International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2016): 79.57 | Impact Factor (2016): 7.296

Optimal Placement and Sizing of Distributed Generation for Voltage Profile Improvement and Power Loss Minimization

Shah Jubin Rahman[1], Damodar Agarwal[2]

[1]Post Graduate Student, Electrical Engineering Department, Assam Engineering College, Gauhati University, Gauhati-781013, Assam, India

[2]Professor, Department of Electrical and Instrumentation Engineering, Assam Engineering College, Gauhati-781013, Assam, India

Abstract: ***In active distribution network, distributed generators (DG) are integrated with the existing distribution system. It has several advantages but the most important benefits are reduction of line losses and voltage stability improvement. But, sometimes the presence of DG on the distribution system creates an array of potential problems related to safety, stability, reliability and security of the electrical system. Whether the impact of DG is positive or negative on the system will depend on the location and size of the DG. In this paper, objective function is optimal placement and sizing of the DG unit by minimizing power losses and improving voltage profile. The first method is based on analytical approach as well as artificial intelligence method (PSO).The other proposed method is Voltage Stability Index based analytical approach. Both the methods have been implemented using MATLAB 2013 software, and tested using IEEE 33-bus test radial distribution. The results obtained from the first method and the second method are compared with the results published by Nguyen Tung and Dam Xuan Dong (using Artificial Bees Colony Algorithm)[12] . It is found that the Voltage Stability Index based analytical approach gives improved results in case of power loss minimization and voltage profile improvement than the other methods mentioned.***

Keywords: Distributed Generation, Power loss, Voltage profile, Voltage Stability Index, Particle Swarm Optimization

1. Introduction

Electricity demand is growing fastest of all the energy consumed worldwide. In order to meet the demands, Distributed Generator units are usually installed near the load site on the radial distribution networks. Active network has the most important benefits like reduced line losses and voltage profile improvement which again, are initially dependent on the size and location of DG units to be placed in the distribution networks. Studies indicate that poor selection of location and size of a DG in a distribution system would lead to higher losses than the losses without DG. Different researchers have proposed different ways for solving the problem of voltage improvement and loss minimization in distribution systems.

Recently, researchers are moving away from the usual use of capacitors to the introduction of DGs in the systems. In the recent past, much effort has been put forward to solving the optimal DG placement problem utilizing different algorithms and considering different objectives. The majority of DG placement objectives are minimization of power or energy losses in the network. In addition, other technical parameters like voltage profile, reliability of distribution network, line loadings, reactive power requirement, maximizing DG capacity, investment cost, operating cost, etc. have also been considered to form single or multi-objective problem formulations in different studies. The DG placement can be considered as an optimization problem, and various algorithms are used to solve this problem**.** [1] Optimal placement and size of DG for power loss minimization using Loss Sensitivity Factor Method (LSF). An analytical approach has been presented in [2] to identify appropriate location to place single DG in radial as well as loop systems to minimize losses. A new approach presented in [3] involving two new quadratic voltage profile improvement indices (VPII1 and VPII2*)* for voltage profile improvement using DGs. The Primal- Dual Interior Point (PDIP) method was employed to identify the optimal location and real and reactive power generation on the basis of the newly proposed indices. An analytical method was proposed in [4] to determine the optimal capacity of DG. The optimal sizes corresponding to each network bus were calculated using a direct equation derived from the sensitivity factor equation. In addition, an effective methodology based on an exact loss formula was applied to determine the optimal site of DG that minimizes total power losses. [5] Optimal allocation and sizing of capacitors using modified discrete PSO to minimize the transmission line loss and to improve the voltage profile. [6]A PSO based technique for the optimal allocation of DG units in the power system to help in power loss reduction and voltage profile improvement. [7] Optimal placement of DG for minimum system losses in radial distribution networks using GA. [8] A PSO based multi - objective approach for optimal sizing and placement of DG. Though these methodologies gives optimal or near optimal solution to the optimization problems with constraints but it suffer from some drawbacks like increase in computational time and are less accurate.

2. Distributed Generation

Distributed Generation means small sized generators which are mainly installed near the consumer site or load site in order to cope up with the growing demand without needing to increase existing traditional generation capacity. DG employs numerous, but small plants and can provide power onsite with little reliance on the distribution and transmission grid. It can employ both renewable and non-renewable technologies and can be either off grid or on grid. Electricity networks are in the era of major transition from stable passive distribution networks with unidirectional electricity transportation to active distribution networks with bidirectional electricity transportation. Radial distribution networks without any Distributed Generation units are considered passive. Distributed Generators are integrated with the existing distribution system which is then called an Active Distribution Network.

2.1 DG placement and sizing

DGs are only beneficial if their installations are carried out according to an appropriate plan. Type, size and locations are the three important parameters in this plan. DGs are integrated with the existing distribution system, and lots of studies have been carried out to find out the best location and size of DGs to produce utmost benefits. Studies show that if the size and location of DGs are not identified appropriately, not only are the network parameters are not improved, but they are also even deteriorated. Siting and sizing of DGs with the aim of improving a single parameter enhances the considered parameter significantly, but may have a negative impact on the other parameters on the network. The main characteristics that are considered for the identification of an optimal DG location and size are the minimization of transmission loss, maximization of supply reliability, improvement of voltage profile and maximization of profit of the distribution companies (DISCOs). Due to extensive costs, the DGs should be allocated properly with optimal size to enhance the system performance in order to minimize the system loss as well as to get some improvements in the voltage profile while maintaining the stability of the system. The effect of placing a DG on network parameters usually differs on the basis of its type, location and load at the connection point.

3. Problem Formulation and Solution Algorithm

The main objective of this project is to effectively integrate DGs into distribution network to achieve the aim of improving distribution network performance rather than degrading it. Thus, the objective functions formulated are
i) minimization of power loss and ii) improvement of voltage profile. Two methods have been proposed and implemented; one method is PSO based Analytical Approach and the other one is Voltage Stability Index based Analytical Approach.

3.1 For PSO based Analytical Approach

The methodology proposed is based on both analytical approach as well as artificial intelligence method (PSO) for finding the optimal location and size of DG for maximum loss reduction of the distribution system. The methodology proposed is capable of functioning under randomly distributed load conditions with low power factor for single DG as well as multi-DG system.

3.1.1 Power loss and voltage drop without DG

For a standard test distribution system shown in figure 1,

$$S_i = S_1 + S_2 + \ldots\ldots S_n \quad (1)$$

$$I_{Total} = I_{0-1} = \frac{S_i}{\sqrt{3}kV_0} = \frac{KVA_{Total}}{\sqrt{3}kV_0} \quad (2)$$

$$V_{0-1} = I_{0-1} Z_{0-1} \quad (3)$$

$$P_{loss(0-1)} = I_{0-1}^2 R_{0-1} \quad (4)$$

$$V_1 = V_0 - V_{0-1} \quad (5)$$

Where,

$S_1, S_2, \ldots\ldots, S_n$ are known values of the load connected to individual nodes of a this system.

S_i=total load where, i =1, 2,…,n

$Z_{0-1}, Z_{1-2}, \ldots\ldots, Z_n$ are known values of impedence of each feeder segment.

I_{Total} = total current supplied by the source at reference node

V_0=known voltage at the reference node

V_{0-1}=voltage drop for segment between nodes 0 and 1

$P_{loss(0-1)}$=Power loss for segment between nodes 0 and 1.

V_1 = the voltage at node 1

Similarly the voltage drop for next segment, voltage at next node, load current for next node and segment current for next segment are computed.

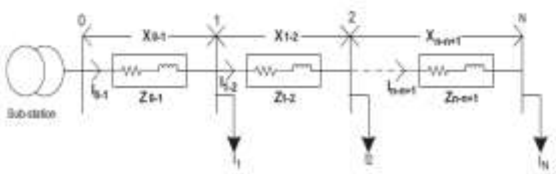

Figure 1: Feeder without DG

3.1.2 Power loss and voltage drop implementing DG

Now, consider to the ''nth'' node of the feeder, DG is connected as shown in Fig.1. As the voltage profile is improved along the line, this will change the feeder current in each segment which will further cause the feeder current to decrease. As a result of the injected current source, the feeder current between the source and the location of DG will also change. The change in feeder current due to DG installation is determined for each feeder segment. Equations (1) to (5) are used to calculate the incremental power loss, total power loss, the incremental voltage drop and the total voltage drop can be calculated after DG is incorporated in the feeder.

3.1.3 Algorithm for solving DG placement and sizing problem using PSO based Analytical Approach

Step 1: Read the input data
Step 2: Calculate feeder parameters and using equations from (1) to (5), find segment currents, node voltages, power losses and voltage drop.
Step 3: Check the voltage limits for each node.
Step 4: If node voltages are out of limit, then connect a DG to the last node.

Step 5: Evaluate the change in each segment current due to DG implementation and, calculate the power loss and voltage drop using the equations.
Step 6: Check whether node voltages are within limit.
Step 7: Randomly generate an initial population (array) of particles with random positions and velocities on dimensions in the solution space (PSO implementation).
Step 8: For each particle, if the node voltage is within limits, calculate the total power loss and voltage drop and these values are considered as the p_{best}.
Step 9: Compare the minimum individual best of each particle with this p_{best}. If it lower than p_{best}, then set this value as the current p_{best} , and record the corresponding particle position.
Step 10: Choose the particle associated with the minimum individual best p_{best} of all the particles, and set the value of this p_{best} as the current overall best g_{best}.
Step 11: Update the velocity and position of particle using the equations below.

$$V_{id}^{iter+1} = wV_{id}^{iter} + c_1 r\,(P_{best_{id}} - S_{id}^{iter}) + c_2 r\,(G_{best_{id}} - S_{id}^{iter}) \qquad (6)$$

$$S_{id}^{iter+1} = S_{id}^{iter} + V_{id}^{iter+1}\ ;\ i=1, 2,\ldots, n \ \&\ d = 1, 2,\ldots,m \qquad (7)$$

Step 12: If the iteration number reaches the maximum limit, go to step 12. Otherwise, set iteration index $k = k + 1$, and go back to step 7.
Step 13: Print out the optimal solution to the target problem. The best position includes the optimal location and size of DG, and the corresponding fitness value representing the minimum total power loss and voltage drop.

3.2 For Voltage Stability based Analytical Approach

Using load flow, bus current injections are determined and the relationship between the bus current injections and branch currents can be obtained by applying Kirchhoff's Current Law (KCL) to the distribution network. The branch currents can then be formulated as functions of equivalent current injections. Therefore, the relationship between the bus current injections and branch currents can be expressed as

$$[B] = [B1BC][I] \qquad (8)$$

Where, BIBC is the bus-injection to branch-current matrix.

The relationship between branch currents and bus voltages can be obtained as follows

Step 1: Read BIBC matrix, Z_b branch impedance vector.
Step 2: Convert Z_b vector to a diagonal matrix Z by setting off diagonal elements to zero.

$$Z = diag\,(Z_b) \qquad (9)$$

Step 3: Multiply transpose of BIBC matrix with Z matrix.

$$BCBV = ([BIBC]^T * Z) \qquad (10)$$

Where BCBV stands for Branch-Current to Bus-Voltage matrix.

3.2.1 Voltage Stability Index

When a power system approaches the voltage stability limit, the voltage of some buses reduces rapidly for small increments in load, and the controls or operators may not be able to prevent the voltage decay. In some cases, the response of controls or operators may aggravate the situation and the ultimate result is voltage collapse. Many incidents of system blackouts because of voltage stability problems have been reported worldwide. In order to prevent the occurrence of voltage collapse, it is essential to accurately predict the operating condition of a power system. Therefore, engineers need a fast and accurate voltage stability index (VSI) to help them monitoring the system condition. The voltage stability margin is a parameter that identifies the near collapse nodes. The node with small stability indices are called weak nodes and these should be reinforced by injecting reactive power. In the present analysis, voltage stability index is calculated for time variant realistic ZIP load model. ZIPS are the coefficients of a load model comprised of constant impedance, constant current and constant power loads.

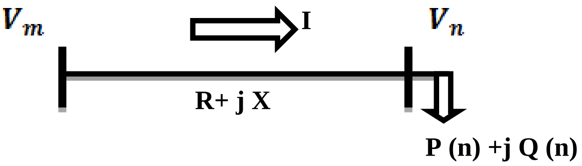

Figure 2: Single Line Layout of System

Voltage stability index is determined for each bus using Equation (11) and the bus with minimum VSI is determined. VSI of each bus is a number between 0 and 1.

$$|V_m|^4 - 4(P_{m2}R_{mn} - Q_{m2}X_{mn})|V_m|^2 - 4.0\{(P_{m2}X_{mn} - Q_{m2}R_{mn})\}^2 = SI \qquad (11)$$

Where,
P_{m2} = Total real power load fed towards node m2
Q_{m2} = Total reactive power load fed towards node m2
R_{mn} =Branch resistance
X_{mn} =Branch reactance
V_m = bus voltage of m^{th} bus
SI= stability index

3.2.2 Mathematical modeling for distributed generation

For determining the optimal size of DG, let us assume;

$$\zeta = (sign)*\tan\,(cos^{-1}(DG_{pf})) \qquad (12)$$

Sign = + 1: DG injects reactive power;
Sign = - 1: DG is consuming reactive power

The real and reactive power loss are given as follows:

$$P_1 = \sum_{\substack{m=1 \\ n=1}}^{N} [\alpha_{mn}(P_m P_n + Q_m Q_n) + \beta_{mn}(Q_m P_n - P_m Q_n)] \qquad (13)$$

$$Q_1 = \sum_{m=1, n=1}^{N}[\gamma_{mn}(P_m P_n + Q_m Q_n) + \xi_{mn}(Q_m P_n - P_m Q_n)] \quad (14)$$

Where,

$$\alpha_{mn} = R_{mn}\left(\frac{\cos(\delta_m - \delta_n)}{|V_m||V_n|}\right),\ \beta_{mn} = R_{mn}\left(\frac{\sin(\delta_m - \delta_n)}{|V_m||V_n|}\right)$$

$$\gamma_{mn} = X_{mn}\left(\frac{\cos(\delta_m - \delta_n)}{|V_m||V_n|}\right),\ \xi_{mn} = X_{mn}\left(\frac{\sin(\delta_m - \delta_n)}{|V_m||V_n|}\right)$$

The DG optimal size at m^{th} bus is given by

$$P_{DGm} = \frac{\alpha_{mm}(P_{Dm} - \zeta^{*} Q_{Dm}) - \beta_{mm}(\zeta^{*} P_{Dm} + Q_{Dm}) - X_m + \zeta Y_m}{\zeta^{2*}\alpha_{mm} + \alpha_{mm}} \quad (15)$$

Where,

P_{Dm}= Optimal real power demand at m^{th} bus

Q_{Dm}= Optimal reactive power demand at m^{th} bus

X_m= reactance at m^{th} bus

Y_m=admittance at m^{th} bus

DG can be classified into four major types based on their terminal characteristics in terms of real and reactive power delivering capability as follows:

Type 1 DG: Only active power injection by DG, so $DG_{pf} = 1, \zeta = 0$

Type 2 DG: Only reactive power injection by DG, so $DG_{pf} = 0, \zeta = \infty$

Type 3 DG: Active(P) and Reactive(Q)power injection mutually and the PF ranges between $0 < DG_{pf} < 1$, so $\zeta = P_{DGm}$, constant sign= +1.

Type 4 DG: Mutual Active (P) and Reactive (Q) power injection and the PF ranges between $0 < DG_{pf} < 1$, so $\zeta = P_{DGm}$, constant sign= -1

3.2.3 Cost Analysis

The economics attributes of energy loss, active and reactive power of DG are calculated based on the mathematical model represented as:

(i) Energy losses (EL): The cost of energy loss on an annual basis is given by

EL_{cost} = (Total real power loss)*(E_C *T) Rs/year (14)

Where,

E_C = 4.63 Rs/kWh

T = 8760 hours/year

Cost attributes of DG is selected as per the data [11]

(ii) Cost characteristics is selected as per the data available [11]

$C(P_{DG}) = a*P_{DG}^2 + b*P_{DG} + c$ Rs (15)

Where a=0, b=20, c= 0.25

Cost of reactive power supplied by DG is given as

$C(Q_{DG})$= [Cost(C(S_{max})-Cost($\sqrt{S_{max}^2 - Q_{DG}^2}$))*K in Rs/hr (16)

Where,

K=0.05 to 0.1

3.2.4 Constraints of Allocating DG's

CIGRE engineers designed and gave some important constraints regarding optimal allocation of DG into the system. Below steps shows the constraints for allocating DG.

(a) 5 MW capacity will be the maximum value of DG to be installed in the system.

(b) The Power balance condition should be followed for installation of DG.

(c) The operator should follow the voltage limits as l ± 0.05 within a tolerance of 0.001.

3.2.5 Algorithm for solving DG placement and sizing problem using Voltage stability based Analytical Approach

(a) For finding minimum voltage and voltage stability index:

The objective is to find out minimum voltage and voltage stability index for identifying weak nodes in the test case with considered IEEE standard test case data.

Step 1: Standard test case data are considered for running the load flow.

Step 2: Select central bus at which the substation is placed.

Step 3: Make element ordering by considering the bus with respect to the root bus (sort row operation with respect to bus).

Step 4: Formulate BIBC and BCBV matrix.

Step 5: Initialize all the voltages by 1 .0 pu and consider tolerance of 0.0001.

Step6: Calculate load current for every iteration.

Step 7: Calculate voltages with the obtained currents and matrices up to which the test case has converged with specified tolerances, and find out minimum voltage index value.

Step 8: Calculate the voltage stability index by Equation (11) from the obtained voltages by injection of total real power load and reactive power load fed to the node, and find out the minimum voltage stability index value and inject a DG to the bus having minimum voltage stability index. The DG is assumed to be of that type, which injects both active power and reactive power.

(b) For Optimal Size and Allocation of DG

The main objective is to determine the optimal size and location of DG with optimum power factor considering minimum power losses and improved voltage profile with low cost attributes.

The steps for this are as follows;

Step 1: Run the base power flow with BIBC matrix and the BCBV matrix for finding the bus voltages and voltage stability index.

Step 2: Find the optimum size of added DG for each bus except the reference bus using Equation (15).

Step 3: Real power losses are calculated from Equation (13) for each individual bus for allocating optimum size of DG to the bus.

Step 4: Minimum power loss node is chosen as the optimal node for allocating DG.
Step 5: Check voltage and power balance constraints according to CIGRE as referred to in section 3.2.4. This algorithm is applied for both single as well as multi (two)-DG case with type 3 DG.

4. Simulation Results

IEEE 33-bus test system has been considered for implementing the proposed methodologies. Figure 3 shows 33-bus test case.

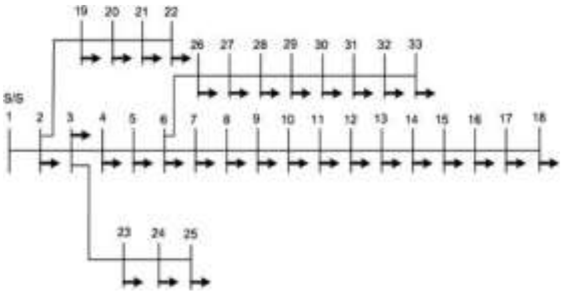

Figure 3: 33-bus Radial Distribution Network

4.1Simulation results for PSO based Analytical Approach

The analysis is carried out on an IEEE 33-bus test system to show that the algorithm can be applied to enhance the performance of the system in terms of node voltage profile improvement and power loss reduction. The results show that optimal placement of DG can reduce the power loss and voltage drop in a distribution system. The algorithm of this method is programmed in MATLAB 2013. This algorithm is tested on a 12.66 kV, 100 MVA IEEE 33-bus test system. The 33 bus system has 32 nodes or sections with the total load of 3.715 MW and 2.3 MVar. According to IEEE standards, the voltage magnitude at all nodes of distribution feeder should be ±5% of rated value. The limit has been considered in the proposed algorithm. It is found that with the introduction of single DG, the active power loss reduces from 206.732 kW to 111.573 kW. The optimal location is at node 30 with total size of 1.310 MVA. From this proposed approach for multiple DG allocation, the system losses are reduced from 206.732 kW to 71.85 kW for 33 bus system and the optimal location is at node 6 and node 32 with DG size of 1.310 MVA and 0.873 MVA respectively. The results for single and multiple DG for 33 bus system are presented in Table 1.

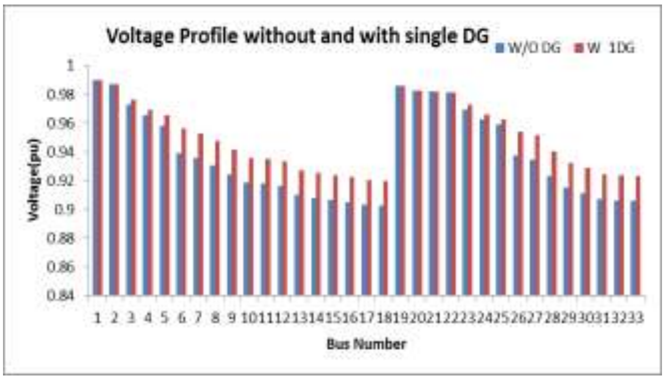

Figure 4: Voltage profile without and with single DG

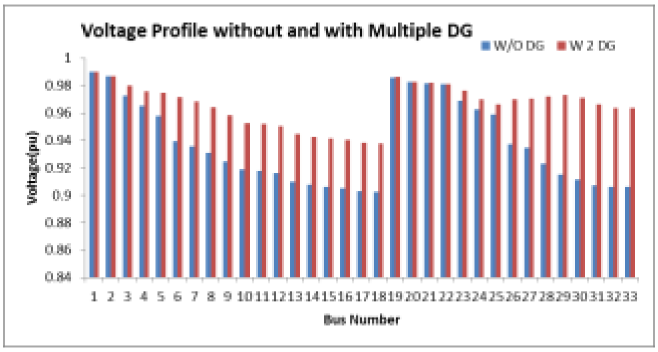

Figure 5: Voltage profile without and with multiple DG

Table 1: Review of results for single and multiple DG

Test Case	Installed DG (MVA)			Min voltage (pu)	Ploss (kW)	% Change in loss
	No DG			0.9024 @18	206.732	
1 DG	Size	1.31		0.9247 @18	111.573	46.03
	Bus	30				
2 DG	Size	1.31	0.873	0.9378 @18	71.85	65.24
	Bus	6	32			

4.2 Simulation results for Voltage Stability based Analytical Approach

4.2.1 Simulation results without DG

The results of the considered 33 bus test system have been tabulated in table 2.From this table, it is noticed that a minimum voltage of 0.9036 pu appears at 18th bus and the corresponding VSI is 0.6686 pu. It is noticed that the bus number 18 is the weak bus according to stability index. From table 3, the real power loss in the 33 bus system is 211.2939 kW, so that the percentage of real power loss in total system is 5.6686% of the total load in the system for the operating power factor of 0.8225 lag.

Table 2: Voltage and VSI without DG for 33 bus system

Bus No.	Voltage in pu	VSI in pu
1	1	1.0000
2	0.9970	0.9994
3	0.9828	0.9846
4	0.9753	0.9314
5	0.9679	0.9033
6	0.9493	0.8739
7	0.9458	0.8119
8	0.9322	0.7987
9	0.9258	0.7545
10	0.9199	0.7343
11	0.9191	0.7161
12	0.9175	0.7134
13	0.9113	0.7085
14	0.9091	0.6899
15	0.9077	0.6830
16	0.9063	0.6787
17	0.9042	0.6746
18	0.9036	0.6686
19	0.9965	0.9383
20	0.9929	0.9859
21	0.9922	0.9718
22	0.9915	0.9691
23	0.9792	0.9149

24	0.9725	0.9191
25	0.9692	0.8944
26	0.9474	0.8173
27	0.9449	0.8055
28	0.9334	0.7959
29	0.9251	0.7585
30	0.9216	0.7325
31	0.9174	0.7211
32	0.9164	0.7082
33	0.9162	0.7054

Table 3: Review of result in 33 bus test system without DG

Test system	33 bus
Power factor	0.8225
Min VSI without DG	0.6686@ 18
Min Voltage without DG	0.9036 @ 18
Load demand with real power loss without DG	3.715MW @211.29 39 kW
Active power loss cost Rs/year without DG	85.698 lakh

4.2.2 Simulation results for single DG

Table 4 shows the simulation results for the proposed network. This table shows at which position the DG is allocated and the optimal size of DG in MVA, power factor of DG unit and cost attributes. For the proposed 33-bus network, table 5 shows the voltage and stability index after DG integration. It is seen that bus 18 has minimum voltage of 0.9546 pu having the minimum voltage stability index of 0.8323 pu at 18th bus only. The voltage and voltage stability index have been improved after placing DG in the optimal position. In 33-bus test system, from Figure 6, bus 6 is found to be the best location with minimum power loss. The optimal power factor for the system obtained is 0.8225 lagging and corresponding optimal size is 3.016 MVA. It has a cost for real power 49,622 Rs/hr for a real power injection of 2481.09 kW according to cost analysis. The test case needs both real and reactive power injection to reduce losses. The total losses with optimal location, optimal size, having best power factor is 74.9128 kW with real power loss cost as 30, 38, 374 Rs/year

.

Table 4: Review of result in 33 bus test system with DG

DG value in MVA	3.016 MVA @ 6
Min Voltage Stability index	0.8323 @ 18
Min Voltage	0.9546 @ 18
Load demand with Real power loss	3.715 MW@ 74.9128 kW
Active DG cost Rs/hr	49,622
Active Ploss cost Rs/ year	30,38,374

Table 5: Voltage and VSI with DG for 33 bus system

Bus No.	VSI with DG	Voltage with DG
1	1.0000	1.0000
2	1.0075	0.9991
3	1.0363	0.9958
4	1.0135	0.9964
5	1.0172	0.9974
6	1.0701	1.0004
7	1.0005	0.9969
8	0.9830	0.9832
9	0.9326	0.9768
10	0.9089	0.9709
11	0.8885	0.9701
12	0.8851	0.9685
13	0.8785	0.9623
14	0.8572	0.9600
15	0.8492	0.9586
16	0.8442	0.9572
17	0.8392	0.9552
18	0.8323	0.9546
19	0.9888	0.9985
20	0.9940	0.9949
21	0.9799	0.9942
22	0.9771	0.9936
23	0.9963	0.9922
24	0.9686	0.9855
25	0.9430	0.9822
26	1.0065	0.9985
27	0.9931	0.9959
28	0.9801	0.9844
29	0.9369	0.9761
30	0.9071	0.9726
31	0.8938	0.9684
32	0.9792	0.9674
33	0.8760	0.9672

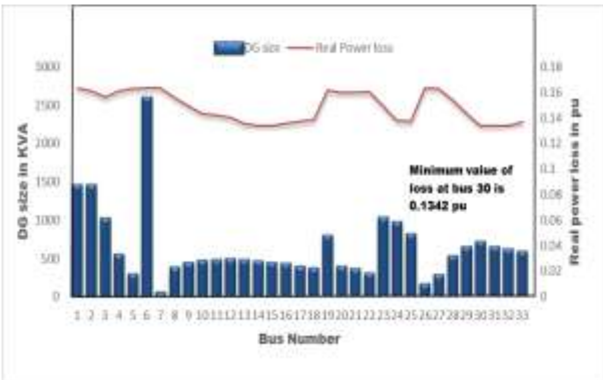

Figure 6: Real power loss and DG size

4.2.3 Simulation results for multi DG

For extending the analysis for multiple DG for further reduction of real power loss, the load flow is run with previously obtained values for finding another optimal location in continuation with the previous one. From Figure 7, it is noticed that bus 30 has the lowest value corresponding to a minimum power loss of 56.3799 kW. For the optimal power factor 0.8225 lag for this system, the optimal size is 2564.070 kVA and 685.656 kVA for bus 6 and bus 30 respectively with a total size of 3.249MVA. The cost for real power is 61,095 Rs/hr for a real power injection of 2410.22 kW and 644.5168 kW. The test case needs both real and reactive power injection to reduce losses.

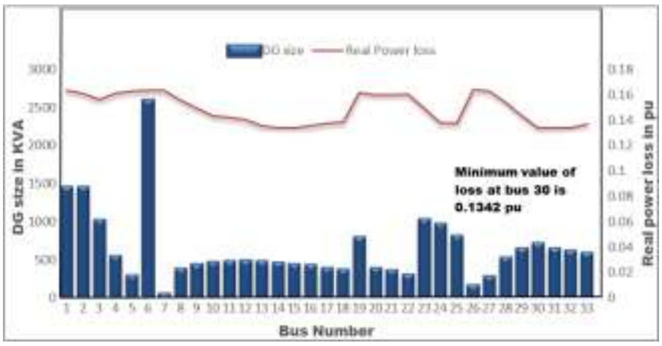

Figure 7: Two DG allocation with real power loss and DG size

5. Comparison of Results

The table 6 gives a comprehensive comparison of the results obtained from the proposed method and the earlier methods. From this table, it is seen that the minimum power loss in case of ABC algorithm with no DG, single DG and multi (two) DG's are 203.90 kW, 106.32 kW and 91.721 kW respectively with %reduction (with base case) in power loss of 47.85% for single DG and 55.02% for multi DG. Similarly, for PSO based analytical approach, the minimum power losses are 206.732 kW, 111.573 kW and 71.85 kW with no DG, single DG and multi (two) DG's respectively with % reduction (with base case) in power loss of 46.03% for single DG and 65.24% for multi DG. For voltage stability based analytical approach, the minimum power losses are 211.2939 kW, 74.9128 kW and 56.3799 kW with no DG, single DG and multi (two) DG's respectively with %reduction in power loss of 64.54% for single DG and 73.316% for multi DG. Thus, we can conclude that the voltage stability based analytical approach gives better results.

Table 6: Comparison of results for single and multiple DG for 33 bus system

	Test Case	Installed DG (MVA)			Min Volt (pu)	Ploss (kW)	% Drop In loss
ABC algorithm (Nguyen Tung and Dam Xuan Dong)		No DG			0.9118	203.9	
	1 DG	Size	2.563		0.9467	106.32	47.85
		Bus	6				
	2 DG	Size	1.924	0.587	0.9541	91.721	55.02
		Bus	6	15			
PSO based analytical approach-proposed approach		No DG			0.9024	206.732	
	1 DG	Size	1.310				
		Bus	30		0.9247	111.573	46.03
	2 DG	Size	1.310	0.873			
		Bus	6	32	0.9378	71.85	65.24
Voltage Stability index based analytical approach-proposed approach		No DG			0.9036	211.2939	
	1 DG	Size	3.016				
		Bus	6		0.9546	74.9128	64.54
	2 DG	Size	2.564	0.6856			
		Bus	6	30	0.9765	56.3799	73.316

6. Conclusion

DG units are usually installed near the load site on the radial distribution networks. Thus, part of the transmission power is replaced by the injected DG power, causing a reduction in transmission and distribution line losses, which minimizes costs related to loss. Injecting active and reactive power by DG units improves system voltage profiles and the load factor, which minimizes the number of require voltage regulators, capacitors and their ratings and maintenance costs. However, the amount of improvement depends on the size and location of the DG unit. This paper presents two methodologies to find out the optimal location and size of DG unit for voltage profile improvement and minimizing power loss in IEEE 33 Bus distribution system; one is Particle Swarm Optimization based analytical approach and other is voltage stability based analytical approach. The methodologies proposed are capable of functioning under randomly distributed load conditions with low power factor for single DG as well as multiple DG system. The voltage stability based analytical approach gives better results as compared with other methods that is, results published by Nguyen Tung and Dam Xuan Dong (using Artificial Bees Colony Algorithm) [12] and PSO based analytical approach with minimum power losses of 211.2939 kW, 74.9128 kW and 56.3799 kW with no DG, single DG and multiple (two) DG's respectively.

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