615	1.0655	198.9023
19	2.9578	-1.8338	3.4797	308.0637
20	1.2529	-0.7768	1.474	219.3851
21	1.0956	-0.6793	1.2889	220.4645
22	0.8996	-0.5577	1.0583	189.6181
23	2.7155	-1.6836	3.1947	252.1943
24	1.9324	-1.1981	2.2734	235.0709
25	**1.4708**	**-0.9119**	**1.7304**	**182.8092**
26	2.5336	-1.5708	2.9807	241.1323
27	2.4048	-1.491	2.8292	282.4202
28	2.0078	-1.2449	2.3622	270.2093
29	1.793	-1.1117	2.1094	261.1407
30	1.6772	-1.0399	1.9732	269.9803
31	1.471	-0.912	1.7306	250.2721
32	1.408	-0.873	1.6565	250.4048

B. Economic analysis of Optimal DG Placement

For the economic analysis of the system, the system is studied with the peak power demand. For the purpose of economics of loss calculations the average loading per day is considered which approximately 60% of the peak load demand. The power lost is dependent upon the current squared, so the reduction of power level from peak value to average value causes the losses to get reduced to 36%. Further it is assumed that DGs are supplying power for a duration of 8 hours in a day and for rest 16 hours the power is being supplied by the substation.

The loss cost with four DG types is tabulated in table V:

Table V: Loss cost comparison of system

Observation	Loss (kW)	V_{min} @17*	Loss Cost (in lacs/annum)	Saving (in lacs per annum)
Base Case	200.15kW	0.916	Rs. 37.87/-	-
Type 1	108.0375	0.952	Rs.32.06/-	Rs. 5.81/-
Type 2	144.4078	0.928	Rs.34.36/-	Rs. 3.51/-
Type 3	67.0901	0.968	Rs.29.48/-	Rs. 8.39/-
Type4	182.8092	0.926	Rs. 36.78/-	Rs.1.09/-

* Bus 17 as counted from bus 2. It is bus no. 18 of the 33 bus system.

V. SUMMARY

A. Optimal Placement of DG for Loss Minimization

Foregoing analysis of optimal DG placement is summarized in following table:

Table VI: Optimum size and site

DG type	**DG Capacity**			**DG Location (bus no.)**
	P (MW)	**Q(MVAr)**	**S(MVA)**	
Type 1	2.6646	-	-	7
Type 2	-	1.3633	1.3633	30
Type 3	2.9315	1.8175	3.4488	6
Type 4	1.4708	- 0.9119	1.7304	25

B. Economics of DG Placement

Benefit obtained in cost reduction due to system loss minimization can be summarized as given in following table.

Table VII: Loss cost reduction benefit

DG Type	**Benefit (in lacs per annum)**
Type 1	Rs. 5.81/-
Type 2	Rs. 3.51/-
Type 3	Rs. 8.39/-
Type4	Rs.1.09/-

VI. CONCLUSION

The paper is written for the purpose of comparing the economic feasibility four type of distributed generators placement in primary distribution network. This is done by optimizing loss cost of DG with the help of optimum sized DGs placed at optimal nodes in the radial distribution system. Analytical method using exact loss formula is used for determination of optimal size and a methodology is then employed for the purpose of determining optimal location.

The best sites so obtained are not always feasible for DG placement because of many constraints, but as the losses increase with a variation in optimal size and site, so this factor must be taken into account. Load flow analysis is done for determination of various bus voltages, branch currents and active power loss in the system. Results of all optimum placement for all four type of DGs are shown and it is found that Type 3 DG placement is the best option economically as well as technically in terms of voltage profile betterment. Economics of DG placement for each case is given by respective table. The benefit of DG placement is determined in terms of saving in real power losses. Monetary benefit can also be attained by relieving some capacity of the substation and hence by proper design the substation size can be reduced. The economic analysis can further be extended by incorporating DG fixed and variable costs and for determination of payback period.

CERC (central Electricity Regulatory Commission) website is referred to get the costs for DG cost determination and the costs are approximated [23].

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