

Chapter 3

Optimal Integration of Classified Dispersed Generation Units using Hybrid PSO-GSA Algorithm

3.1 Introduction

Distributed generators having a unity power factor and injecting only active power to the power system (like PV cells and fuel cells) fall into the category of Type-1 DG. Zero power factor DGs (like kVAr compensators, synchronous condensers, and capacitors) inject only reactive power to the power system and fall in the Type-2 category of DGs. Distributed generators with leading power factor such as diesel genset that injects both active and reactive power to the power system network fall into the category of Type-3 DG. Type-4 DG injects active power into the power system and absorbs reactive power. Such types of DGs operate at a lagging power factor. Wind turbines/wind energy generators or induction generators operating at fixed speed fall under the category of Type-4 DG. However, the Doubly Fed Induction Generator (DFIG) can either absorb or deliver reactive power to the grid. Wind turbine-driven DFIG operating at the leading power factor and injecting reactive power to the grid can be considered as Type-3 DG instead of Type-4 DG.

Table 3.1 categorizes different types of DGs where “+” sign indicates injection of real/reactive power to the system, whereas, “-” sign indicates absorption of these. Zero indicates neither injection nor absorption.

Table 3.1 Categorization of DG

DG Type	Real Power	Reactive Power	Example
Type-1	+	0	PV Arrays, Fuel Cell
Type-2	0	+	Synchronous Condenser, Capacitors
Type-3	+	+	Diesel Genset, Wind turbine-driven DFIG operating at a leading power factor
Type-4	+	-	Wind turbine/Induction generator at a fixed speed and operating at a lagging power factor.

In this chapter, the optimal placement of Type-1, Type-2 and, Type-3 DGs have been considered. The various combination cases of different types of DGs have also been considered. A hybrid metaheuristic approach consisting of a combination of Gravitational Search Algorithm (GSA) and Particle Swarm Optimization (PSO) has been proposed to determine the optimal location and size of different type of DGs. Case studies have been performed on IEEE 33-bus and IEEE 69-bus radial distribution systems.

3.2 Problem Formulation

Active power loss is minimized at fixed loading condition in radial distribution system subjected to constraints of power flow equations and voltage limits. The fitness function is the active power loss. Mathematical modeling of the fitness function is presented in Section 2.2.1 and various constraints considered are given in Section 2.2.5 of Chapter-2. As the present work has considered the placement of Type-1, Type-2, and Type-3 DGs and their combinations, additional constraints regarding the permissible maximum size of Type-2 and Type-3 DGs are given below:

For Type-2 DG

$$Q^{T-2DG} \leq (Q_{D,load}^T + Q_{Loss}) \quad (3.1)$$

where, Q^{T-2DG} is the maximum permissible size of Type-2 DG and $Q_{D,load}^T$ is total reactive power demand by the connected loads.

For Type-3 DG

$$S^{T-3DG} \leq (S_{D,load}^T + S_{Loss}) \quad (3.2)$$

where, S^{T-3DG} , $S_{D,load}^T$ and S_{Loss} represent the maximum permissible size of Type-3 DG, total MVA demand in the system and total MVA loss in the system, respectively.

3.3 Proposed Approach for Placement of Different Types of DGs along with Their Combinations

Various qualitative attributes of power supply are improved by the application of DGs. The benefits of DG may be achieved when DGs are installed at suitable locations with appropriate sizes. The utmost role of DGs is to bring down the loss and strengthen the voltage of buses in the distribution system. This chapter has proposed the PSO-GSA optimization technique for optimal integration of Type-1, Type-2, and Type-3 DGs in the radial distribution system. The PSO algorithm is presented in section 2.3.1. The GSA algorithm and the hybrid PSO-GSA algorithm that has been used in this work are presented below.

3.3.1 Gravitational Search Algorithm (GSA)

Gravitational Search Algorithm (GSA) is based on the gravitational force of attraction between different objects in the universe. As per Newton's law of gravity, each particle (object) in the universe attracts every other particle with a 'gravitational force'. The gravitational force between two particles is directly proportional to the product of their masses and inversely proportional to the square of the distance between them:

$$F = G \frac{M_1 M_2}{R^2} \quad (3.3)$$

where, F is the magnitude of the gravitational force, G is the gravitational constant, M_1 and M_2 are the mass of the first and second particle, respectively, and R is the distance between the two particles. Newton's second law says that when a force, F , is applied to a particle, its acceleration, a , depends on the force and its mass, M as given below:

$$a = \frac{F}{M} \quad (3.4)$$

Based on (3.3) and (3.4), there is an attracting gravity force among all particles of the universe and lighter particles get accelerated towards heavier particles. An increase in the distance between two particles decreases the intensity of this force. The net gravitational force on a particle is equal to the vector sum of forces exerted on it by all other particles as shown in Fig. 3.1. In this figure, F_{1j} is the force acting on M_1 from M_j and F_1 is the resultant force that acts on M_1 that leads to acceleration a_1 in the direction of the resultant force.

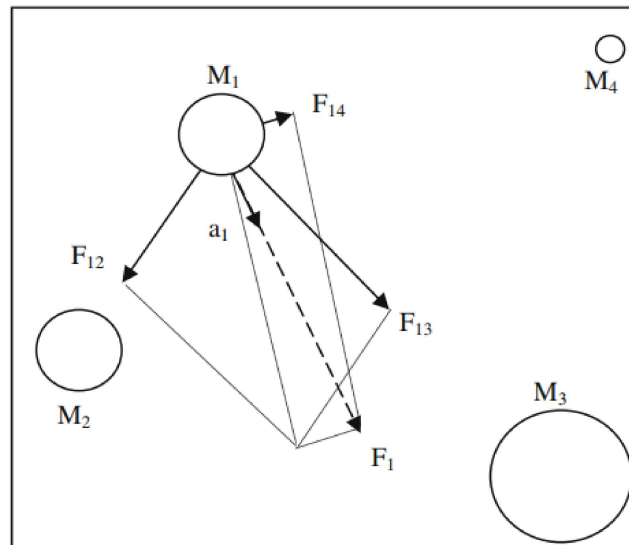


Fig. 3.1 Gravitational force between a group of masses

Hence, In GSA, each mass (agent) has four specifications: position, inertial mass, active gravitational mass, and passive gravitational mass. The position of the mass corresponds to a solution to the problem, and its gravitational and inertial masses are determined

using a fitness function. Masses cooperate using a direct form of communication, through gravitational force. The heavy masses – which correspond to good solutions – move more slowly than lighter ones, this guarantees the exploitation step of the algorithm.

The gravitational search algorithm can be realized by the process as follows.

Consider a system with N agents (masses) in n -dimensional space. We define the position of i^{th} agent by:

$$x_i = (x_i^1 \dots x_i^d \dots x_i^n) \quad for \quad i = 1, 2, \dots, N. \quad (3.5)$$

where, x_i^d presents the position of i^{th} agent in the d^{th} dimension.

At specific time t , we define the force acting on mass i from mass j in d^{th} dimension as [104] :

$$F_{ij}^d(t) = G(t) \frac{M_i(t) \times M_j(t)}{\mathfrak{R}_{ij}(t) + \varepsilon} (x_j^d(t) - x_i^d(t)) \quad (3.6)$$

where, $M_i(t)$ and $M_j(t)$ are the gravitational mass related to agent i and j , respectively, $G(t)$ is the gravitational constant, initialized at the beginning and will be reduced with time to control the search accuracy. In other words, G is a function of initial value and time, ε is a small constant and $\mathfrak{R}_{ij}(t)$ is the Euclidian distance between two agents i and j at time t . The Euclidian distance $\mathfrak{R}_{ij}(t)$ is given by:

$$\mathfrak{R}_{ij}(t) = \|x_i(t), x_j(t)\|_2 \quad (3.7)$$

To give stochastic favor to the algorithm, it is assumed that the total force that acts on agent i in a dimension d is a randomly weighted sum of d^{th} component of the forces exerted on it from all other agents as given below:

$$F_i^d(t) = \sum_{j=1, j \neq i}^N rand_j F_{ij}^d(t) \quad (3.8)$$

where, $rand_j$ is a random number in the interval $[0,1]$.

By the law of motion, the acceleration $a_i^d(t)$ of agent i at time t and in d^{th} direction, is given as:

$$a_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)} \quad (3.9)$$

where, $M_{ii}(t)$ is the inertial mass of i^{th} agent.

Furthermore, the next velocity (at a change in time Δt) of an agent in a particular direction is considered as a fraction of the current velocity added to the product of acceleration in that direction with the duration Δt . The position of the particle in d^{th} direction at the end of duration Δt may be obtained by adding its current position with the product of its velocity at the end of duration with the duration Δt . Therefore, its position and velocity could be calculated at a change in time Δt as follows:

$$v_i^d(t + \Delta t) = rand_i v_i^d(t) + a_i^d(t) \Delta t \quad (3.10)$$

$$x_i^d(t + \Delta t) = x_i^d(t) + v_i^d(t + \Delta t) \Delta t \quad (3.11)$$

where, $rand_j$ is a uniform random variable in the interval $[0,1]$. We use this random number to give randomized characteristics to the search. In this work, the next velocity and position of an agent have been calculated for a time change, $\Delta t = 1$ second.

3.3.2 Proposed Optimal Placement of DGs using Hybrid PSO-GSA Algorithm

In a hybrid of PSO and GSA, PSO is responsible for the exploration of the best solution and GSA searches for local solutions. It is low-level and co-evolutionary because we combine the functionality of both algorithms and do not use one algorithm after another, respectively. It is heterogeneous because both algorithms run in parallel to produce final results. In the hybrid PSO-GSA algorithm PSO is responsible for searching for the global

best solution (i.e. gbest) and GSA searches for local best (pbest) solution. After combining PSO and GSA equations for velocity and position are updated as:

$$v_i^d(t + \Delta t) = \omega v_i^d(t) + c_1 rand_1 a_i^d(t) \Delta t + \frac{c_2 rand_2 (gbest - x_i^d(t))}{\Delta t} \quad (3.12)$$

$$x_i^d(t + \Delta t) = x_i^d(t) + v_i^d(t + \Delta t) \Delta t \quad (3.13)$$

where, ω is the weight function given in (2.17). c_1 and c_2 are the cognitive (individual) and social (group) learning rates, respectively, and $rand_1$ and $rand_2$ are uniformly distributed random numbers in the range 0 and 1. The next velocity and position of an agent have been calculated at a change in time $\Delta t = 1$ second.

The flowchart for finding the optimal size and location of DGs using the hybrid PSO-GSA algorithm is shown in Fig. 3.2. In this flowchart x_{loc} and x_{size} represent the location and size of DG, respectively, with $[X_{par}]$ representing the set consisting of the location and size of all DGs to be placed in the system.

3.4 Results and Discussion

The PSO-GSA optimization approach is tested for optimal DG placement in 33-bus and 69-bus IEEE networks for minimization of power loss. Five cases have been studied. In **Case 1** independent placement of Type-1, Type-2, and Type-3 DGs one at a time has been considered. The remaining four cases consider the combinations of different types of DGs. DG combination of Type-1 and Type-2, Type-2 and Type-3, and Type-3 and Type-1 have been considered in **Case 2**, **Case 3**, and **Case 4**, respectively. **Case 5** considers a combination of all three types (viz. Type-1, Type-2, Type-3) of DGs considered in this work. The power loss given by (2.1) has been optimized using the hybrid PSO-GSA algorithm for the five cases considered. The impact of DG placement by the proposed approach has also been investigated in the voltage profile improvement of the network. The results and comparative analysis of all five cases are presented below in further subsections.

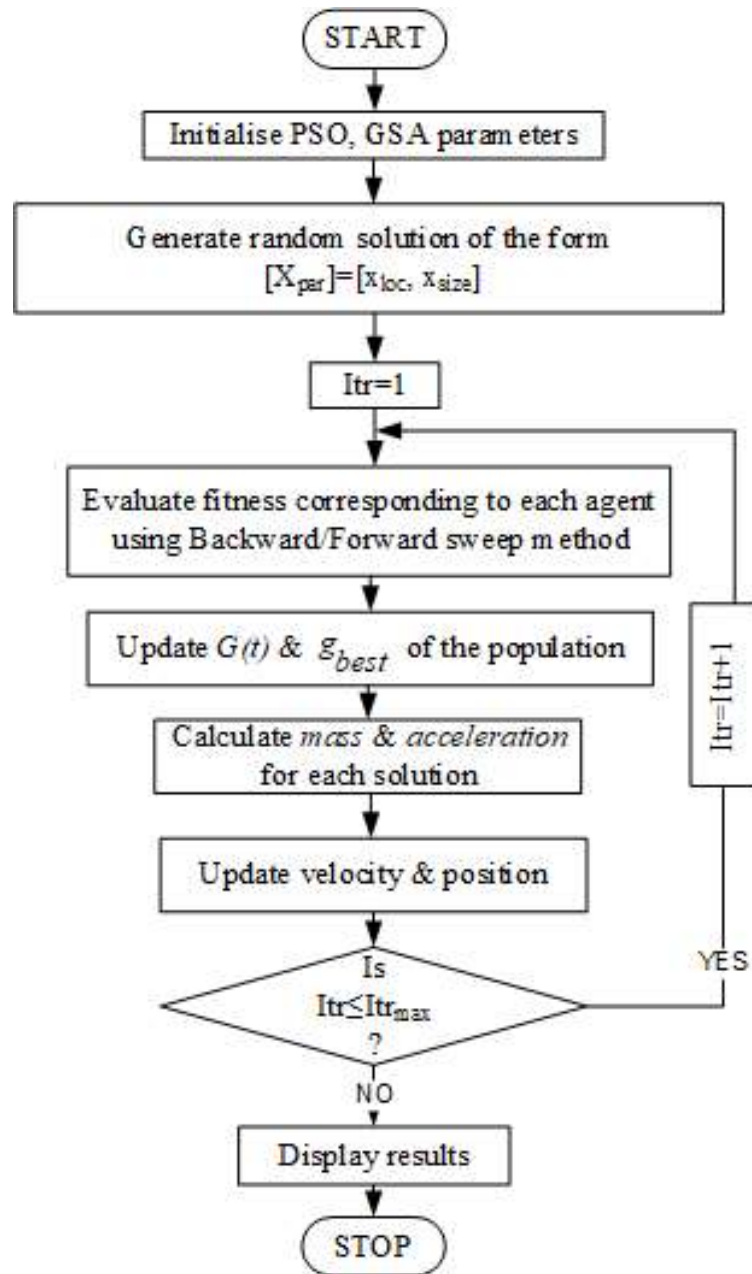


Fig. 3.2 Flowchart for optimal siting & sizing of DGs using PSO-GSA Algorithm

The methodology is taking 50 samples per bus and executing the process 10 times. The testing and validation of the adopted methodology and optimization approach have been done on two test systems.

Programming codes are simulated in MATLAB R2018a environment on a computer with configuration Intel(R) Core (TM) i5-10210U CPU @2.11 GHz processor, 16 GB RAM, and 64-bit operating system.

3.4.1 33-bus IEEE Network

The first test system is the 33-bus IEEE network on which the proposed approach is tested for optimal siting and sizing of individual Type-1, Type-2, and Type-3 DGs considered one DG at a time as well as their various combination as mentioned above. The total active power load, reactive power load, and active power loss (calculated for the base case in the absence of DGs) in the 33-bus IEEE network are 3.27 MW, 3.30 MVAR, and 210.9983 kW, respectively. The details of the 33-bus IEEE network are shown in Appendix A. The exact values of maximum permissible size for Type-1, Type-2, and Type-3 DGs are calculated as 3.931 MW, 2.435 MVAR, and 4.624 MVA, respectively. However, considering practical limitations, maximum permissible size for Type-1, Type-2, and Type-3 DG were considered as 4 MW, 2.5 MVAR, and 4.5 MVA, respectively. The minimum permissible sizes were considered as 0.1 MW, 0.1 MVAR, and 0.1 MVA, respectively, for Type-1, Type-2, and Type-3 DG, respectively.

In **Case-1**, the independent integration of Type-1, Type-2, and Type-3 DGs considered one DG at a time, has been done using the PSO-GSA approach. Plots of real power loss after placement of the different types of DGs of optimal size are shown in Fig. 3.3 for all the buses in the system. Plots of DG optimal size against bus number for different type of DGs are shown in Fig. 3.4. It is observed from Fig. 3.3 and Fig. 3.4 that power loss is minimum for optimal DG size of 2.5902 MW, 1.2579 MVAR, and 3.1063 MVA, respectively, for Type-1, Type-2 and Type-3 DG, respectively, with their optimal location as bus-6, bus-30 and bus-6, respectively. Though the DGs sizes obtained by the PSO-GSA algorithm represent impractical values, these have been used in the present work to make a comparison of DG performance for various cases studied. The plot of power loss against DG power factor for the placement of Type-3 DG at bus-6 is shown in Fig. 3.5. It is observed from Fig. 3.5 that power loss is minimum for the DG power factor of 0.82. Hence,

Type-3 DG of 3.1063 MVA having a power factor of 0.82 was considered for placement at an optimal location (bus-6).

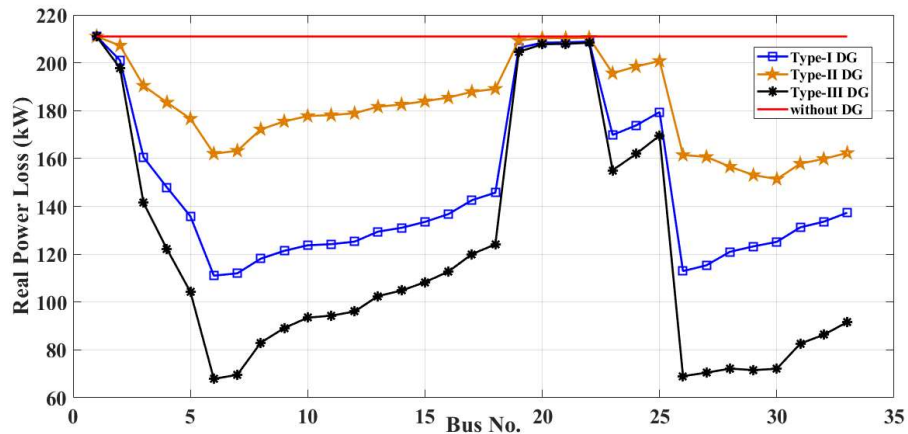


Fig. 3.3 System loss corresponding to optimal DG size at each bus in 33-bus IEEE network using PSO-GSA

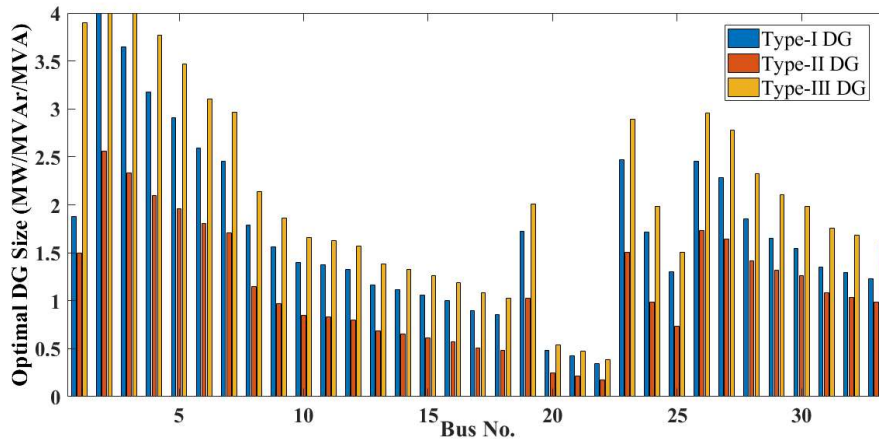


Fig. 3.4 Optimal DG size for various types of DGs at each bus in 33-bus IEEE network using PSO-GSA

Table 3.2 displays the optimal location, DG size, and % loss reduction for the three types of DGs using the PSO-GSA approach. It is observed from Table 3.2 that the base case power loss was 210.9983 kW in the absence of DG placement gets reduced to 111.0299 kW, 151.3787 kW, and 67.8738 kW, respectively, after placement of Type-1, Type-2,

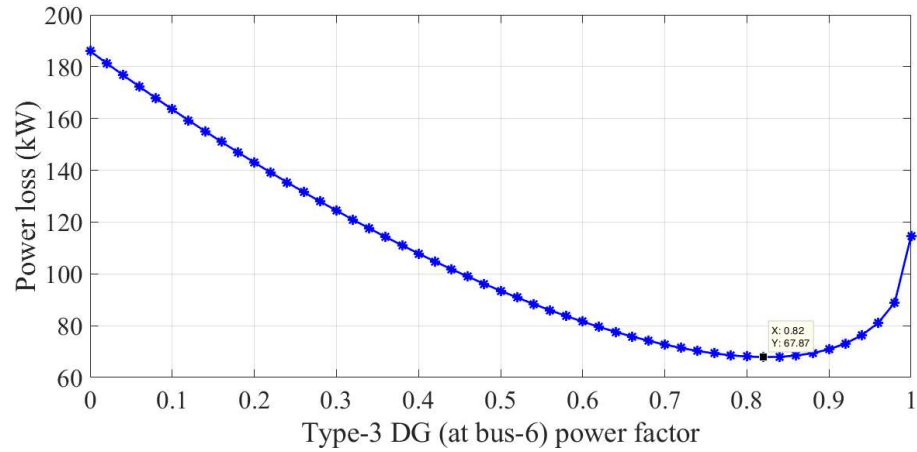


Fig. 3.5 power factor vs power loss for Type-3 DG at bus-6 in IEEE 33-bus system

and Type-3 DG, respectively. The percentage loss reduction corresponding to Type-3 DG placement is 67.8320 % and it is highest among Type-1, Type-2, and Type-3 DGs placement. Hence, Type-3 DG is the most effective in reduction of power loss followed by Type-1 DG. Type-2 DG is the least effective in power loss reduction. Type-2 DG injects only reactive power into the system, and hence, is less effective in loss reduction compared to Type-1 and Type-3 DGs. Type-3 DG compensates real as well as reactive power requirements and hence is most effective in loss reduction.

In **Case-2**, the combination of Type-1 and Type-2 DGs are placed at optimal locations (bus-6 and bus-30, respectively) with optimal size as calculated in Case 1. Table 3.2 shows the system power loss of 58.5019 kW for **Case-2**. In **Case-3**, the combination of Type-2 and Type-3 DGs are placed at optimal locations (bus-30 and bus-6, respectively) with optimal size as calculated in **Case-1**. Table 3.2 shows system power loss as 77.2983 kW for **Case-3**. In **Case-4**, the combination of Type-3 and Type-1 DGs are placed at optimal locations (bus-6 and bus-6, respectively) with optimal size as calculated in **Case-1**. Table 3.2 shows system power loss as 151.2145 kW for **Case-4**. In **Case-5**, Type-1, Type-2, and Type-3 DGs are placed at optimal locations (bus-6, bus-30, and bus-6, respectively) with optimal size as calculated in **Case-1**. Table 3.2 shows system power loss as 158.6511 kW for **Case-5**. A comparison of results of all five cases shows that power loss is least for

Case-2 (i.e. combination of Type-1 and Type-2 DGs placed at optimal locations) followed by **Case-3** (i.e combination of Type-2 and Type-3 DGs). **Case-4 & Case-5** are not as effective in loss reduction as **Case-2 & Case-3**, since Type-1 & Type-3 DGs are connected at the same bus leading to over compensation at bus-6.

Table 3.2 Optimal location, DG size, and % loss reduction corresponding to various types of DGs using PSO-GSA in 33-bus IEEE network

IEEE system	Optimal Locations of DGs			Case	Optimal Size			Power Loss(kW)		% Reduction in Loss
	Type-1	Type-2	Type-3		MW	MVAr	MVA	Without DG	With DG	
33-Bus	6	-	-	1	2.5902	-	-	210.9983	111.0299	47.3787
	-	30	-		-	1.2579	-		151.3787	28.2559
	-	-	6		-	-	3.1063		67.8738	67.8320
	6	30	-	2	2.5902	1.2579	-		58.5019	72.2737
	-	30	6	3	-	1.2579	3.1063		77.2983	63.3654
	6	-	6	4	2.5902	-	3.1063		151.2145	28.3337
	6	30	6	5	2.5902	1.2579	3.1063		158.6511	24.8092

Table 3.3 displays the minimum and maximum per unit voltage and corresponding bus number along with the range of voltage variation in the system after integration of Type-1, Type-2, and Type-3 DGs independently one at a time as well as their different combinations as mentioned earlier. It is observed from Table 3.3 that various combinations of DGs of different types are more effective in voltage profile improvement as compared to DG integration of only one type. Integration of the combination of DGs of different types compensates the real as well as reactive power requirements of the system leading to an improved voltage profile. Integration of Type-2 DG only is least effective in voltage control since the distribution system has a high R/X ratio and reactive power compensation alone is not sufficient to improve the voltage profile. **Case-3** (the combination of Type-2 and Type-3 DGs) results in the least voltage variation among buses. However, **Case-5** (combination of all three types of DGs) leads to maximum enhancement in minimum as well as maximum voltages as this case corresponds to the highest compensation being provided by DGs.

Plots of voltage magnitudes against bus numbers are shown in Fig. 3.6 for all five cases. It is observed from Fig. 3.6 that all five cases lead to improvement in voltage profile. However, **Case-3** leads to a voltage profile having minimum voltage variations among

Table 3.3 Voltage variation with DG placement and without DG placement (33-bus IEEE network) using PSO-GSA.

IEEE System	DG Type*	Voltage (pu)/bus no. Without DG			Voltage (pu)/bus no. With DG		
		Vmin	Vmax	Vmax-Vmin	Vmin	Vmax	Vmax-Vmin
33-Bus	T-1	0.9038/18	1.000/1	0.0962	0.9424/18	1.000/1	0.0576
	T-2				0.9165/18		0.0835
	T-3				0.9332/18		0.0668
	T-1 & T-2				0.9544/18	1.0000/1	0.0456
	T-2 & T-3				0.9696/18	1.0123/6	0.0427
	T-3 & T-1				0.9919/25	1.0347/6	0.0428
	T-1, T-2 & T-3				0.9942/25	1.0452/6	0.0510

*' T-1 represents Type-1 DG, T-2 represents Type-2 DG, and T-3 represents Type-3 DG

buses followed by **Case-4**. However, **Case-5** leads to maximum enhancement in minimum as well as maximum voltage in the system.

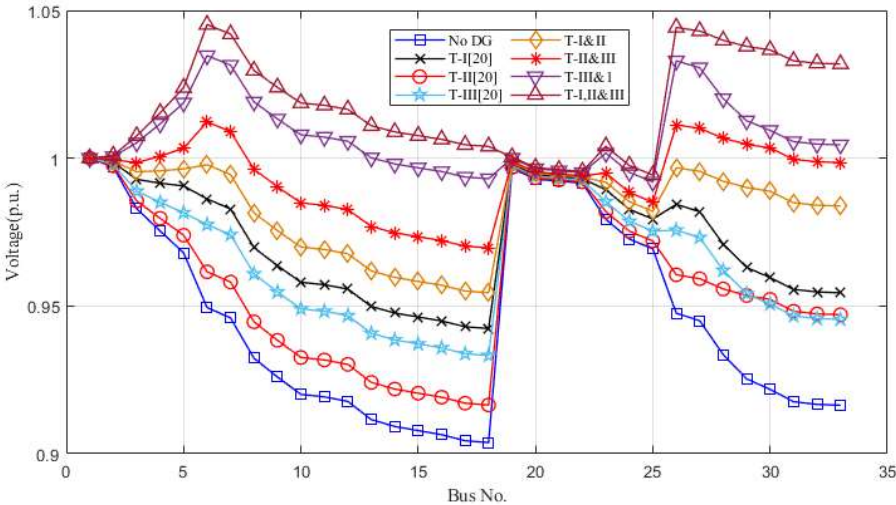


Fig. 3.6 Voltage at each bus for various cases in 33-bus IEEE network using PSO-GSA

3.4.2 69-bus IEEE Network

The second test system is the 69-bus IEEE network on which the proposed approach is tested for the problem optimal siting and sizing of individual Type-1, Type-2, and Type-3 DGs considered one DG at a time as well as their various combinations as mentioned above. The total active power load, reactive power load, and active power loss (calculated

for the base case in the absence of DGs) in the 69-bus IEEE network are 3.80 MW, 2.69 MVAR, and 225.0020 kW, respectively. The details of the 69-bus IEEE network are shown in Appendix B. The exact values of maximum the permissible size for Type-1, Type-2, and Type-3 DG are calculated as 4.025 MW, 2.793 MVAR, and 4.899 MVA, respectively. However, considering practical limitations, the maximum permissible size for Type-1, Type-2, and Type-3 DG were considered as 4 MW, 3 MVAR, and 5 MVA, respectively. The minimum permissible sizes for Type-1, Type-2, and Type-3 DGs were considered as 0.1 MW, 0.1 MVAR, and 0.1 MVA, respectively.

In **Case-1**, the independent integration of Type-1, Type-2, and Type-3 DGs considered one DG at a time has been done using the PSO-GSA approach. Plots of real power loss after placement of different types of DGs of optimal size are shown in Fig 3.7 for all the buses in the system. Plots of DG optimal size against bus number for different types of DGs are shown in Fig. 3.8. It is observed from Fig. 3.7 and 3.8 that power loss is minimum for optimal DG size of 1.8685 MW, 1.3059 MVAR, and 2.2386 MVA for Type-1, Type-2, and Type-3 DG, respectively, with their optimal location as bus-61 for all the three types of DGs. Though DGs sizes obtained by the PSO-GSA algorithm represent impractical values, these have been used in the present work to make a comparison of DG performance for various cases studied. The plot of power loss against DG power factor for the placement of Type-3 DG at bus-61 is shown in Fig. 3.9. It is observed from Fig. 3.9 that power loss is minimum for the DG pf of 0.82 for this system, too. Hence, Type-3 DG of 2.2386 MVA having a power factor of 0.82 was considered for placement at the optimal location (bus-61).

Table 3.4 displays the optimal location, DG size, and % loss reduction for the adopted type of DGs using the PSO-GSA approach. It is observed from Table 3.4 that the base case power loss that was 225.0020 kW gets reduced to 83.9013 kW, 152.4033 kW, and 24.1675 kW, respectively after placement of Type-1, Type-2, and Type-3 DG, respectively. The percentage loss reduction corresponding to Type-3 DG placement is 89.2588 % and it is highest among Type-1, Type-2, and Type-3 DG placement. Hence, Type-3 DG is the most effective in reduction of power loss followed by Type-1 DG as in the 33-bus IEEE network.

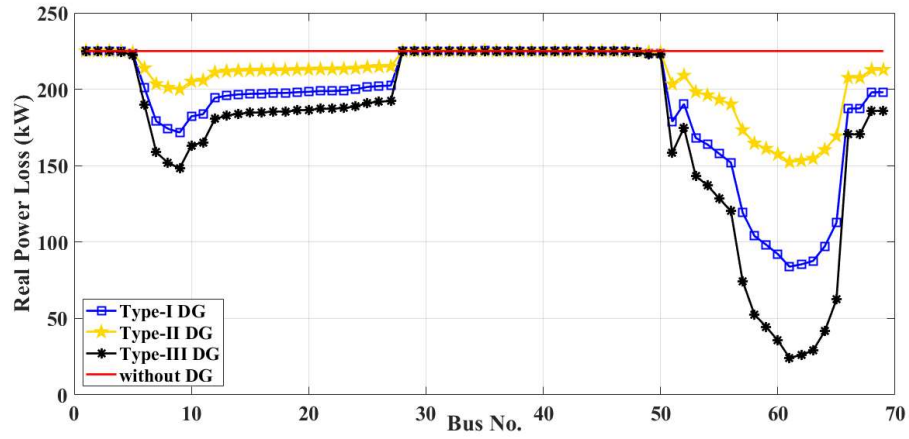


Fig. 3.7 System loss corresponding to optimal DG size at each bus in 69-bus IEEE network using PSO-GSA

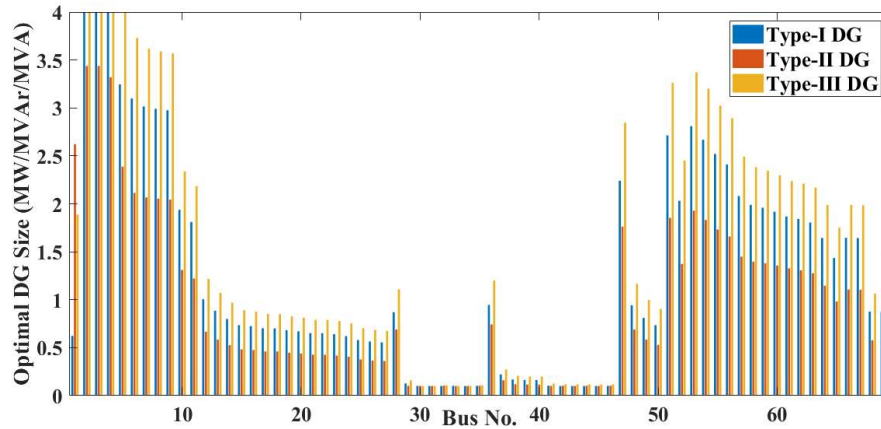


Fig. 3.8 Optimal DG size for various types of DGs at each bus in 69-bus IEEE network using PSO-GSA

Type-2 DG is the least effective in power loss reduction as it injects reactive power only into the system. Type-3 DG compensates real as well as reactive power requirements and hence is most effective in loss reduction.

In **Case-2**, the combination of Type-1 and Type-2 DGs are placed at optimal locations (bus-61 for both types of DGs) with optimal size as calculated in **Case-1**. Table 3.4 shows the system power loss of 24.0017 kW for **Case-2**. In **Case-3**, the combination of Type-2 and Type-3 DGs are placed at optimal locations (bus-61 for both types of DGs) with

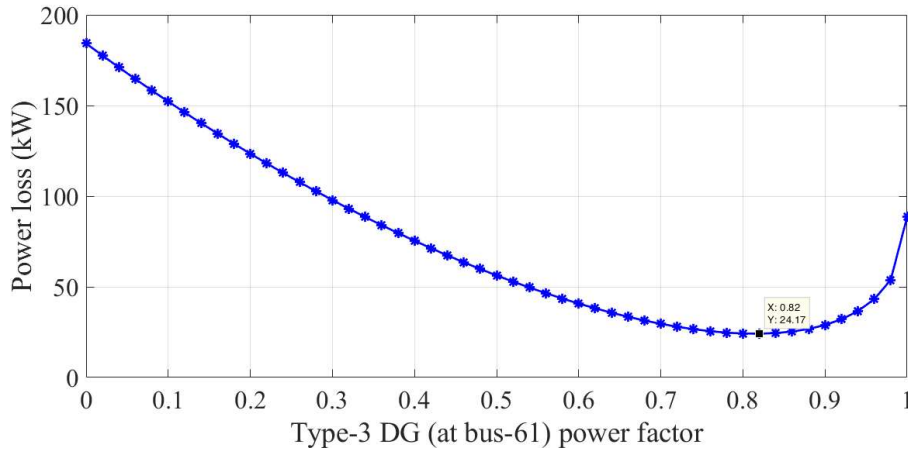


Fig. 3.9 power factor vs power loss for Type-3 DG at bus-61 in IEEE 69-bus system

optimal size as calculated in **Case-1**. Table 3.4 shows system power loss of 79.1116 kW for **Case-3**. In **Case-4**, the combination of Type-3 and Type-1 DG are placed at optimal locations (bus-61 for both types of DGs) with optimal size as calculated in **Case-1**. Table 3.4 shows the system power loss of 130.2313 kW for **Case-4**. In **Case-5**, the combination of Type-1, Type-2, and Type-3 DGs are placed at optimal locations (bus-61 for all the three types of DG) with optimal size as calculated in Case 1. Table 3.4 shows the system power loss of 174.6452 kW for **Case-5**. A comparison of results of all five cases shows that power loss is least for **Case-2** (i.e. combination of Type-1 and Type-2 DGs placed at optimal location) followed by **Case-1** (integration of Type-3 DG only). The next most efficient case in loss reduction is **Case-3** (combination of Type-2 and Type-3 DGs) **Case-4** & **Case-5** are not as effective in loss reduction as **Case-2** & **Case-3**. As bus-61 is towards the remote end of the feeder, voltage support at this bus through reactive power injection by Type-2 DG helps in controlling line current flows resulting in a significant loss reduction. Hence, **Case-2** (combination of Type-1 and Type-2 DGs) and **Case-3** (combination of Type-2 and Type-3 DGs) are more effective in loss reduction compared to **Case-4** (combination of Type-3 and Type-1 DGs). However, reactive power injection alone is not sufficient to control bus voltages, but a sufficient amount of real power injection is also required. Therefore, integration of Type-2 DG alone is not that efficient in voltage control. It is

observed further that integration of Type-3 DG alone is very effective in loss reduction as it injects a sufficient amount of real power as well as reactive power into the system. But **Case-4** and **Case-5** lead to overcompensation of real power and hence are not as effective as other cases.

Table 3.4 Optimal location, DG size, and % loss reduction to various types of DGs using PSO-GSA in 69-bus IEEE network

IEEE system	Optimal Locations of DGs			Case	Optimal Size			Power Loss(kW)		% Reduction in Loss
	Type-1	Type-2	Type-3		MW	MVA _r	MVA	Without DG	With DG	
69-Bus	61	-	-	1	1.8685	-	-	225.0020	83.9013	62.7105
	-	61	-		-	1.3059	-		152.4033	32.2652
	-	-	61		-	-	2.2386		24.1675	89.2588
	61	61	-	2	1.8685	1.3059	-		24.0017	89.3326
	-	61	61	3	-	1.3059	2.2386		79.1116	64.8396
	61	-	61	4	1.8685	-	2.2386		130.2313	42.1199
	61	61	61	5	1.8685	1.3059	2.2386		174.6452	22.3821

Table 3.5 displays the minimum and maximum per unit voltage and corresponding bus number along with the range of voltage variation in the system after integration of Type-1, Type-2, and Type-3 DGs independently one at a time as well as their different combinations as mentioned earlier. It is observed from Table 3.5 that **Case-2** (combination of Type-1 and Type-2 DGs) results in the lowest voltage variation among buses followed by the case of independent integration of Type-1 DG, only. **Case-3** is also very effective in the control of voltage variations among buses. However, in **Case-4** (combination of Type-3 and Type-1 DGs) and **Case-5** (combination of all the three types of DGs), independent integration of Type-2 DG alone and independent integration of Type-3 DG alone are comparatively less effective in the control of voltage variation among buses. This indicates that a combination of Type-1 and Type-2 DG (**Case-2**) leads to sufficient injection of real as well as reactive power injection resulting in maximum control of voltage among buses. It is interesting to note that the next most efficient case in control of voltage variation among buses is the case corresponding to the integration of Type-1 DG only that inject only real power to the system. The reason behind this could be high a R/X ratio of distribution lines where considerable real power compensation is required to control the bus voltages. Integration of Type-2 and Type-3 DG (**Case-3**) is also very effective in the control of voltage variation

due to real as well reactive power injection. However, **Case-5** (combination of all three types of DGs) leads to maximum enhancement in minimum as well as maximum voltages as this case corresponds to the highest compensation being provided by DGs though it is the least effective in control of voltage variations among buses.

Table 3.5 Voltage changes with and without various types of DGs in 69-bus IEEE test system using PSO-GSA

IEEE System	DG Type	Voltage (pu)/bus no. Without DG			Voltage (pu)/bus no. With DG		
		Vmin	Vmax	Vmax-Vmin	Vmin	Vmax	Vmax-Vmin
69-Bus	T-1	0.9035/65	1.000/1	0.0965	0.9630/27	1.000/1	0.0370
	T-2				0.9306/65		0.0694
	T-3				0.9306/65		0.0694
	T-1 & T-2				0.9674/26	1.0013/61	0.0339
	T-2 & T-3				0.9709/27	1.0167/61	0.0458
	T-3 & T-1				0.9774/27	1.0591/61	0.0817
	T-1, T-2 & T-3				0.9812/27	1.0751/61	0.0939

** T-1 represents Type-1 DG, T-2 represents Type-2 DG, and T-3 represents Type-3 DG

Plots of voltage magnitudes against bus numbers are shown in Fig. 3.10 for all five cases. It is observed from Fig. 3.10 that all five cases lead to improvement in voltage profile. However, **Case-2** leads to a voltage profile having minimum voltage variations among buses followed by the case of independent integration of Type-1 DG only. **Case-3** is also very effective in the control of voltage variation among buses.

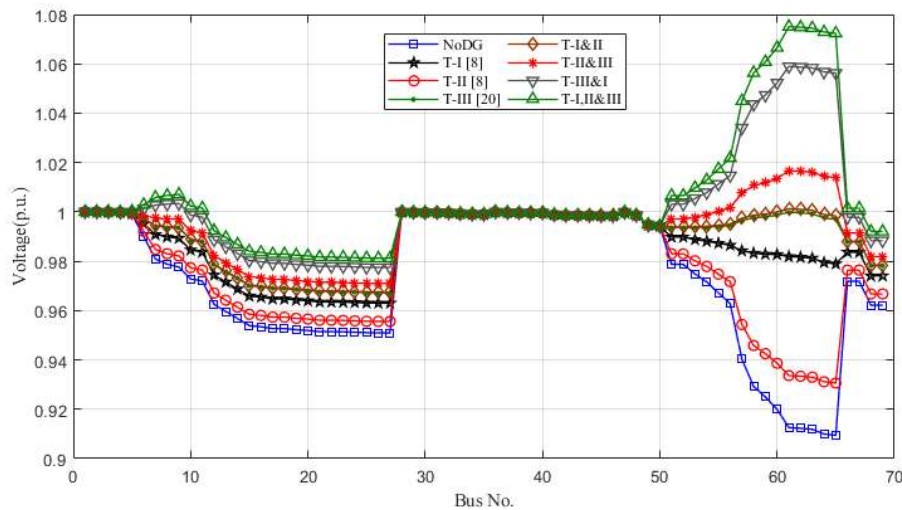


Fig. 3.10 Voltage at each bus for various cases in 69-bus IEEE network using PSO-GSA

3.5 Summary

Integration of different combinations of Type-1, Type-2, and Type-3 DGs as well as their independent integration to the grid has been suggested in this chapter to minimize power loss and improve voltage profile, therefrom. A hybrid metaheuristic approach combining PSO and GSA algorithms has been proposed to determine the optimal location and size of different types of DGs. Case studies performed on two test systems show that the proposed approach of DG placement is very effective in loss reduction and voltage profile improvement. Simulation results show that the integration of a combination of Type-1 and Type-2 DGs is most effective in loss reduction for both systems, which is also most effective in the control of voltage variations among buses for the 69-bus system. However, for the 33-bus system, a combination of Type-2 and Type-3 is most effective in the control of voltage variations. Power loss and voltage variations depend upon different factors such as the R/X ratio of lines, and connected loads with their locations. Thus, the same combination of DGs may not be most suitable for two different systems as observed in the case of voltage variations in two systems.
