Allocation of PV unit in Distribution Network using Analytical Method

Ritesh Kumar Rai, Anand Kumar Pandey, Anshu Parashar, Sujatha K S

Abstract: Inappropriate selection of location and corresponding size of Distributed Generator (DGs) in electrical network may have increased power losses in the system. Application of incorporating DG in system has eased the problem of high power losses, voltage stability, low reliability and poor power quality. This paper suggests a simple and efficient load flow technique known as direct load flow method to find the optimal allocation of Type-3 DG in the distribution system. The presented method was developed and tested in two distribution networks with varying size and complexities and the effect of size and location of DG with respect to real power losses while maintaining the voltage profile of system within limits is examined with verification and discussed in detail.

Index Terms: Power system optimization, Distribution system, Optimization techniques. Location and sizing.

I. INTRODUCTION

Generation of energy through 'Green Technologies' is considered as an alternative to the conventional power generation methods from fossil fuels. As the energy generation through these sources has increased significantly, there is rapid growth in the distributed renewable energy production. Energy sources located at load canters are named as distributed sources. Conventional DG's can be considered as the diesel generator or natural gas turbine while latest DG's can be Fuel Cells, storage device , or renewable energy source like Solar Photovoltaic , Wind turbine etc [1-3].

Production of energy from renewable sources is promoted through various policies and initiatives and this will further increase the growth in the distributed energy generation as more number of DG's will be installed within the distribution system. Even though, Solar Photovoltaic energy generation has various advantages circuit problems are created due to their placements in the system.

In [4] it is discussed that it is not possible to insert DG of large size in distribution systems because it is not economical. The size of DG should be designed so as the power limit be within the distribution substation boundary. Exporting power beyond the substation by installing high capacity DG resulted in high distribution loss. Therefore it is very important to note that distribution system size gives the idea of the size of DG to be place in distribution network.

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Size of the DG and location to place that particular size is very important from the loss and voltage point of view. If size and location of the DG is not selected optimally then it will result in higher power losses and poor voltage profile. This will leads to technical, economical and environmental loss of the system. Different methods are existing in the literature to determine the best size and location of DG in distribution network. In [4-7] different methods for the optimal placement of DG to reduce the losses are discussed and in [8-9] voltage stability is discussed while placing DG in distribution network. In [9-13] different researchers have presented their ideas for the location and sizing of DG, some researchers have considered multiobjective function while others have considered single objective function. The parameters considered are power loss minimization, voltage profile improvement, voltage stability enhancement, reliability improvement. The techniques presented can be divided in three parts mainly analytical, metaheuristic and hybrid method. The performance of the technique depends on the problem modelling and size of the system. It is seen in the literature that for some problem modelling analytical methods are best while for some heuristic methods are best and for some problem modelling hybrid methods are best.

In this paper, step by step a simple and efficient load flow method is explained to find the optimal location and size of single type-3 DG i.e. DG which supplies only real power to the system in distribution systems In literature [14, 15] different method to solve the transmission and distribution load flow methods are presented. Conventional load methods like Newton raphson, Gauss seidal and fast decoupled method are not suitable for distribution load flow analysis. In this paper an easy and fast method to determine the distribution load flow is proposed. Details about the load flow are given in [16]. Only line data and bus data is required to execute this load flow analysis. The technique proposed in this paper does not require formation of admittance or impedance matrix which is a time consuming process. The objective of this method is to develop a mathematical expression, which considers advantages of the topological characteristics of distribution networks, and solve the distribution load flow results directly. Load flow solution in distribution system is basically the matrix multiplication of two matrices one is known as bus-injection to branch-current (BIBC) matrix and the second is known as branch-current to bus-voltage (BCBV) matrix. This method can be utilised in treatments for weakly meshed distribution systems. The Direct load flow technique among other conventional techniques of transmission and distribution systems, it is robust and efficient [16]. Test results validate the feasibility and efficiency of the methodology used.

II. PROBLEM FORMULATION

One of the main problems is deploying DG's in distribution system is that if the size of DG is increased beyond an optimal size at the specific buses, the losses increases and it exceeds the base case loss. The location and sizing so plays an essential role in minimizing the losses of the total system. So, it is advised not to deploy DG's of high capacity as it will increase the losses to very high extent.

Hence, the problem of Solar PV allocation in distribution line can be interpreted as to determine the best size and position of the Solar PV plant according to its capacity to assure the desired objective function subject to different constraints [19].

The mathematical formulations for the Solar PV application in distribution network are as follows:

The Objective function is to minimize the loss:

$$ObjectiveFunction = min \sum_{i=0}^{n} \left(\frac{P_i^2 + Q_i^2}{V_i^2} \right) \times r_{i+1}$$

Under the constraints of:

1. The voltage limits $|V_{min}^{system}| \le |V_i^{system}| \le |V_{max}^{system}|$

i.e. ±5% of the nominal value.

2. The boundary of sizing of the Solar PV plant are desired from the following constraints

$$|S_{max}^{pv}| \ge |S_i^{pv}| \ge |S_{min}^{pv}| .$$

The voltages of the distribution system buses are maintained between 0.90 pu to 1.05 pu as per the constraints. The preselected value of the Solar PV unit are from 10% to 80% of the KVA demand ($\sum|S_{L,im}|$) and it is discretized into integer values of one step to calculate the losses of system.

So, the Solar PV unit are set to operate at practical values, hence the total power of the solar PV at that particulat bus will get reduced.

In this Paper, we discuss about the reduction in the real power loss on injection of DG (Solar PV unit) at optimal location & sizing of the plant.

III. METHODOLOGY

The method used here to calculate the power loss of the system is the direct approach for balanced three phase distribution load flow equation. Input required in this method is the bus data and line data as per the distribution line selected.

Two matrices are required to be developed 1) Bus Injection to Branch Current (BIBC) and 2) Branch Current to Bus Voltage (BCBV) matrix and by simple matrix multiplication Distribution Load Flow (DLF) matrix is generated.

To calculate the change in voltage at any bus, we use equation (1). This expression can be written as:

$$[\Delta V] = [BCBV] * [BIBC] * [I] = [DLF] * [I] \quad (1)$$

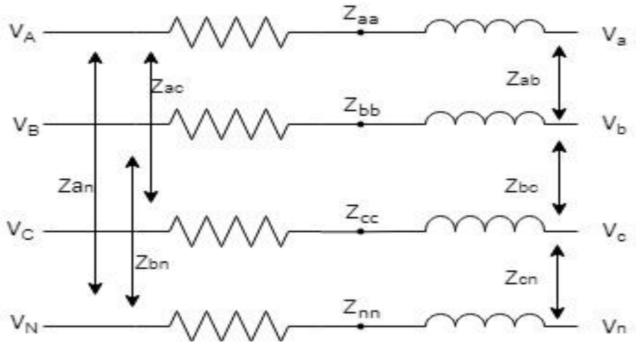

Fig.1. 3-phase line section model

Fig. 1 shows an equivalent circuit diagram of three phase distribution system. Now to find the relation between voltage and current of the distribution system we use equation 2

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} - \begin{bmatrix} Z_{aa-n} & Z_{ab-n} & Z_{ac-n} \\ Z_{ba-n} & Z_{bb-n} & Z_{bc-n} \\ Z_{ca-n} & Z_{cb-n} & Z_{cc-n} \end{bmatrix} * \begin{bmatrix} I_{Aa} \\ I_{Bb} \\ I_{Cc} \end{bmatrix}$$

(2)

Total load at any bus a can be calculated as:

$S_a = (P_a + jQ_a)$ Where a=1,2,3,........,N

(3)

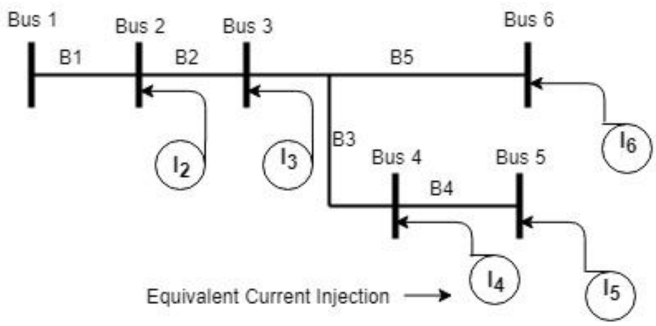

Fig. 2. Sample of 6 Bus Distribution network

And the equivalent current injection at K^{th} iteration solution is given by equation 4

$$I_i^K = I_i^r * V_i^K + jI_i^i * V_i^K = \left(\frac{P_i + jQ_i}{V_i^K} \right)^*$$

(4)

Where

Bus voltage is V_i^K ; current injection I_i^K ; real part of equivalent current injection I_a^r ; imaginary part of equivalent current at I_a^i.

Branch Injection Branch Current matrix formation:

We consider a 6 Bus system with Branch Current Injection. The considered system is shown in Fig. 2. By applying Krichoff's Current rule to the distribution network, we get branch currents as function of equivalent current injections.

$$B_1 = I_2 + I_3 + I_4 + I_5 + I_6$$
$$B_3 = I_4 + I_5$$
$$B_5 = I_6 \quad (5)$$

In matrix form, we express it as

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} \quad (6)$$

In general form equation 6 can be expressed as

[B] = [BIBC]* [I](7)

Where BIBC is Bus-injection to branch current (BIBC) matrix and BIBC is upper triangular matrix which contains values of 0 and +1 only..

Voltages at different buses can be obtained as:

$V_2 = V_1 - B_1 Z_{12}$

$V_3 = V_2 - B_2 Z_{23}$

$V_4 = V_3 - B_3 Z_{34}$

(8)

Where,

V_i – ith bus voltage

Z_{ij} - Impedance between bus i and j

Equation (8) is used to calculate the voltage of any particular bus and equation (9) is used to find the load flow analysis.

$$I_i^r = \left(\frac{P_i + jQ_i}{V_i^r}\right)^*$$

(9a)

$$[\Delta V^{r+1}] = [DLF] * [I^r]$$

(9b)

$$[V^{r+1}] = [V^0] + [\Delta V^{r+1}]$$

(9c)

Only one matrix known as DLF matrix is required to solve the load flow.

Algorithm for calculation of Power Loss

1. Read system data for bus and line to form BIBC and BCBV matrices.
2. Calculate real power loss of the system as in Section III.
3. Initialize the Bus count = 1.
4. Set DG size to initial loading i.e. 10% of total system load.
5. Form new BIBC and BCBV matrix after the DG loading.
6. Find real power loss of the new system data
7. Increment the DG size by 1% and go to Step 5 till maximum DG loading.
8. Increment the Bus count by 1 and go to Step 4 till maximum Bus count achieved.

IV. RESULTS AND DISCUSSIONS

Test System

Problem formulation model is tested on radial bus of 16 Bus and 33 Bus Distribution networks. The 16 Bus Distribution network has total real load of 28.7 MW and have reactive load of 5.9MVar. The second radial test system is 33 bus system has real Load of 3.7 MW and reactive load of 2.3 MVar .The test system has varying size and complexities.

The technique discussed in this paper is developed and implemented in MATLAB, Version 2014a (32 bit). After the analytical program is developed, the program is run to calculate the Power loss of the test system and accordingly we analyze the optimal location and size of placement of Distribution generator (Solar PV) and the respective voltage profile after placing the optimal size of Distribution Generator at optimal location is plotted. The program developed can be used to calculate the objective for all types of DGs, but here we only analyse the optimal location and voltage profile of test system on injection of real Power i.e. Type 3 DG, hence, the result of mention test system is presented.

Assumption and Constraints

1. The bound of Voltage profile of the buses are set at 0.90 p.u. to 1.05 p.u. respectively.

2. Only placement of one DG location in each test system is considered and solar PV (Type 3 DG) Placement is taken for the allocation of 16- Bus and 33- Bus radial network.

Results are presented in Table 10

Test System 1: Modified 16-bus radial distribution system

16 Bus distribution network is a standard 12.66 kV network, with 3 feeders. The system is given in [17]. To solve the 3 feeder system, the standard system is changed to single feeder,

15-bus radial distribution test system, as shown in Fig. 3. After the developed algorithm of DG placement as per location and sizing is applied on modified 16-bus radial distribution test system, Results generated are given in Table 1

For the test system, the results can be concluded as:

By running base case load flow we can find the base loss of the system. Accordingly, now the DGs are allocated at varied buses and with varying size, which varies from 10% (i.e. 2870 kW) to 80% (i.e.22960 kW) in terms of their real power

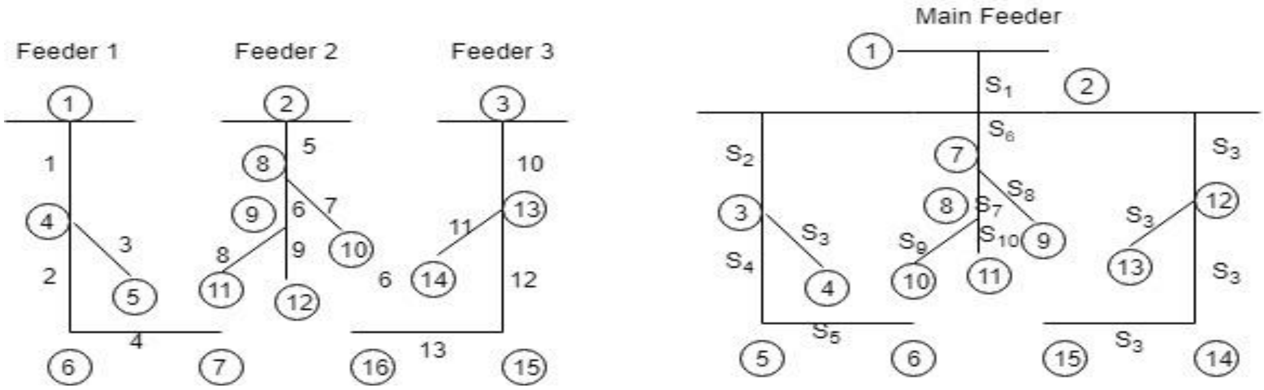

Fig.3. Modified 16-Bus radial distribution network

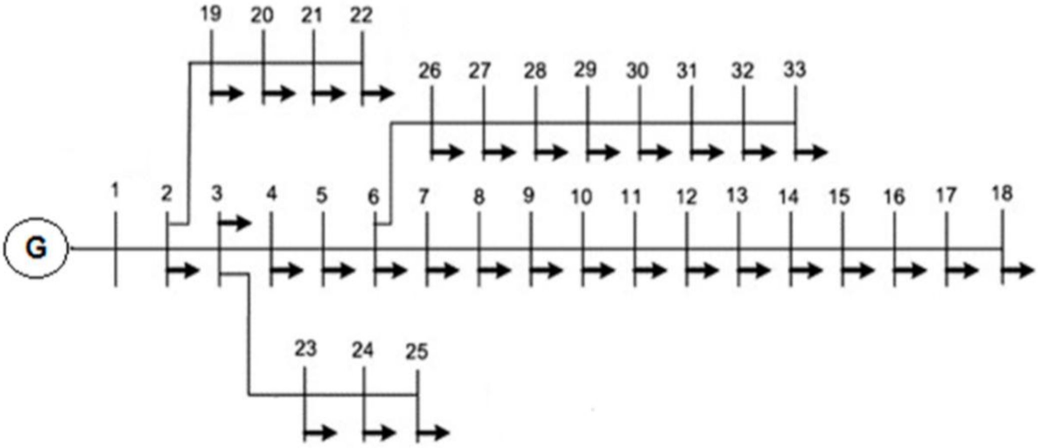

Fig.4. 33-Bus radial distribution network

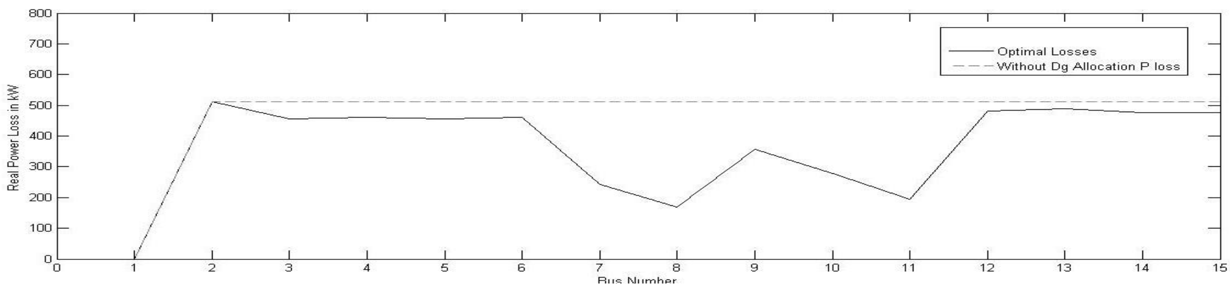

Fig. 5.Base loss v/s Optimal Loss of 16 Bus Distribution System

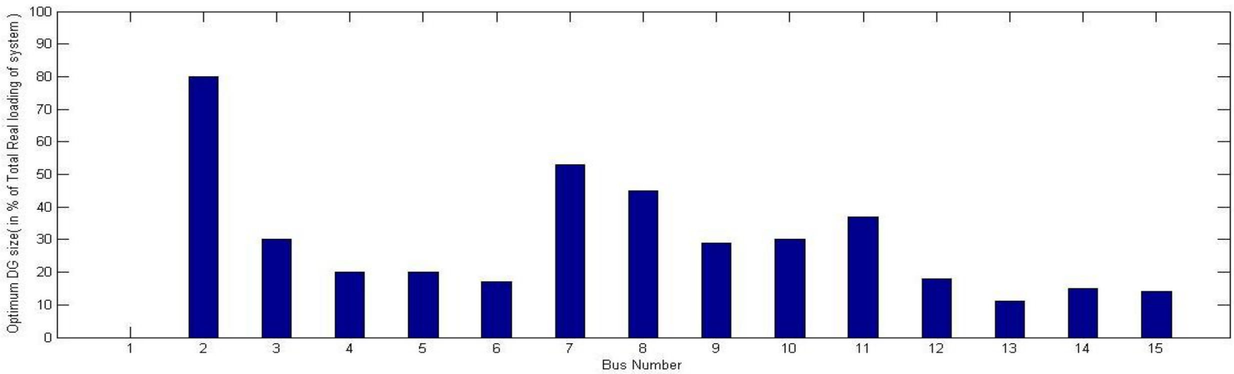

Fig. 6. Optimal Sizing at each bus of 16 Bus Distribution System

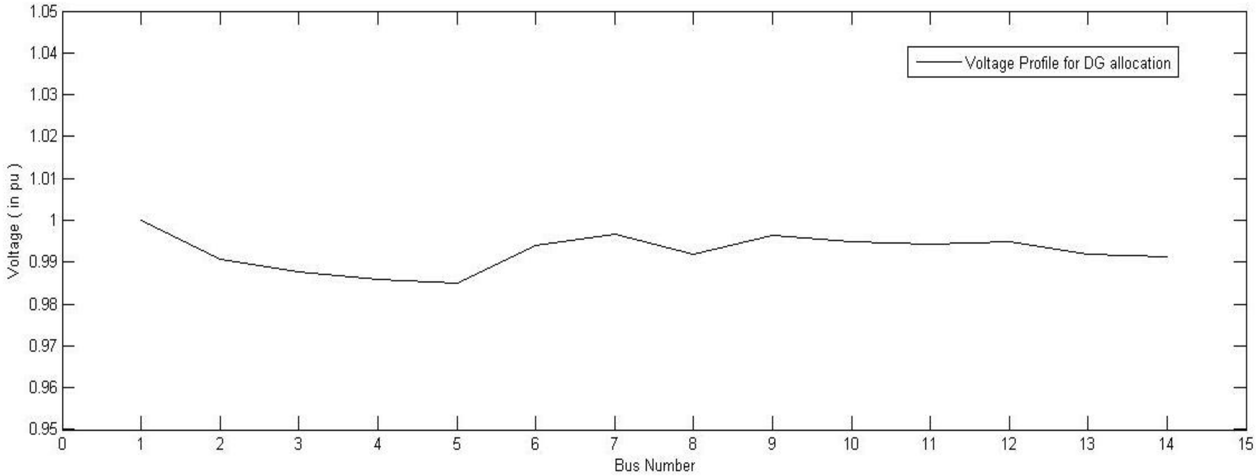

Fig. 7. Voltage Profile after DG allocation of 16 Bus Distribution System

capacity. Fig.5, shows the comparison between the base power loss without DG inserted and when the optimal size of the DG is allocated at the buses and corresponding loss reduction. For Test case 1, the Real Power Loss at base case is 511.4 kW.

Maximum Real power loss reduction can be observed at bus number 8 which is reduction by 67.05%. The Base Power loss is 511.4 kW and the reduced real Power loss is 168.49 kW at Bus Number 8.

For Sizing allocation, the optimal sizes of DGs inserted for maximum Real Power loss reduction is shown in Fig.6. For the test system 1, the range of DG requirement for the system

varies between 3715 kW to 22960 kW, but it is important to locate the bus at which the total power loss is minimum. It is obtained by the method explained in section 3. The DG optimal size can be concluded as 45% (i.e. 12915 kW) at bus

number 8. The voltage profile of the system after allocation of DG at Bus number 8 having real power capacity 12915 kW is shown in Fig. 7.

From the discussed simulation results for modified 16 bus radial distribution system, the above results are concluded and we analyze importance of allocation of Solar PV at optimal location for increasing reliability of system.

Test System 2: 33 Bus radial distribution system

The same program developed was run for the 33 bus radial Distribution system, and successfully the results were concluded. The system data is given in [18].

By running the program for base case load flow, the real power loss of the test system 2 is 210.998 kW. Now the DG with size varying from 10% (i.e. 371.5 kW) of the total load of the system is placed in discrete manner with unit step increase

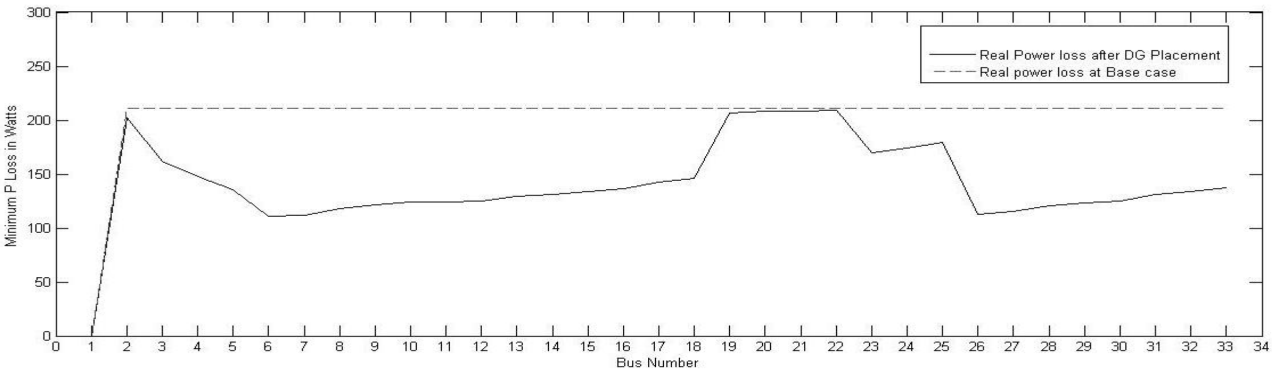

Fig.8. Base loss v/s Optimal Loss of 33 Bus Distribution System

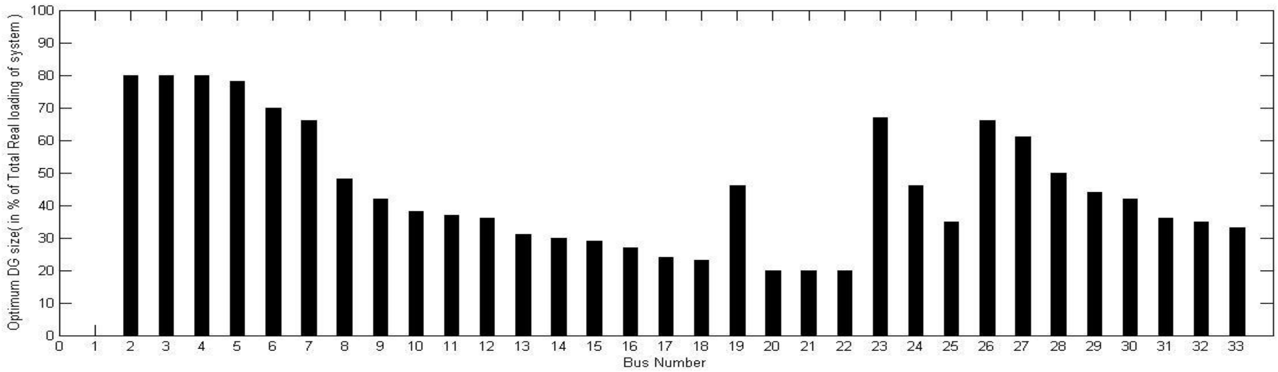

Fig.9. Optimal Sizing at each bus of 33 Bus Distribution System

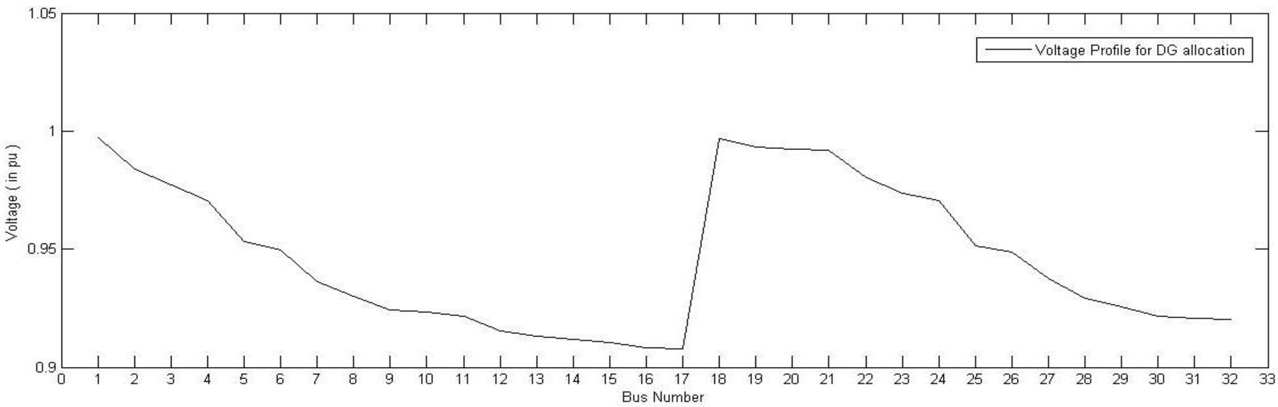

Fig.10. Voltage Profile after DG allocation of 33 Bus Distribution System

Table 1: Results of test Systems

S. No.	Test System	Base Case Real P loss (kW)	Optimal Allocation at Bus No.	Optimal DG Size (Solar PV) (% of Total System Load)	Real P loss after DG allocation (kW)	Percentage Reduction (%)
1	16 Bus	511.400	8	45% of 28700 kW	168.498	67.05
2	33 Bus	210.998	6	70% of 3715 kW	111.031	47.3

in loading (1%) up to 80% (i.e. 2972 kW) loading.

Fig.8. Shows the plot of optimal power loss at each bus after placing DG's of optimal size corresponding to each bus. From the reference / base loss line, we can analyse the effect or reduction in real power loss after installing the DG at optimal location.

The minimum reduction can be obtained while placing the DG at 6^{th} bus in the system. The base case real power loss is 210.99 kW while power loss after placing DG at 6^{th} bus is 111.03 kW which gives 47.3 % of loss reduction of the system.

Fig.9 is plotted for the corresponding buses best optimal DG loading to get maximum loss reduction in the system. Although, the system is varied from 371.5 kW to 2972 kW, the optimal DG capacity also varies from 371.5 kW to 2972 kW subject to constraints in the paper.

At Bus 6, where maximum power loss decline is obtained, the best possible size of DG is 70 % loading (i.e. 2600.5 kW). So, we need to install the DG of size correspondingly rather than maximum size of the unit.

Fig.10. is the plot for the voltage outline of network when we install the DG at bus number 6 and of 2600.5 kW capacity. After placing the DG at the location the limits were not violated as variation from 0.90 pu to 1.05 pu of the system is assumed.

Validation Case

This case is considered in order to compare the results with the method where author has proposed the results [7] for 33 Bus system using different techniques. The application of DLF method is compared with Loss Sensitivity Factor (LSF), IA, Exhaustive load flow (ELF) method and comparison is presented in Table 2.

V. CONCLUSION

Size and location of DG's are important factors in the installation of DG for reducing power loss. This paper presents a method to calculate the optimum size of DG at

Table2: DG placement by various techniques for 33 bus system.

Techniques	Installed DG Schedule		PLoss(KW)	% Reduction
LSF	Bus	18		
	Size(kW)	743	146.82	30.48
ELF	Bus	6		
	Size(kW)	2601	111.10	47.39
IA	Bus	6		
	Size(kW)	2601	111.10	47.39
Proposed method	Bus	6		
	Size(kW)	2600.5	111.031	47.85

various buses using direct approach for distribution load flow solution methodology to identify the best location corresponding to the optimum size for reducing real power losses in distribution system. Two matrices are developed to solve load flow problem i.e. BIBC which relates bus current injections and branch currents, and BCBV matrix which relates branch currents and bus voltages. The method avoid time-consuming procedures , such as LU factorization and forward/backward flow substitution of the Jacobian matrix or Y admittance matrix to make load flow more robust and efficient. The benefit of the proposed algorithm for size calculation is that a look up table can be created with only one power flow calculation and the table can be used to restrict the size of DG at different buses, along with verifying their voltage limits with the view of minimizing total losses. The methodology proposed in this paper correctly identifies the optimal size for single DG placement in the distribution system to reduce the power losses. Due to many constraints, the choice of best site is always not possible. However, as per analysis in this paper, it represents that losses due to different size and location of placement of DG's varies greatly and hence it must be taken into consideration for determining an appropriate location and size of the DG's in distribution system.

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