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Optimal Integration of Classified Dispersed Generation Units for Loss Minimization and Voltage Profile Enhancement in Radial Distribution Networks

The various combination cases of the Type I, Type II and Type III DGs are proposed in the paper for network loss minimization and voltage profile enhancement. Optimal planning of Type III DG with power factor for minimum power loss is also given in the paper. Voltage deviation corresponding to individual and each combination of DGs is also presented in the paper. Various qualitative attributes of power supply improve by application of DGs. The benefits of DG may be achieved when DGs are installed at suitable location with appropriate size. The utmost role of DGs in power system is bring down of loss and strengthen the voltage at buses in distribution system. Optimal integration of DG is a swerving and concave optimization problem. Gravitational search algorithm and Particle swarm optimization hybrid metaheuristic technique is used in this paper for optimal planning of individual and various combinations of Type-I, Type-II and Type-III DGs. The optimal planning of DG by the adopted hybrid metaheuristic approach is done on 33 and 69 bus IEEE networks.

Keywords: Distributed generation (DG), Gravitational search algorithm (GSA), Particle Swarm Optimization (PSO), Power loss, Radial Distribution System (RDS).

1. Introduction

Distributed generation, Decentralized Generation, Embedded Generation or Dispersed generation are generators typically rated from fewer kW to 100 MW, installed commonly in the vicinity of the consumer's load to strengthen the traditional powersystem[1], [2].

The definition of DG is inconsistent in literature and varies with factors like location,rating, purpose, environmental impact, penetration, etc. IEEE states that sources whichare low rated [3]compared to central generation and provide flexibility enough to beconnected at almost any node in the network are termed as distributed generation [4].

Distributed generators are exploited only when they are properly sited and sized in a network. There are several benefits of optimally placed DGs like load power factor improvement, voltage profile enhancement, grid strengthening, postponing or disregarding system upgrades, reduction in power losses, on-peak operating costs reduction, harmonic mitigation, elimination of voltage sags/swells, improving system integrity, loadability, voltage stability and security, reliability, power quality, efficiency and a cut in AT&C losses [5], [6]. A misplaced and mis sized DG will convert the above-mentioned merits into adverse. The benefits mentioned are achieved by integrating different type of DG into network. Apart from their individual integration, their various combination may have better impact in the network. So, integrating various DG type combination may add something new to the literature. Authors in [7] integrated three unity power factor DGs optimally for loss minimization but impact of rest type of DGs and their combinations are missing. A hybrid genetic algorithm (GA)-adaptive PSO adopted by [8] for optimal planning of only

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single type DG. An improved Harmony search algorithm (HSA) has been proposed in [9] for optimal planning of individual diesel, wind and PV type DGs. Only a single combination of wind, PV and diesel has been proposed for loss and voltage digressions. The optimal planning attributes were optimized on IEEE 33, 69 and 85-bus RDS. [10] has raised a method based on PSO for optimal planning of individual unity and non-unity type DGs to minimize loss. The combination of both is missing in the paper. The proposed method was validated on IEEE-16, 33 and 69-bus RDS. [11] build an optimization model based on affine arithmetic (AA) for individual DG (i.e. wind, PV and microgrid turbine) planning. Combined effect of these type of DGs is absent. Hybrid of Cuckoo Search (CS) with Grasshopper Optimization Algorithm (GOA) has been proposed in [12] for optimal planning of single type DG. The approach was executed on IEEE 33 and 69-bus RDS. Optimal planning for other type of DGs and their combination is absent in the paper.[13]adopted hybrid of binary PSO and shuffled frogleap (SFL) algorithm for optimal planning of individual single type and multiple single type DGs. Minimization of loss improves voltage at each bus in 33 and 68 bus IEEE network. Also, the result section presented various cases like single DG alone, single DG with network reconfiguration, andMultiple DG of same type with network reconfiguration. Various other type DGs and their combinations may be the scope left in the paper. [14] has proposed a novel metaheuristic approach for optimalintegration of capacitor bank, single and multiple DGs in IEEE 33, 69 & 119-bus RDS. Capacitor and DG may be combined together to see the effect in the network. Chaos map theory in integration with sine cosine algorithm (SCA) based optimization algorithm has been introduced in[15]. Further enhanced power system reliability, reduced power loss and improved voltage profile has been achieved through optimally location allocation of individual and multiple single type of DGs in IEEE 33 and 69-bus RDS. In[16] an improved Harris Hawks optimization algorithm has been adopted for calculation of optimal planning attributes of individual type DGs. Authors in[17] has developed a novel moth search optimization (MSO) algorithm to solve the complex DG integration problem in IEEE 33 and 118-bus RDS. The research gap found in the literature and, the proposed work in the paper to fill the research gap is given beneath.

Literature	**DG Type**						
	I	**II**	**III**	**I & II**	**II & III**	**III & I**	**I, II & III**
[7][8][12] [13][15][17]	√	×	×	×	×	×	×
[9]	√	×	√	×	×	√	×
[10][11][12]	√	×	√	×	×	×	×
[14]	√	√	×	×	×	×	×
Proposed work	√	√	√	√	√	√	√

The literature in the past motivated for optimal integration of individual types of DG. Their combinations may also be tested corresponding to their optimal attributes calculated through optimization algorithm on the adopted test systems.

The further sections in paper are sort out as fallows. Section 2 presents the notation used in the paper. Section 3 discusses objective function and constraints. Different metaheuristic techniques are discussed in Section 4. Section 5 presents the insight of adopted test systems. Simulation results come under Section 6. The last Section 7 concludes findings of the paper.

2. Notation

P_L	Active power loss
Z_{sr}, R_{sr}&X_{sr}	Impedance, resistance & reactance of line
V_s and V_r	Sending and receiving end voltages
P and Q	Watt and VAr power
X	Position of particle
V	Velocity of particle
$G_c(t)$	Gravitational constant
$Mass_i(t)$and$Mass_j(t)$	Mass of individual element
$R_{ij}(t)$	Euclidean distance between individuals
$ff_i(t)$	Fitness value
ϵ	Small constant
best(t) and worst(t)	Best and worst fitness value

3. Problem Formulation

Active power loss is minimized at fixed load condition in RDS subjected to constraints power flow equations, voltage and current limit. The fitness function is active power loss. Mathematical equation of the fitness function is given as.

$$ff = \min(P_L) \quad (1)$$

where P_L is exact active power loss[18] and given as

$$P_L = \sum_{s=1}^{n} \sum_{r=1}^{n} \left(\alpha_{sr} \left(P_s P_r + Q_s Q_r \right) + \beta_{sr} \left(Q_s P_r - P_s Q_r \right) \right) \quad (2)$$

where,

$$\alpha_{sr} = \frac{R_{sr}}{V_s V_r} \cos(\delta_s - \delta_r) \quad (3)$$

$$Z_{sr} = R_{sr} + X_{sr} \quad (4)$$

$$\beta_{sr} = \frac{R_{sr}}{V_s V_r} \sin(\delta_s - \delta_r) \quad (5)$$

4. Optimization Techniques

This paper used PSO-GSA optimization technique for optimal integration of Type-I, Type II and Type III DG (shown in figure 1)[19] in RDS.

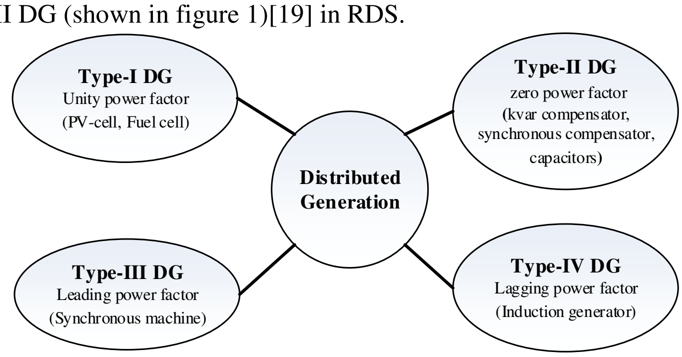

Fig. 1: Classification of DGs

4.1 Particle Swarm Optimization (PSO)

Each member of the swarm consists of two attributes, position and velocity. Both attributes update in every iteration by the knowledge of its own and by the knowledge experience from the neighbor[20].

Mathematical equations for attributes of p-particle in d-dimensional space are written below.

$$\chi_P = (\chi_{p,1}, \chi_{p,2}, \chi_{p,3} \ldots\ldots \chi_{p,d}) \qquad (6)$$

$$v_p = \left(\vartheta_{p,1}, \vartheta_{p,2}, \vartheta_{p,3} \ldots\ldots\ldots\ldots \vartheta_{p,d}\right) \qquad (7)$$

In each iteration, after 1st iteration position and velocity coordinates are updating according to the fallowing equations[21].

$$v_{mn}^{k+1} = \omega \times v_{mn}^{k} + c_1 rand\left(pbest_{mn} - \chi_{mn}^{k}\right) + c_2 rand\left(gbest_{mn} - \chi_{mn}^{k}\right) \qquad (8)$$

$$\chi_{mn}^{k+1} = \chi_{mn}^{k} + v_{mn}^{k+1} \qquad (9)$$

where,

m(particle): 1, 2, 3 . . . . p.

n(dimention): 1, 2, 3 .... d.

$$\omega = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{k_{\max}}.k \qquad (10)$$

The values ω_{max}, ω_{min}, c_1 and c_2 has been optimizedthrough hit and trial method. $K_{max}$is the maximum iteration.

4.2 Gravitational Search Algorithm (GSA)

Gravitationalsearchalgorithmisgravitational force (Fg)-basedoptimization technique[22]. Eachparticle of the swarmisconsidered as mass/agent. As we know that the Fg betweentwo agents depend on their masses and distance betweenthem. In optimizationproblemthis force isrepresented by fitness function. And decides the movementfromlower mass to higher mass agent. In thisway all particles move towards the optimal solution.

Gravitationalsearchalgorithm can berealized by the process as follows. Firstly, then agents/mass are initialized in d dimensionalspace. Initial position of anyith agent isshown as $\chi_i = (\chi^1_i, \chi^2_i ..., \chi^d_i)$. Afterthat interaction betweentwoindividualsestablishedby gravitational force $Fg^d_{ij}(t)$.

$$Fg_{ij}^{d}(t) = G_c(t)\frac{Mass_i(t) \times Mass_j(t)}{R_{ij}(t) + \varepsilon}\left(\chi_j^d(t) - \chi_i^d(t)\right) \qquad (11)$$

The mass $M_i(t)$ of anyindividualiscalculated as

$$mass_i(t) = \frac{ff_i(t) - worst(t)}{best(t) - worst(t)} \qquad (12)$$

$$Mass_i(t) = \frac{mass_i(t)}{\sum_{l=1}^{n} mass_l(t)} \quad (13)$$

$$Fg_i^d(t) = \sum_{j \in K_b, j \neq i} r_j Fg_{ij}^d(t) \quad (14)$$

where, $k_b$is k best agents in the population, $r_j$israndom value in the interval [0, 1].

Finally, the velocity and positions of the individuals are updated for the nextiteration.

$$v_i^d(t+1) = r_i v_i^d(t) + a_i^d(t) \quad (15)$$

$$\chi_i^d(t+1) = \chi_i^d(t) + v_i^d(t+1) \quad (16)$$

where$a_i^d(t)$ is the acceleration for the iteration t. Accelerationis the ratio of total gravitational force and mass the individual.

4.3 Hybrid PSO-GSA

The PSO-GSA is a lowlevelco-evolutionaryalgorithm. It isalsoheterogeneous innature. In hybrid of PSO and GSA, PSO isresponsible for exploration of best solutionand GSA search for local solution. Velocity and position update equation for hybridalgorithmis as fallows.

$$v_i^d(t+1) = w \times v_i^d(t) + c_1' \times r \times a_i^d(t) + c_2' \times r \times \left(gbest - \chi_i^d(t)\right) \quad (17)$$

$$\chi_i^d(t+1) = \chi_i^d(t) + v_i^d(t+1) \quad (18)$$

Flowchart for the hybrid PSO-GSA algorithm is shown in figure 2.

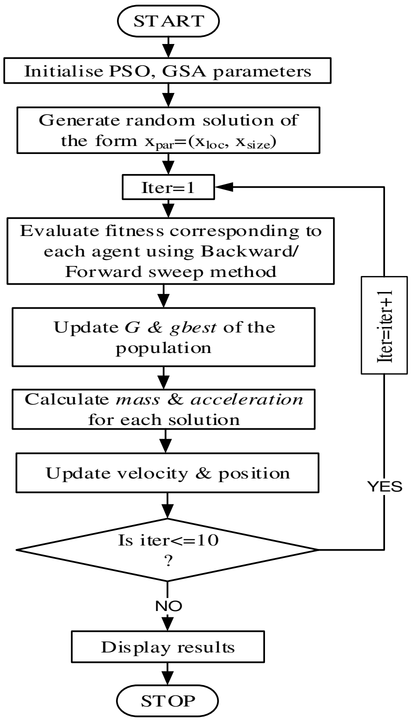

Fig. 2. Flowchart for optimal siting & sizing using PSO-GSA

5. Test Systems

The PSO-GSA optimizationapproachistested for optimal DG planning on IEEE-33 bus (figure 3)[23] and 69 bus (figure 4) [24] RDS. The total active power load, reactive power load and active power loss in IEEE-33 bus network is 3.27 MW, 3.30 MVAr and 210.9983 kW respectively. Similarly, for IEEE 69 bus network total active power load, reactive power load and active power lossis 3.80 MW, 2.69 MVAr and 225.0020 kW respectively.

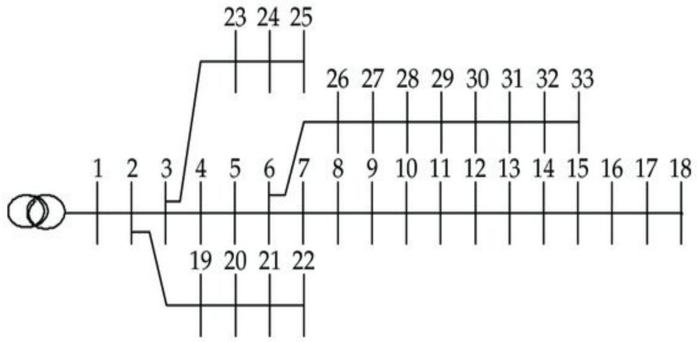

Fig. 3: IEEE 33 RDS

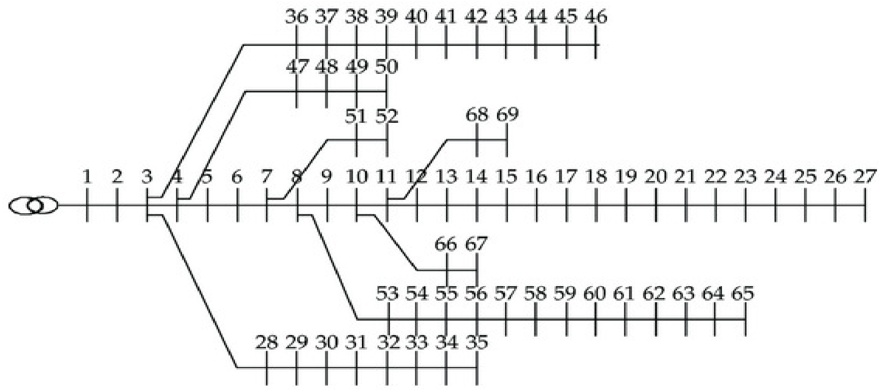

Fig. 4: IEEE 69 RDS

6. Result and Discussion

Optimal integration process of DG in RDS isdisplayed in figure 5. Methodologyistaking 50 samples per bus and executes the process for 10 times. The range of Type I, II and III DG in paperis 0.1-4 MW/MVAr/MVA. The testing and validation of adoptedmethodology and optimizationapproach have been done on adopted test systems. Programs are simulated in MATLAB R2018a environmentinstalled in the computer with configuration Intel(R) Core (TM) i5-10210U CPU @2.11 GHz processor, 16 GB RAM and 64-bit operating system.

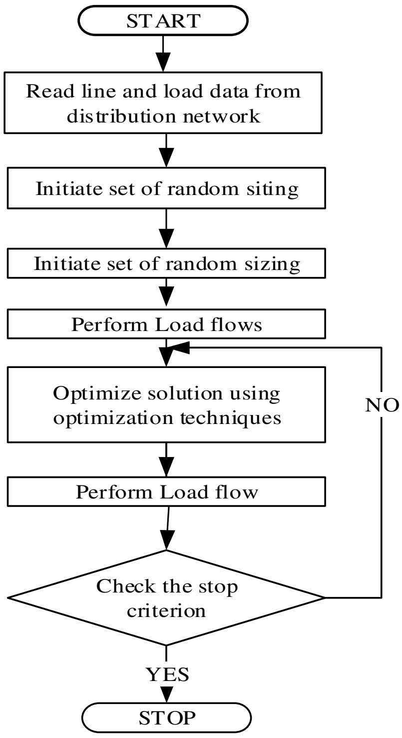

Fig. 5: Flowchart for optimal siting & sizing of DGs

6.1 Optimal integration of various type of DG

Here,we plan to optimallyintegratevarious type of DGs for minimum system power loss. In thispaper five cases have been discussed. In Case 1 Type I, II and III DGs are independentlyoptimallyinstalledwithappropriate size for minimum system power loss. Afterachieving optimal site and capacity of all type DGs, various combination cases are proposed. Case 2 combines Type I and II DGs and place them at optimal site withappropriate size and calculate the system power lossalongwith minimum and maximum voltage in the system. Similarly, Case 3, Case 4 and Case 5 combine Type II and III, Type III and I and Type I, II and III respectively, and place them at optimal site withappropriate size and calculate the system power lossalongwith minimum and maximum voltage in the system. The results and comparative analysis of all the cases ispresented in further sections.

6.1.1 Case 1 : Independent integration of Type I, II and III DGs

The independentintegration of Type I, II and III DGs have been doneusing PSO-GSA approach. The parametersadopted in PSO and GSA are enlisted in optimization technique section. Table 1 displays the optimal location, DG size and % lossreduction for adopted types of DG using PSO-GSA approach. In 33 bus IEEE network optimallocations are 6, 30 and 6 forType I, II and III DG respectively. The optimal size values are 2.5902 MW, 1.2579 MVAr and 3.1063 MVA for Type I, II and III DG respectively. The values of optimal system power loss are 111.0299 kW, 151.3787 kW and 67.8738 kW respectively. The percentage lossreductioncorresponding to Type III DG is 67.8320% and ithighestamongType I, II and III DG. In 69 bus IEEE network the optimal location for all type of adoptedDGsis 61. The optimal DG size are 1.8685 MW, 1.3059 MVAr and 2.2386

MVA for Type I, II & III DG respectively. The values of optimal system power loss are 83.9013 kW, 152.4033kW and 24.1675kW respectively. The percentage lossreductioncorresponding to type III DG is 89.2588% and ithighestamongType I, II and III DG.

Type III DG at power factor value 0.82 gives optimum system power loss. Figure 6 and 7 areshowing power factor vs power losscurvein 33 and 69 bus test system respectively. Table 2 displays the minimum and maximum voltage in per unit and corresponding bus numberafterintegration of Type I, II and III DG. In 33 bus IEEE network minimum voltage/bus are 0.9424/18, 0.9165/18 and 0.9332/18 for Type I, II and III DG respectively. The maximum voltage of the 33 bus IEEE network remains 1 per unit for all type of DG.

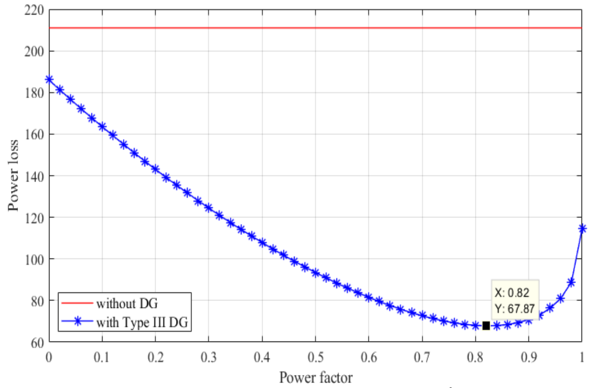

Fig. 6. Power factor vs power loss for Type III DG at 6th bus in IEEE 33 bus system

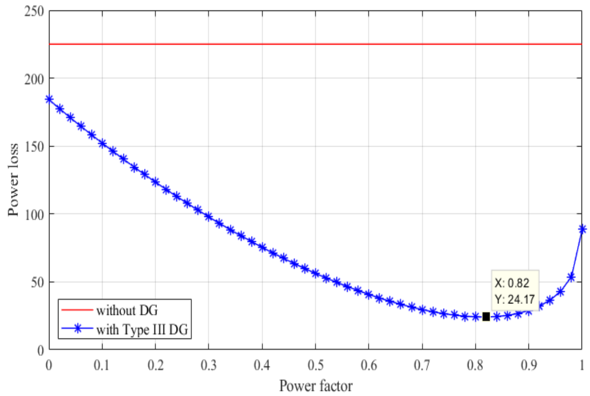

Fig. 7. Power factor vs power loss for Type III DG at 61st bus in IEEE 69 bus system

In 69 bus IEEE network minimum voltage/bus for Type I, II and III DGs are 0.9630/27, 0.9306/65 and 0.9672/27 respectively. The maximum voltage of the 69 bus IEEE network remains 1 per unit for all type of DG.

Figure 8 and 9 display the optimal size of Type I, II and III DG at each busin 33 and 69 bus IEEE networks respectively.

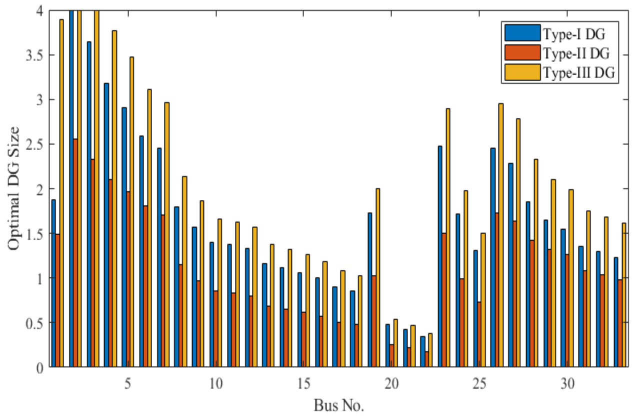

Fig. 8. Optimal DG size for various type of DG at each busin 33 bus IEEE network using PSO-GSA

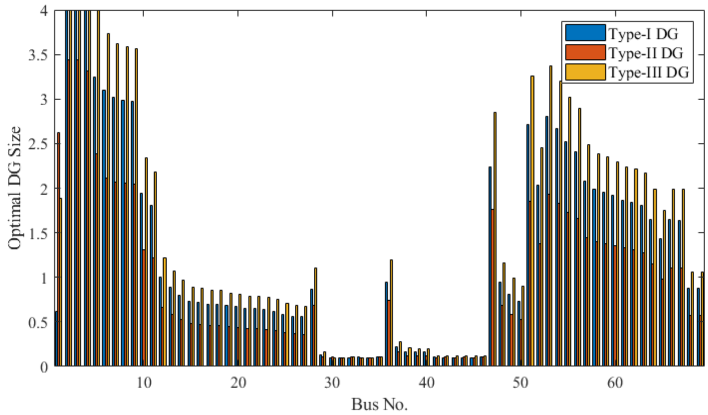

Fig. 9. Optimal DG size for various type of DG at each busin 69 bus IEEE network using PSO-GSA

System losscorresponding to optimal DG size for Type I, II and III DG at each busin 33 and 69 bus networks shown in figure 10 and 11.

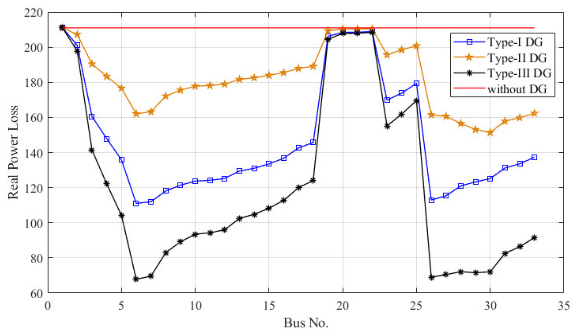

Fig. 10. System losscorresponding to optimal DG size at each busin 33 bus IEEE network using PSO-GSA

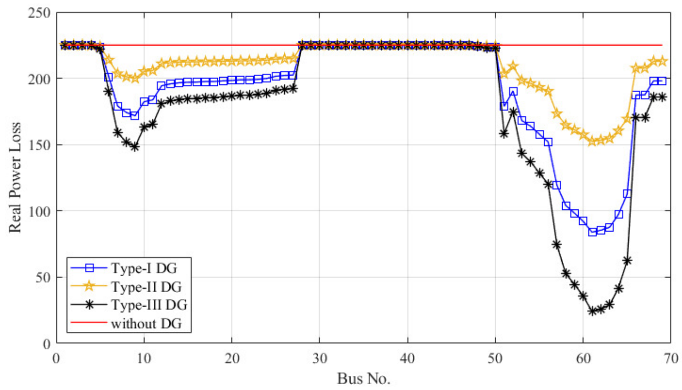

Fig. 11. System losscorresponding to optimal DG size at each busin 69 bus IEEE network using PSO-GSA

6.1.2 Case 2:Integration of Type I and Type II DG

Type I and II DG are placed at optimal locations withappropriate size as calculated in case 1. Table 1 shows system power loss 58.5019 kWand 24.0017 kWfor 33 and 69 bus IEEE networks respectively. The minimum voltage/bus in 33 and 69 bus IEEE network are 0.95448/18 and 0.96748/26 respectively. The maximum voltage/bus in 33 and 69 bus IEEE network are 1.0000/1 and 1.0013/61 respectively.

6.1.3 Case 3:Integration of Type II and Type III DGs

Type II and III DG are placed at optimal locations withappropriate size as calculated in case 1. Table 1 shows system power loss 77.2983 kWand 79.1116 kWfor 33 and 69 busIEEE networks respectively. The minimum voltage/bus in 33 and 69 bus IEEE network are 0.96964/18 and 0.97093/27 respectively. The maximum voltage/bus in 33 and 69 bus IEEE network are 1.0123/6 and 1.0167/61 respectively.

6.1.4 Case 4:Integration of Type III and Type I DGs

Type III and I DG are placed at optimal locations withappropriate size as calculated in case 1. Table 1 shows system power loss 151.2145 kW and 130.2313 kW for 33 and 69 bus IEEE networks respectively. The minimum voltage/bus in 33 and 69 bus IEEE network are 0.99196/25and 0.97745/27 respectively. The maximum voltage/bus in 33 and 69 bus IEEE network are 1.0347/6 and 1.059/61 respectively.

6.1.5 Case 5:Integration of Type I, Type II and Type III DGs

Type I, II and III DG are placed at optimal locations withappropriate size as calculated in case 1. Table 1 shows system power loss 158.6511 kW and 174.6452 kW for 33 and 69 bus IEEE networks respectively. The minimum voltage/bus in 33 and 69 bus IEEE network are 0.99429/25 and 0.9812/27 respectively. The maximum voltage/bus in 33 and 69 bus IEEE network are 1.0452/6 and 1.0751/61 respectively.

Table 1. Optimal location, DG size and % lossreductioncorresponding to various type of DGsusing PSO-GSA

IEEE system	Optimal location of DGs			Case	Optimal size of DGs			Power loss (kW)		% Lossreduction
	Type -I	Type -II	Type -III		MW	MVAr	MVA	Without DG	With DG	
IEEE-33 Bus	6	-	-	1	2.5902	-	-	210.9983	111.0299	47.38
	-	30	-		-	1.2579	-		151.3787	28.26
	-	-	6		-	-	3.1063		67.8738	67.83
	6	30	-	2	2.5902	1.2579	-		58.5019	72.27
	-	30	6	3	-	1.2579	3.1063		77.2983	63.37
	6	-	6	4	2.5902	-	3.1063		151.2145	28.33
	6	30	6	5	2.5902	1.2579	3.1063		158.6511	24.81
IEEE-69 Bus	61	-	-	1	1.8685	-	-	225.0020	83.9013	62.71
	-	61	-		-	1.3059	-		152.4033	32.27
	-	-	61		-	-	2.2386		24.1675	89.26
	61	61	-	2	1.8685	1.3059	-		24.0017	89.33
	-	61	61	3	-	1.3059	2.2386		79.1116	64.84
	61	-	61	4	1.8685	-	2.2386		130.2313	42.12
	61	61	61	5	1.8685	1.3059	2.2386		174.6452	22.38

Voltage changes for all cases isshown in Table 2. The voltage profile for all cases isshown in figure 12 and 13 for 33 and 69 bus IEEE systemsrespectively.

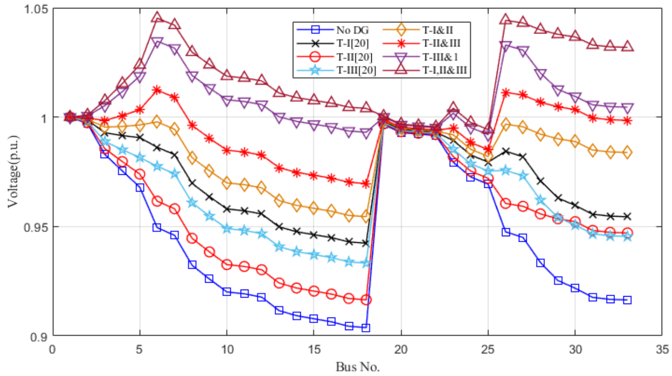

Fig. 12. Voltage at each bus for various cases in 33 bus IEEE network using PSO-GSA

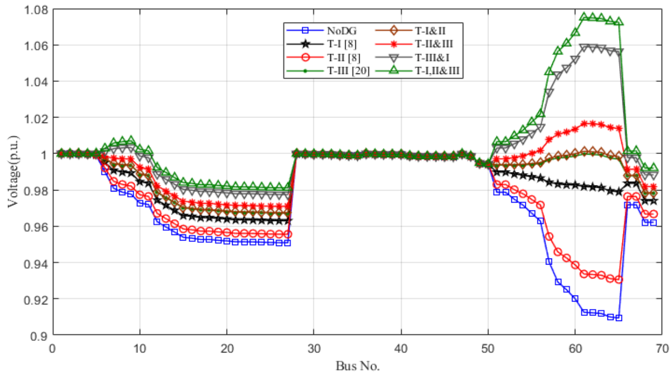

Fig. 13. Voltage at each bus for various cases in 69 bus IEEE network using PSO-GSA

Table 2. Voltage changes with and withoutvarious type of DGs in IEEE test system using PSO-GSA

IEEE system	**DG Type**	**Voltage /bus no. Without DG (pu)**		**Voltage /bus no. With DG (pu)**	
		V_{min}	**V_{max}**	**V_{min}**	**V_{max}**
IEEE-33 bus	Type-I	0.9038/18	1.0000/1	0.9424/18	1.0000/1
	Type-II			0.9165/18	
	Type-III			0.9332/18	
	Type-I & II			0.9544/18	1.0000/1
	Type-II & III			0.9696/18	1.0123/6
	Type-III & I			0.9919/25	1.0347/6
	Type-I, II & III			0.9942/25	1.0453/6

IEEE-69 bus	Type-I	0.9035/65	1.0000/1	0.9630/27	1.0000/1
	Type-II			0.9306/65	
	Type-III			0.9672/27	
	Type-I & II			0.9674/26	1.0013/61
	Type-II & III			0.9709/27	1.0167/61
	Type-III & I			0.9774/27	1.0591/61
	Type-I, II & III			0.9812/27	1.0751/61

The voltage deviation at each bus from the reference value (i.e. 1 pu) ispresented in figure 14 and 15 for 33 and 69 bus IEEE systemsrespectively.In 33 bus IEEE network, combination of Type III & I DGsgivelowestdeviation of voltage between maximum and minimum value among all cases. But there are few outliers are present.

In 69 bus IEEE network, combination of Type III & II DGsgivelowestdeviation of voltage between maximum and minimum value among all cases. And also, there are not outliersfound.

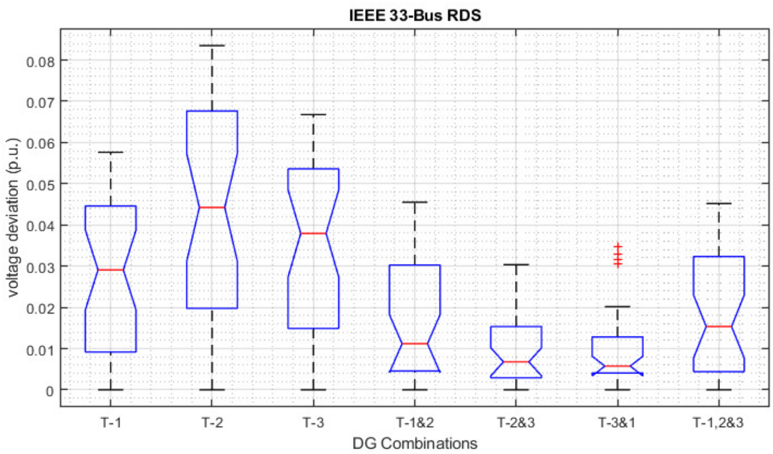

Fig. 14. Voltage deviation from reference value (i.e. 1 pu) at each bus for various cases in 33 bus IEEE network

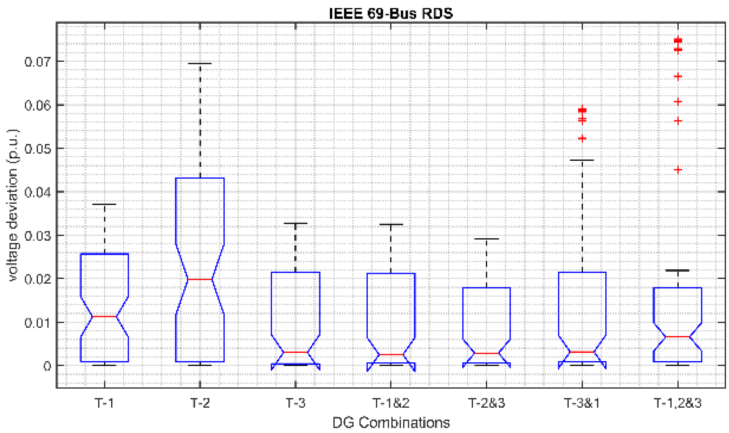

Fig. 15. Voltage deviationfromreference value (i.e. 1 pu) at each bus for various cases in 69 bus IEEE network

6. Conclusion

Integration of PSO with GSA isutilized in the paper for optimal planning of Type I, II and III DGsin 33 and 69 bus IEEE networks. This hybridizationgivesbetter exploration capability to GSA and avoid the solution to stuck at local minima. Power factor of Type III DG corresponding to optimal power loss for both test system has been calculated. Minimum power loss for the said type of DGs has been computed. Optimal site and capacity of the said type DGsisobtainedthrough PSO-GSA algorithm. Various combinations out of Type I, II and III DG have been proposed in the paper. Each combination isspecifiedthrough a specific case. For each case system power loss and voltage profile has been computed and presented in both table and figure. Placement and sizing of said type of DG and their combinations have been done by minimizing system power loss. Comparative performance analysis of assignment of DG shows that for the given test systems combination of Type I and II DG reduce more system power lossthananyother case. Voltage deviationfrom the reference value for individual and various combination of DGsiscomputed and displayedusing box plot statisticalmethod. Furtherintegration of DG withlagging power factor (i.e. Type IV DG) maybe the scope of work in future.

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