

# A Multi Target Function for Ideal Siting and Sizing of Distributed Generation (DG) Systems using Particle Swarm Optimisation (PSO)

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**Abstract:** Different load centers where the energy is utilized are connected to the generating stations through high voltage transmission systems and a low voltage distribution systems. The losses occurring in the distribution network amount to nearly 40% of the total losses. Optimally located Distributed Generation (DG) systems offer multiple benefits in reducing the losses and supplying quality power. In this work a multi target formulation is suggest for ideal placement and capacity of the DG. The proposed formulation is optimized with Particle swarm optimization (PSO) Algorithm. Three constraints like power loss, voltage profile and thermal flow limits have been considered in the optimization. The approach is validated using an IEEE 69 Bus radial distribution system and the results proves the suitability of the proposed approach in diminishing the losses and improving the voltage profile of the network. A cost benefit analysis has also been incorporated to assess the suitability of different types of DG units.

**Keywords:** Distribution network, Distributed Generation (DG), Particle swarm optimization (PSO), IEEE 69 Bus system.

## 1. INTRODUCTION

In organize to deliver quality power to the consumers great attention should be paid to the arranging and planning of distribution system. The distribution system can be broadly classified into primary and secondary distribution networks [1]. The primary distribution system can further be classified into a radial distribution network or a mesh network. Ordinarily a large portion of the primary distribution network is intended to be radial in nature. The radial network offers many advantages like lesser cost, predictable performance, simple protection schemes and simplicity of analysis. A mesh system is rather complex having two paths between substation and purchaser. It is additionally requires complex protection strategies which incorporates higher investment than in radial distribution systems.

Even though the radial distribution networks have lesser reliability when compared to the mesh base systems, their reliability can be greatly enhanced through good design factors. Different strategies have been effectively employed to reduce energy losses and maintain the better voltage profile at different buses in the network. Most of these approaches have employed reactive power compensation methods to diminish reactive components of the currents in the buses so that the energy losses can be reduced. Wide verities of methods have been successfully employed for optimization of the distribution systems. The current trend in optimization of distribution system is heavily skewed towards the installation of distributed generators which can be switched at closed proximity to the load centers. A universal meaning of DG suggested in [2] which is now extensively accepted defines DG as: "Distributed Generation is electric power sources associated straightforwardly to the distribution network or on the consumer site of the meter". From a distribution system point of view DG provides a viable option for ability expansion in an highly aggressive electricity environment market. A DG system offers many advantages like reduced lead time with lower

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investment risk, it deployed in smaller sizes are capable of tracking of the load variations more closely and there exists a wide options and range for different DG technologies.

In order to exploit the benefits of distribution systems it can be constructed as optimization problem determine its optimal size and location. This optimization can be directed towards the reduction of active losses of the feeders [3], [4]; are towards reducing the supply cost of the total network. The optimization approaches also tend to optimize the operation of generators and compensation of losses [5], [6], [7]; and enhanced utilization of the circuit available generation of capacity [8] Lagrangian Based Method was employed by Rosehart and Nowicki [9] to study the placing and sizing of DG in distribution systems. Similarly Celli et. al., [10] employed Genetic Algorithm for the above approach while Wang and Nehir [11] employed analytical methods. While the above methods analyzed in the effects of DG placements without reconfiguration Raj et. al., [12] proposed Particle Swarm Optimization technique to identify the optimize size and location employing indices to provide maximum improvement in the power quality. Alemi and Gharehpetian [13] have proposed a diagnostic technique which depends on affectability elements for ideal allocation and sizing of DG units keeping in mind the end goal to reduce power loss and to enhance the voltage profile in distribution networks. The sensitivity factor technique lessens the inquiry space by the linearization of nonlinear conditions around the preliminary point. Ahmadigorji et. al., [14] have joined the advantages of cost of DG in their technique to locate the ideal area and size of DG further more have considered imperatives on voltage limits and operational points of confinement of DG in the figuring of target capacity. Firouzi et. al., [15] have proposed Ant Colony Optimization Based Algorithm for finding ideal siting and size of DG in distribution systems. Shayeghi and Mohammadi [16] have proposed probabilistic model for ideal area and estimating of DG for decreasing the losses and voltage profile enhancement in distributed power systems. Lee and Park [17] have proposed a strategy to choose the ideal areas of numerous DGs by considering the power loss in consistent state operation. From there on, their ideal sizes are dictated by utilizing Kalman Filter Algorithm. Padma Lalitha et. al., [18] have proposed new system known as Artificial Bee Colony (ABC) calculation to locate the ideal size of DG by taking number and area of DG as information sources. The area of DG is distinguished by single DG position strategy [19], which is a the simultaneous reconfiguration and siting of DG with appropriate estimating has been appeared by Rao et. al., [20] utilizing harmony search algorithm (HSA) which dealt with making harmony in music standards. Artificial bee colony method province calculation taking into account passerby and scout honey bee's was utilized by Murthy et. al., [21]. Nayak [22] utilized hyper cube and colony calculation in light of pheromone aroma following by ants inside hypercube outline work.

In this paper a multi target function is used to identify the best possible location and capacity of the DG units. The objective function has been optimized using Particle Swarm Optimization (PSO). The primary objective of the function is to recognize the suitable position and size of DG so as to reduce the power losses and enhance the overall voltage profile of the system. The primary constraints considered for optimization include the power loss, voltage profile and thermal flow limits. The proposed approach is validated using an IEEE 69 bus radial distribution system. A cost benefit analysis of different types of DGs has also been incorporated.

## 2. PROBLEM STATEMENT

The primary intention of this formulation is to ensure best possible placement and capacity of DG units while considering multiple objective of diminution in power loss and enhancing the voltage profile. These multiple targets are collective through weights to form a liner function which is representative of all the three objectives. The primary constraints considered in this work are;

1. Loss before introducing DG in power grid ought to be not as much as losses subsequent to introducing of it.

$$\text{Loss}_{\text{with DG}} \leq \text{Loss}_{\text{without DG}}$$

2. Voltage limitations  $V_{\text{BUS min}} \leq V_{\text{BUS}} \leq V_{\text{BUS max}}$
3. Line limits constraints in terms of line thermal flow limits are subjected to  $S_1 \leq S_{\text{max}}, \forall = \{1, 2, 3 \dots L\}$ ,

Where  $S_1$  is the thermal limit of each line and number of lines in the system is  $L$ .

The multi target function is given as

$$\begin{aligned} \text{Max (F)} = & W_1 \left\{ \max \left[ 0, \frac{1}{n} \sum_{i=1}^n (\text{Voltage}\%_{i \text{ with DG}} - \text{Voltage}\%_{i \text{ without DG}}) \right] \right\} \\ & + W_2 \left\{ \max \left[ 0, \frac{1}{n} \sum_{i=1}^n (P_{j \text{ with DG}} - P_{j \text{ without DG}}) \right] \right\} \\ & + W_3 \left\{ \max \left[ 0, \frac{1}{n} \sum_{i=1}^n (Q_{j \text{ with DG}} - Q_{j \text{ without DG}}) \right] \right\} \end{aligned} \quad (1)$$

Where,

$\text{Voltage}\%_{i \text{ with DG}}$  : Percentage of Voltage in  $i_{\text{th}}$  bus with DG source

$\text{Voltage}\%_{i \text{ without DG}}$  : Percentage of Voltage in  $i_{\text{th}}$  bus without DG source

$P_{j \text{ with DG}}$  : Active Power Loss in  $j_{\text{th}}$  branch with DG source

$P_{j \text{ without DG}}$  : Active Power Loss in  $j_{\text{th}}$  branch without DG source

$Q_{j \text{ with DG}}$  : Reactive Power Loss in  $j_{\text{th}}$  branch with DG source

$Q_{j \text{ without DG}}$  : Reactive Power Loss in  $j_{\text{th}}$  branch without DG source

$m$  : Total Number of Branches.

$n$  : Total Number of Buses

$W_1 + W_2 + W_3 = 1$ , where  $W_1$ ,  $W_2$  and  $W_3$  are proposed weights in this work, they are assumed to be equal.

### 3. PARTICLE SWARM OPTIMIZATION (PSO)

Particle Swarm Optimization (PSO) algorithm is one of the pioneering algorithms in the domain of swarm intelligence. It was earliest presented in 1995 by Eberhart and Kennedy, and it was developed under the motivation of performance laws of bird groups, fish schools and human communities [23]. Unlike Genetic Algorithm (GA) which is also a population based approach, PSO doesn't employ operators like mutation, cross over and selection. It enhances the populace through data trade among individual components of the populace. It begins its operation by arbitrarily browsing a gathering of arrangement and afterward looking it iteratively. In PSO each solution is consider to be a particle having specific fitness value which is defined by the objective function. These particles investigate the solution of space for their best position and for the position of the best particles in the swarm. The PSO identifies the optimum solution through repeated searching after initial configuration of a group of random solutions. In every iteration the best position identified with a particle is called  $p_{\text{best}}$ , similarly the best position identified with the whole swarm is called  $g_{\text{best}}$ . For each particle id, the velocity and its position are redesigned. Every particle updates its position

based upon its individual best position, global best position surrounded by particles and its earlier velocity vector according to the subsequent equations:

$$v_i^{k+1} = w \times v_i^k + c_1 \times r_1 (p_{\text{best}_i} - x_i^k) + c_2 \times r_2 \times (g_{\text{best}_i} - x_i^k) \quad (2)$$

$$x_i^{k+1} = x_i^k + \chi \times v_i^{k+1} \quad (3)$$

In this equations,

$v_i^{k+1}$  : The  $i^{\text{th}}$  Particle velocity at  $(k + i)^{\text{th}}$  iteration

$w$  : The Particle's Inertia weight

$v_i^k$  : The  $i^{\text{th}}$  Particle velocity at  $k^{\text{th}}$  iteration

$c_1, c_2$  : Optimistic constants having values among [0, 2.5]

$t_1, r_2$  : Arbitrarily generated numbers among [0, 1]

$p_{\text{best}_i}$  : The  $i^{\text{th}}$  particle the best position obtained based upon its own experience

$g_{\text{best}}$  : The particle Global best position in the population

$x_i^{k+1}$  : The  $i^{\text{th}}$  particle position at  $(k + i)^{\text{th}}$  iteration

$x_i^k$  : The  $i^{\text{th}}$  particle position at  $k^{\text{th}}$  iteration

$\chi$  : Constriction factor. It may facilitate assure convergence.

Appropriate choice of inertia weight  $w$  provides good balance between global and local explorations.

$$w = w_{\text{max}} - \frac{w_{\text{max}} - w_{\text{min}}}{\text{iter}_{\text{max}}} \times \text{iter}$$

In the above expression,  $w_{\text{max}}$  is the value of inertia weight at the commencement of iterations,  $w_{\text{min}}$  is the value of inertia weight at the finish of iterations, present iteration number is  $\text{iter}$  and maximum number of iterations is  $\text{iter}_{\text{max}}$ .

**Step 1:** In the first step, the control variables are defined. In this case the control variables are 'DG Size' and 'DG Location'. The maximum bound for the DG size is considered as a percentage of total load. This percentage is given as an input by the users. Similarly the possible locations are identified from the bus data of the respective system. At this step the PSO parameters are also defined like population size, number of iterations, minimum and maximum velocities are defined.

**Step 2:** The iteration number is considered to be '0' i.e., ' $\text{iter} = 0$ '

**Step 3:** The particles are randomly populated and for each particle a particular velocity is assigned

**Step 4:** The fitness of each particle is obtained by evaluating the fitness function described in Equation (1)

**Step 6:** The "personal best (Pbest)" of all particles and "global best (Gbest)" particle is found out from their fitness

**Step 7:** The iteration is incremented as  $\text{iter} = \text{iter} + 1$

**Step 8:** Velocity of each particle is calculated using Equation (2) and adjusted it if its limit gets violated

**Step 9:** New position of each particle is calculated using Equation (3)

**Step 10:** The fitness function of each particle is calculated using Equation (1)

**Step 11:** Pbest = P if for each particle if current fitness (P) is better than Pbest then

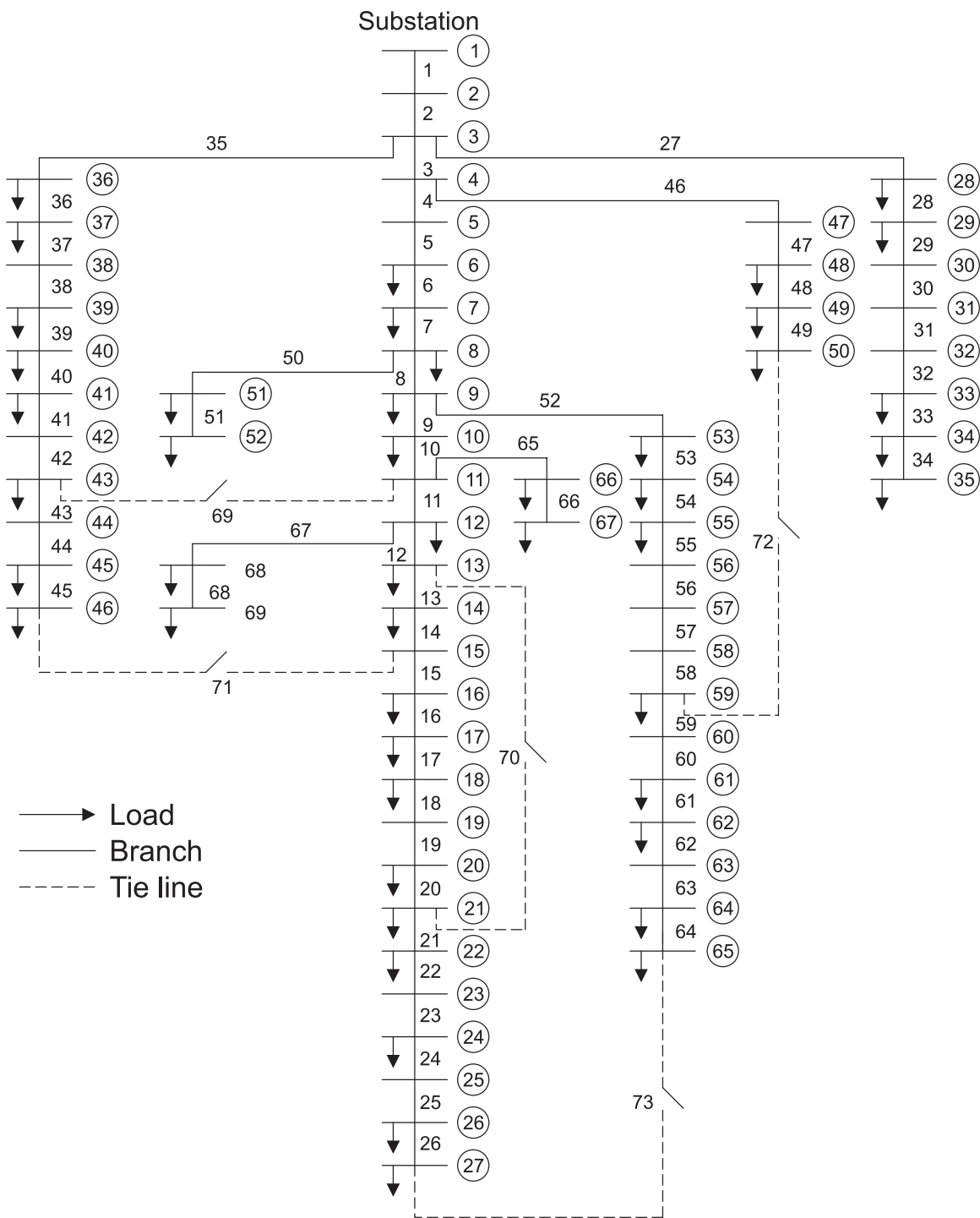
**Step 12:** Best of Pbest is set as Gbest

**Step 13:** The stopping criteria is checked for total number of iterations

**Step 14:** Coordinate of Gbest particle gives optimized values of control variables (the size and location of DG).

**4. TEST SYSTEM DESCRIPTION**

The test system for the case study is a radial distribution system of 12.66 kV with 69 buses, 7 laterals and 5 tie – lines (looping branches) [24].The total real power loss is 224.9457 kW and reactive power losses is 102.1397 kVar. For this system the minimum voltage has 0.9092 p.u. at bus 65. The single line diagram of the system is given in the Figure (1).



**Figure 1: 69 Bus Radial Distribution System**

**Table 1.0**  
**Details of 69 Bus Distribution System**

<i>Number of Buses</i>	<i>Number of Branches</i>	<i>Number of Tie Lines</i>	<i>Total Real Power</i>	<i>Total Reactive Power</i>
69	68	5	3.8MV	2.69Var

## 5. RESULTS AND DISCUSSION

The arranged approach is coded utilizing Matlab Version R2012a and MatPower version 5 [25] is utilized to run the optimal power flow solution utilizing Newton-Raphson strategy. The iteration settings for PSO incorporate 100 greatest quantities of iterations, with acceleration constant of 2 and 2.5 and most extreme and least inertia weights at 1 and 0.2 individually. The greatest and least velocity of particles is altered at 0.9 and 0.4 separately. The simulation are done in a system having Intel i5 Core processor shrouding a speed of 2.7GHz with a RAM of 4GB. PSO is implemented and the best of the results of 20 trail runs are presented in this section. The algorithm optimizes the multi-objective function and identifies the optimum placement and capacity of the DG unit. The location is specified in terms of the suitable Bus in which the DG of specified size has to be placed. To show the performance of the planned approach five cases are considered. These cases are in regard to maximum permissible DG sizing as a percentage of total load of the system. This constraint helps in validating the performance of the approach by binding the size of the DG unit and can be considered as one way of optimizing or representing the cost. The cases are

**Case 1:** Maximum size of DG in percentage of summation of total load is fixed at 10 %

**Case 2:** Maximum size of DG in percentage of summation of total load is fixed at 15 %

**Case 3:** Maximum size of DG in percentage of summation of total load is fixed at 20 %

**Case 4:** Maximum size of DG in percentage of summation of total load is fixed at 25 %

**Case 5:** Maximum size of DG in percentage of summation of total load is fixed at 30 %

**Table 2.0**  
**Optimal DG size and location**

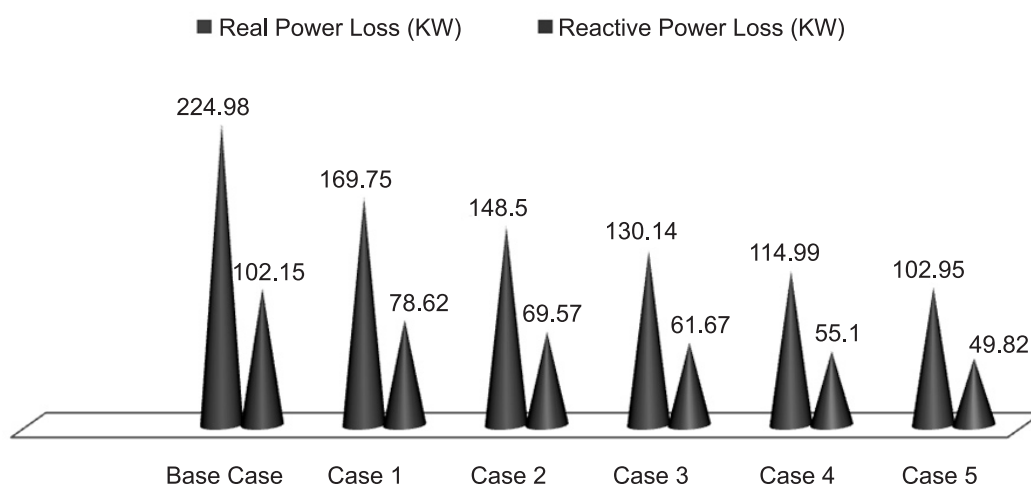
<i>Case</i>	<i>Location (BUS Number)</i>	<i>DG Size (KW)</i>
Case 1	64	380.19
Case 2	64	570.28
Case 3	61	760.37
Case 4	61	950.47
Case 5	61	1140.56

It can be inferred from the Table 2, the optimum location of the DG varies with the size of the DG. While the algorithm fixes a DG size of 380.19 KW to be optimally located in Bus 64, the DG size for Case 2 is fixed at 570.26 KW to be located at Bus 64. For other 3 cases the optimal location is identified as Bus 61 with a DG size of 760.37 KW, 950.47 KW, and 1140.56 KW for Case 3, Case 4 and Case 5.

**Table 3.0**  
**Real and Reactive Power loss for different cases**

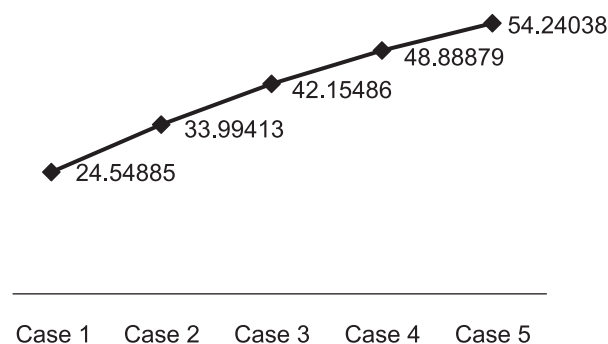
Case	Location ( BUS Number)	DG Size (KW)	Real Power Loss(KW)	Reactive Power Loss (KW)
Base Case	–	–	224.98	102.15
Case 1	64	380.19	169.75	78.62
Case 2	64	570.28	148.50	69.57
Case 3	61	760.37	130.14	61.67
Case4	61	950.47	114.99	55.10
Case5	61	1140.56	102.95	49.82

The effect of DG placement has a profound impact on real power losses and reactive power losses as can be observed from figure (2).



**Figure 2: Plot of Real Power loss and Reactive Power loss for different cases**

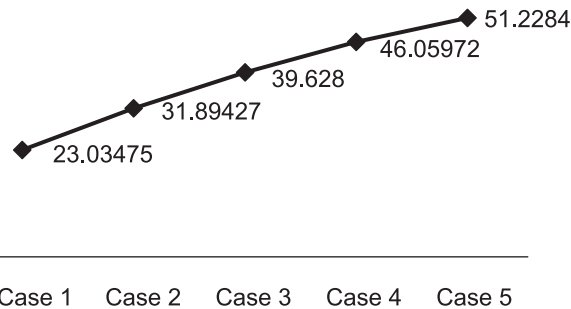
The real power loss for base case is 224.98 KW and there is substantial diminution in the real power loss with the placement of DG. The percentage reduction in real power loss in accordance with the size and location of DG is illustrated in the Figure 3. It clearly points to the significant diminution in power loss with the increase in size of DG.



**Figure 3: Percentage reduction of Real Power Loss for various cases as contrasted to the base case**

It can be inferred from the Figure 3 that there is greater reduction in losses with the increase in size of the DG. It can be observed from the figure while placement of DG of size 380.19 KW reduces the real power loss by 24.55 %, a DG of Size 570.28 KW placed in the same bus number 64 will reduce the real power loss by 33.91 %. With subsequent increase in the size of DG there is significant diminution in real power loss. A 42.15% reduction in real power loss when compared to base case can be achieved by insertion a DG of size 760.37 KW at bus 61, a reduction of 48.88 % can be brought about by insertion a DG of

size 950.47 KW at the same bus 61. A DG size of 1140.56 KW located at bus number 61 brings the real power loss to 102.95 which amounts to reduction of nearly 54.24 % contrasted to the base case without DG.



**Figure 4: Percentage reduction of Reactive Power Loss for various cases as contrasted to the base case**

It can be also inferred from the figure 4, the power quality can also be enhanced by the placement of DG. This can be attributed to the reality that the reduction in reactive power lead to a delivery of high quality power. The percentage of reduction in reactive power loss is comparable to the diminution of real power loss, brought about by the placement of DG. It can be observed from the figure a DG of size 380.19 KW placed at bus number 64 while optimizing for case 1 can reduce the real power loss by 23.03 %. Similarly maximum reduction if reactive power loss at 51.22 % can be achieved by placing a DG of size of 1140.56 KW at bus 61.

The placement of DG also has an improved effect on the voltage profile of the distribution system. Before the position of DG minimum voltage profile is observed at bus number 65. With the location of DG there is an enhancement in voltage profile at bus 65. The improvement for different cases is tabulated in the Table 4.0

**Table 4.0  
Minimum Voltage Profile for different cases**

Case	Location (Bus Number)	DG Size (KW)	Minimum Voltage Profile (pu)	Bus at which Minimum voltage Profile Occurs
Base Case	–	–	0.9092	65
Case 1	64	380.19	0.9116	65
Case 2	64	570.28	0.9129	65
Case 3	61	760.37	0.9141	65
Case 4	61	950.47	0.9153	65

The placement of DG also brings about enhancement in voltage profile of the system. The plot of voltage profiles for various cases after the placement of DG is illustrated in the Figure 5.

The economic aspects of DGs also play a key role in defining the type and size of the DGs. In this paper we have made a cost benefit analysis by considering PV Cells and Wind energy as the probable choice of DGs proposed to be installed. The installation cost of PV for sizes below 1 MW is considered to be \$2,493/KW and the operation and maintenance cost is fixed at \$19/ KW/Year. The installation cost for PV of sizes greater than 1 MW is fixed at \$2,025/KW and the operation and maintenance cost is fixed at \$19/KW/Year [26]. Similarly the cost of installing wind turbines as DG units is fixed at \$3,751/KW for units of sizes 100 KW-1000 KW, having an operation and maintenance cost of \$31/KW/Year. The cost of wind turbines of size greater than 1MW is fixed at \$2,346/KW having an operation and maintenance cost \$33/KW/Year.



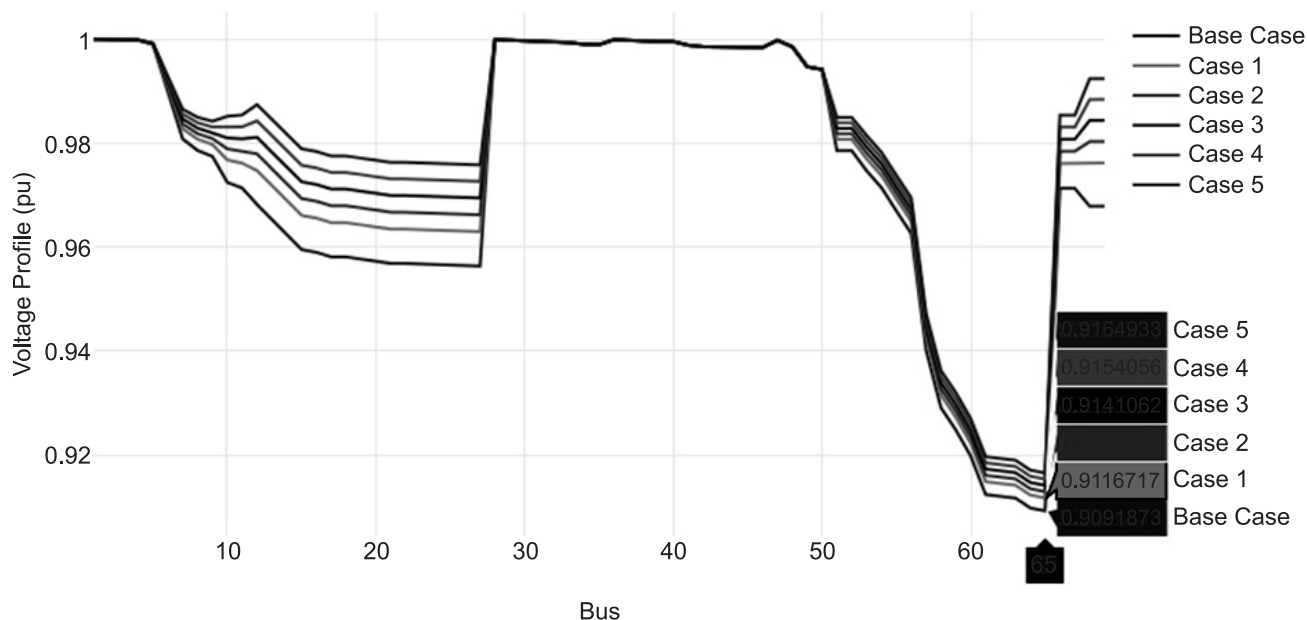


Figure 5: 69 Bus system Voltage Profile after placement of DG for different cases

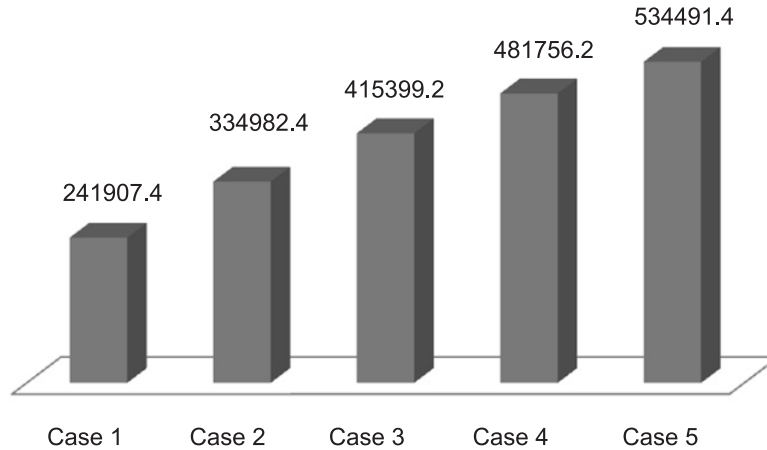
**Table 5.0**  
Installation, Operation & Maintenance cost of DGs

Case	PV		Wind	
	Installation Cost (USD)	Operation & Maintenance Cost/ Year (USD)	Installation Cost	Operation & Maintenance Cost
Case 1	947813.7	7223.61	1426093	11785.89
Case 2	1421708	10835.32	2139120	17678.68
Case 3	1895602	14447.03	2852148	23571.47
Case 4	2369522	18058.93	3565213	29464.57
Case 5	2309634	18248.96	2675754	37638.48

It can be inferred from the above table that there is a steep decline in unit cost curve (\$/kW) as the size of a wind turbine increases. The installation expenditure is justifiable owing to the fact that the installation of DGs results in sufficient savings by the way of reduced real power losses and savings that can be attributed to it. The loss due to real power loss is fixed at \$0.10 / KW-hr. The savings on account of reduced real power loss is illustrated using the Table 7 and cumulative savings over a 5 year operational period is illustrated using Figure 6.

**Table 6.0**  
Cost of Real Power loss and savings that can be brought about by installing DGs

Case	Cost of Real Power Loss (USD)/Year	Savings compared to Base Case USD/Year
Base Case (No DG)	197082.5	0
Case 1	148701	48381.48
Case 2	130086	66996.48
Case 3	114002.6	83079.84
Case 4	100731.2	96351.24
Case 5	90184.2	106898.3



**Figure 6: Cumulative savings in reduced Real Power loss over a 5 year period**

Table 7.0 depicts the net savings in reduced real power losses after deducting the cost of operation and maintenance every year. It can be observed from the table that savings delivered by PV installation is comparatively higher than the wind energy for sizes till 1 MW. Even at sizes greater than 1 MW PV installations offer an 11.08% more savings than the wind farm of corresponding size. The choice of the type of DG units can be arrived at by considering these factors.

**Table 7.0**  
**Net savings per year for different types of DG**

Case	Savings compared to Base Case (No DG) USD/ Year	Net Savings after deducting the O & M cost in USD/Year		Percentage savings in PV compared to Wind DG
		PV	Wind	
Base Case	0	0	0	0
Case 1	48381.48	41157.87	36595.59	12.18522
Case 2	66996.48	56161.16	49317.8	13.29457
Case 3	83079.84	68632.81	59508.37	14.56802
Case 4	96351.24	78292.31	66886.67	21.87215
Case 5	106898.3	88649.34	69259.82	11.08483

## 6. CONCLUSION

In this paper a multi target formulation considering the thermal limits of the line have been formulated for identifying the ideal capacity and placement of the DG. The multi target function is resolved with the help of PSO algorithm for different sizes of DG considered as a percentage of total load of a 69 bus radial distribution system. The results are tabularized for various scenarios demonstrating the sizing and optimal siting of the DG. The results prove the efficacy of DGs in plummeting the power losses and enhancing the voltage profile. The cost benefit analysis demonstrates the suitability of installing DGs from an economic perspective and the choice of PV as a better option asd in terms of reduced installation and operational cost.

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