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Assessment of Deployment of DGs and D-STATCOMs in Distribution Network using Gravitational Search Algorithm

Aadesh Kumar Arya, Ashwani Kumar, Saurabh Chanana

Abstract*: The assessment of distribution network (DN) for reduce the losses and improve power quality, obtaining precise allocation of distributed generation (DG) and distribution static synchronous compensator (D-STATCOM) is mandatory in DN. This paper shows DN analysis with allocation of DG and D-STATCOM for various cases. The nature inspired metaheuristic method, the Gravitational Search Algorithm (GSA) is proposed to obtain the precise allocation of DG and D-STATCOM individually and simultaneously in DN for power losses reduction and total annual energy saving for distribution network operator. To check the performance of algorithm, it is tested on IEEE 33 and IEEE 69 buses DN for various positions of DG and D-STATCOM in DN. The proposed algorithm's performance is compared by some existing algorithms. It is found that proposed technique is able to reduce losses and annual energy saving in distribution network.

***Keywords:* Gravitational Search algorithm, D-STATCOM, DG, Power Loss Minimization, Energy Saving**

I. INTRODUCTION

The existing power system is facing many problems like increased demand and power quality issue. The conventional power plants have environmental and technical restriction for expansion and new installation [1]. Therefore the renewable energy resources or distributed generation (DG) plant viz. PV, wind and biomass etc. are installed. In power system, most loads are of inductive type, so the power factor is lagging and power losses may be high. Due to lagging power factor, voltage profile and security of system may degrade [2].These problems can be overcome by compensation devices such as D-STATCOM, unified power quality conditioner and distribution voltage restorer (DVR) [3]. Due to the random location and incorrect size of D-STATCOM and DG anywhere in DN, the I^2R losses become very high. For the enhancement of voltage profile, loss reduction and energy saving for distribution network operator (DNO), the compensating device D-STATCOM and DG are required [4].Therefore it is of utmost importance to study the allocation of DG along with D-STATCOM in a DN.

In previous studies, the various authors has been analyzed allocation problem of the DG and D-STATCOM. Murthy *et al*. [5] applied four sensitivity based method for allocation of DG for power loss minimization and cost reduction. The Bacterial Foraging Algorithm (BFA) is a nature inspired metaheuristics technique which based on stochastic search algorithm. In [6] authors have applied BFA and Loss Sensitivity Factor (LSF) to find the capacity and location of DG and D-STATCOM respectively. In [7] authors applied Lightning Search Algorithm (LSA) for calculation of accurate location and ratings of D-STATCOM and D-STATCOM for analyzed multi-objective function. Yuvaraj *et al*. [8] applied cuckoo search (CS) optimization technique to obtain the accurate rating of both D-STATCOM and DG. Two different methods Voltage Stability Index (VSI) and LSF are used to obtain the optimal location of D-STATCOM and DG respectively.

One rank cuckoo search algorithm (ORCSA) is extended version of cuckoo search algorithm. Khoa *et al.* [9] applied ORCSA to obtain optimal allocation of multiple DGs to reduce power losses and enhancement of the voltage stability for improving in power quality of DN and ORCSA is tested for 69- bus distribution network. The Cat Swarm (CS) Optimization is a high performance computational method developed by Chu and Tsai [10]. But the authors [11] used improved Cat Swarm (ICS) Optimization to know the impact of proper ratings and location of DG and D-STATCOM in DN reduce losses. The proposed outcome is compared with the PSO. Gupta [12] applied sensitivity analysis for optimal position of compensation devices and Variational procedure is applied to obtain the accurate capacity of compensation devices. Consequently the outcome of this research shows the enhancement in voltage profile and THD reduction.

According to existing literature, DN have many problems with random placement and rating of D-STATCOM and DG viz., voltage profile enhancement, improvement in reliability, enhancement in voltage stability, power loss mitigation, reduction in cost, load balance enhancement and reduction in THD, can be solved [13].

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* Correspondence Author
Aadesh Kumar Arya*, Department of Electrical Engineering, College of Engineering Roorkee, Roorkee, India.
Ashwani Kumar, Department of Electrical Engineering, N.I.T Kurukshetra, India,
Saurabh Chanana, Department of Electrical Engineering, N.I.T Kurukshetra, India,

The authors [14] applied an immune algorithm, an optimization

technique based on the biological immune system, to obtain the optimal position and rating of D-STATCOM in 33 and 69 buses DN, also in order to reduce total loss, cost and improve the voltage profile and proposed method compared to genetic algorithm (GA). The position of D-SATCOM is normally near to load in the distribution network for satisfactory performance [15].

J. Govind Singh *et al.* [16] is applied sensitivity-based technique for accurate location of STATCOM for minimization of the load curtailment in power system Although many researchers have paid attention on allocation of DG and D-STATCOM individually in the DN but optimal allocation of combined D-STATCOM and DG using meta-heuristic algorithms is addressed by limited researchers. However, Most of the researchers applied two techniques to determine the position and rating of compensation devices individually to obtain power loss and voltage profile of the DN. The purpose of proposed research is to reduce the power loss and to increase the total annual energy saving for the DNO along with enhancement the voltage profile of the DN with proper optimal allocation of D-STATCOM and DG. Simultaneously as well as individually considering different cases. The GSA is employed to optimize the position and sizing of both D-STATCOM and DG for different cases.

Another major issue in this problem is to solve for the load flow of DN without which the analysis and planning of power system is not possible. There are several methods to perform power flow analysis, but the conventional power flow method cannot directly calculate the current in branches of DN. To overcome this problem, advanced power flow method is used in this paper [17].

The present paper is divided into six parts. The first part briefly presents the problem and literatures of problem are presented. The second part describes the distribution network model of load flow and describes the objective function for power loss minimization. In part third, the optimization technique GSA is described and flow chart for application of these techniques using load flow is presented. In fourth part, the impact of D-STATCOM and DG in various cases for proposed objective function is discussed. The results of this work are discussed and compared with existing literature. In fifth part shows the comparative performance analysis for Different Cases .The sixth part shows the conclusion of present study.

II. DISTRIBUTION NETWORK MODEL

Consider a two bus system as apart of DN as shown in Fig.1. In this system, i is represent as sending end bus and $i+1$ as receiving end bus. Consider the loads $(P_i + jQ_i)$ at bus i *and* $(P_{i+1} + jQ_{i+1})$ at bus $i+1$ in balanced DN. The bus voltage is V_i at bus i and V_{i+1} at bus $i+1$ respectively. The node voltage at other buses is determined by power flow method [16] using (1)

$$V_{i+1}\angle\theta_{i+1} = V_i\angle\theta_i - (R_i + jX_i)I_i\angle\delta \tag{1}$$

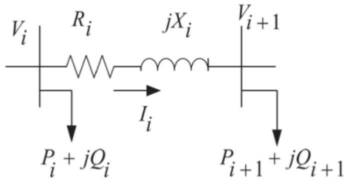

Fig.1 Schematic diagram of two bus distribution network

Let $P_{i,i+1}$ and $Q_{i,i+1}$ betotal real power and reactive power respectively flowing between buses i and $i+1$ and given by (2) and (3)

$$P_{i,i+1} = P_{\ sp} + P_{Loss(,i+1)} \tag{2}$$

$$Q_{i,i+1} = Q_{\ sp} + Q_{Loss(,i+1)} \tag{3}$$

Where $P_{\ sp}$ and $Q_{\ sp}$ is supplied real power and reactive power beyond the bus $i+1$ respectively. Active power loss $P_{Loss(,i+1)}$and reactive power losses $Q_{Loss(,i+1)}$are considered between buses i and $i+1$ respectively.

$$I_i = \frac{P_{I,\ i+1} - jQ_{I,\ i+1}}{V_{i+1}\angle\theta_{i+1}} \tag{4}$$

From (1)

$$I_i = \frac{V_i\angle\theta_i - (V_{i+1}\angle\theta_{i+1})}{(R_i + jX_i)} \tag{5}$$

The real and reactive power loss in the line between buses i and $i + 1$ are calculated

$$P_{Loss(,i+1)} = I_i^{\ 2}R_i \tag{6}$$

$$Q_{Loss(,i+1)} = I_i^{\ 2}X_i \tag{7}$$

In the whole distribution system, the total power losses can be determined by the summation of losses in all line sections, which is given by

$$P_{T,Loss} = \sum P_{Loss}\ (i, i+1) \tag{8}$$

In order to maintain the normal state of the grid and save energy, energy or power loss should be minimal.

$$Min\ F = P_{T,Loss} = \sum_{i}^{N} P_{Loss}(i, i+1) \tag{9}$$

Where N is total no. of branches

Minimization of Power loss using optimally location of DG/DSTATCOM:

The main purpose of DNO is to reduce the loss of the network by proper location of D-STATCOM and DG. The total losses can be reduced with optimal allocation of DG and D-STATCOM in DN is considered as the ratio of total losses with/without DG and D-STATCOM placement in the DN.

$$\left.\begin{aligned} \Delta P_T^{DG} &= \frac{P_T^{DG}}{P_{T,Loss}} \\ \Delta P_T^{DST} &= \frac{P_T^{DST}}{P_{T,Loss}} \end{aligned}\right\} \tag{10}$$

The total power loss minimized by proper position and capacity of D-STATCOM and DG in DN can be maximized by minimizing $\Delta P_T^{DG}, \Delta P_T^{DST}$ and $(\Delta P_T^{DG} + \Delta P_T^{DST})$

Where

P_T^{DG} = Total Loss with Position of DG

P_T^{DST} = Total Loss with Position of D-STATCOM

ΔP_T^{DG} = Loss Reduction Index with DG

ΔP_T^{DST} = Loss Reduction Index with D-STATCOM

Operational Constraints:

Voltage Constraints

At each bus, the voltage should be kept within its range of minimum and maximum with standard value

$$V_i^{min} \le V_i \le V_i^{max} \qquad (11a)$$

$$0.95 \le V_i \le 1.05 \qquad (11b)$$

Where V_i is represented as voltage at bus i.

Power Balance Equation

The generation of total electricity is equal to the total power demand and total power losses.

$$\sum P_D^i + \sum P_{T,Loss} = \sum P_G^{DG} \qquad (12)$$

$$\sum P_D^i + \sum P_{T,Loss} = \sum P_G^{DST} \qquad (13)$$

Where P_D^i is the demand power at bus i and P_G^{DG} and P_G^{DST} isthe generated power using D-STATCOM and DG.

DG and D-STATCOM capacity limits

$$u_{i,DG}.P_{i,DG}^{min} \le P_{i,DG} \le u_{i,DG}.P_{i,DG}^{max} \qquad (14)$$

$$u_{i,DST}.Q_{i,DSTATCOM}^{min} \le Q_{i,DSTATCOM} \le u_{i,DST}.Q_{i,DSTATCOM}^{max} \qquad (15)$$

DG and D-STATCOM number limits

$$\sum u_{i,DG} = N^{DG} \qquad (16)$$

$$\sum u_{i,DST} = N^{DST} \qquad (17)$$

Where, $u = [0, 1]$= binary location of DG/D-STATCOM

$P_{i,DG}^{min}$ = Minimum active power limits of compensated bus

$P_{i,DG}^{max}$ = Maximum active power limits of compensated bus

$Q_{i,DSTATCOM}^{min}$ = Minimum reactive power limits of compensated bus

$Q_{i,DSTATCOM}^{max}$ =Maximum reactive power limits of compensated bus

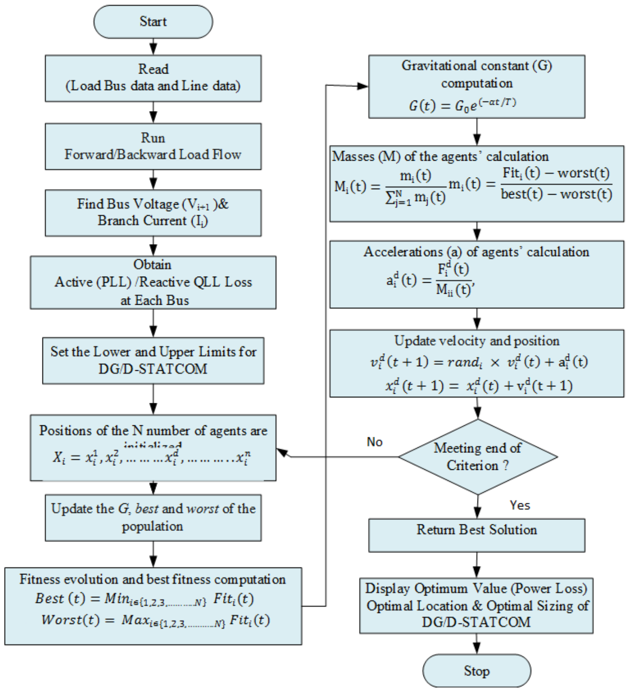

Fig. 2. Flow chart for optimal allocation of DG/ D-STATCOM

N^{DG} and N^{DST} no. of DG and D-STATCOM respectively

Maximization of Total Annual Energy Saving (TAES):

$$= Max\ F_1 = TAES = \sum_{n=1}^{12} (Power)_{loss} * 8760 \qquad (18)$$

n= No. of Month

III. GRAVITATIONAL SEARCH ALGORITHM

The nature-inspired techniques are used to obtain the optimal objective function. The nature-inspired metaheuristic methods are popular for getting optimal solution in terms of efficiency, convergence time and complexity than mathematical solutions. Though there are various methods for optimization. The metaheuristic algorithms have also been widely used in various application of power system. The optimization technique 'GSA' has been well explained in [18-19]. In the present research, GSA is applied to achieve the minimization of total power losses as given by (9). Consequently, The GSA is employed to optimize the allocation of D-STATCOM and DG. The procedure of GSA with embedded load flow for proper allocation of D-STATCOM and DG is shown in Fig. 2. Consequently, the GSA provides the optimize result for power loss, position and ratings of DG and DSTATCOM. In this flow chart, to apply algorithm the line and load data are initially provide and define the minimum and maximum value of DG and D-STATCOM. In order to obtain the power loss at each bus and embedded with GSA. As a result get optimal value of power loss with optimal allocation of D-STATCOM and DG.

IV. OBSERVATION AND DISCUSSION

If In present work, several cases are considered to find out the performance of GSA applied to given problem. The Backward-Forward Sweep power flow method is applied to determine the magnitude of voltage and its phase angle and power losses at each bus. Base MVA and Base kV are as follows: (MVA) Base = 100 MVA and (kV) Base = 12.66 kV. Several cases are considered in order to analyze the effectiveness of the proposed method.

To obtain the effectiveness of the GSA in analyzing the DN, the authors have taken the radial distribution networks of IEEE 33 and IEEE 69 bus systems. Consequently, it is observed that the active power loss is 210.98 kW using the base case of power flow method for IEEE 33 bus of DN.

33-bus Distribution Network:

In this study, in order to find the performance of applied algorithm four different cases is considered. Single line diagram of 33-bus Distribution Network is shown in Fig.3. The nature inspired meta-heuristic algorithm “GSA” is applied along with power flow method for the following cases.

- Case I. Analysis of DN without DG and D-STATCOM (base case).
- Case II. Analysis of DN with DG
- Case III. Analysis of DN with D-STATCOM
- Case IV. Analysis of DN with DG/D-STATCOM

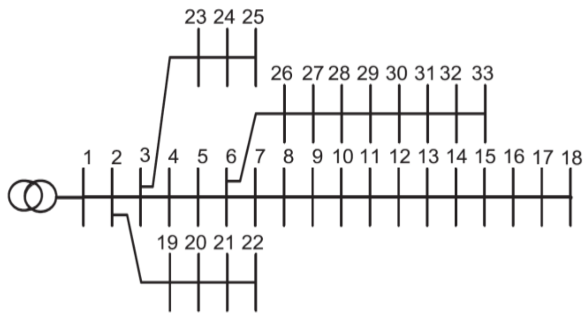

Fig. 3. Single line diagram for 33-bus distribution network

Case I: Analysis of DN without DG and D-STATCOM (base case)The Forward/Backward Sweep load flow technique for IEEE 33 and IEEE 69 bus systems is used and it is obtained the active power losses are 210.9824 kW and 186.6332kW respectively.

Case II: Analysis of DN with DG

In this case study, the GSA has been applied for different cases of DG in distribution system: (i) Single DG, (ii) Two DGs, and (iii) Three DGs for optimal placing and sizing. It has been found that the locations of three DGs are 6th bus, 15th bus and 25th bus with capacities of 2.57 MW, 0.47 MW and 0.64 MW respectively. After placing of one, two and three DGs, power loss has been observed as 111.03 kW, 95.81 kW and 88.20 kW respectively. Average computation time obtained for convergence of applied algorithm is in each case is 34.15 sec., 35.84 sec. and 34.73 sec. respectively. The results for optimal allocation of DGs in different case are illustrates in Table 1. Figure 4 represents the power loss versus iterations for different condition viz. with position one DG, two DGs and three DGs in DN.

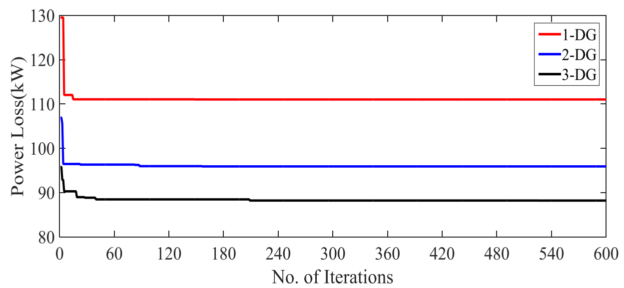

Fig. 4. Power loss versus iterations for different case of DGs allocation

In the Table 1, the results viz. power loss, size and location of DG, average computation time for algorithm convergence has been presented for various cases. The best locations are obtained at 6th, 15th and 25th buses. The results of GSA are also compared with existing methods and also mentioned in Table 1. Consequently, It is observed that the proposed algorithm is excellent compared to other algorithms.

Table – I: Performance of 33-bus distribution network for different cases of DG

Cases	Parameters	GSA (Proposed Method)	[6] BFOA
Only One DG	Power loss (kW)	111.03	111.17
	DG size in MW (Location)	2.57(6)	2.69 (6)
	Average computation time (sec.)	34.15	NA
Simultaneous Two DG	Power loss (kW)	95.81	NA
	DG size in MW (Location)	2.57(6) 0.47(15)	
	Average computation time (sec.)	35.84	
Simultaneous Three DG	Power loss (kW)	88.20	NA
	DG size in MW (Location)	2.57(6) 0.47(15 0.64(25)	
	Average computation time (sec.)	34.73	

Case III. Analysis of DN with D-STATCOM

In this case, the GSA has applied for different cases of D-STATCOM: (i) One D-STATCOM, (ii) Two D-STATCOMs, and (iii) Three D-STATCOMs for getting the satisfactory operation of DN.

Table- II: Performance of 33-bus distribution network for different cases of D-STATCOM

Cases	Parameters	GSA (Proposed Method)	Existing Method [14] IA
Only One D-STATCOM	Power loss (kW)	141.63	171.81
	D-STATCOM size in MVAr (Location)	1.25(30)	149(12)

	Average computation time (sec.)	31.77	21,220
Simultaneous Two D-STATCOM	Power loss (kW)	138.59	NA
	D-STATCOM size in MVAr (Location)	1.25(30) 0.34(14)	
	Average computation time (sec.)	31.16	
Simultaneous Three D-STATCOM			**[7] LSA**
	Power loss (kW)	137.86	138.35
	D-STATCOM size in MVAr (Location)	0.34(14) 0.49(24) 1.25(30)	0.34(14) 0.51(24) 1.01(30)
	Average computation time (sec.)	31.23	-

It has been found that the locations of three D-STATCOMs are 6th, 24th and 30th buses with capacities 0.34, 0.49 and 1.25 MVAr respectively. After placing of one, two and three D-STATCOM, power loss has been observed as 141.63 kW, 138.59 kW and 137.86 kW respectively. Average computation time obtained for convergence in each case is 31.77 sec., 31.16 sec. and 31.23 sec. in each condition respectively. The results for optimal allocation of D-STATCOMs in different case are shown in Table 2. Figure 5 shows the power loss versus iteration no. for different condition viz. with one D-STATCOM, two D-STATCOMs s and three D-STATCOMs in DN. In the Table 2, the results viz. power loss, size of D-STATCOM, location of the device, average computation time for algorithm convergence has been presented for various cases. The best locations are obtained at 30th, 14th and 24th buses for considered case. The results of GSA are also compared with existing methods and also mentioned in Table 2. Consequently, It is observed that the proposed algorithm is excellent compared to other algorithms.

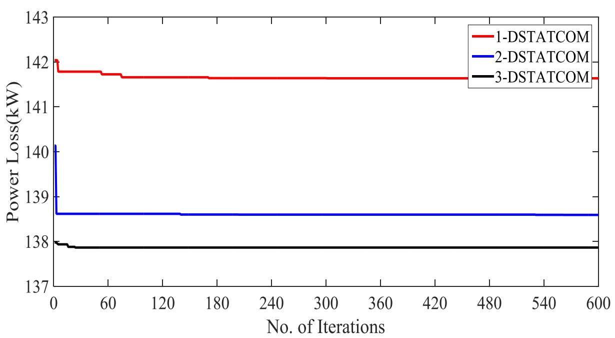

Fig. 5. Power loss versus iteration for different case of D-STATCOMs allocation

Case IV. Analysis of DN with DG /D-STATCOM

In this case study, three different cases are considered for combination of DG and D-STATCOM: (i) Single DG with Single D-STATCOM (ii) Single DG with Two D-STATCOMs and (iii) Two DGs with Two D-STATCOMs. The technique GSA is applied for different case of DG/D-STATCOM in distribution system. From Table 3, it is evident that the power loss has been reduced by different position of simultaneous DGs and D-STATCOMs. In the condition (i), the single DG and single D-STATCOM are placed at 6th and 30th buses with sizing of 2.57 MW and 0.124 MVAr respectively. In this case, the power losses have been observed as 51.18 kW. For condition (ii) single DG and two D-STATCOMs are placed at 6th, 30th and 13th buses with size of 2.57 MW, 0.124 MVAr and 0.36 MVAr respectively. The power loss has been observed as 48.48 kW. Similarly for case, (iii) two DGs and two D-STATCOMs are placed at of 6th , 15th , 30th and 13th buses with size of 2.57 MW, 0.47 MW, 0.124 MVAr and 0.36 MVAr respectively. The power loss has been observed as 35.77 kW. The results for proper allocation of combination of DG and D-STATCOMs s in different cases are shown in Table 3. Figure 6 shows the power loss versus iterations for different condition of DG/D-STATCOM.

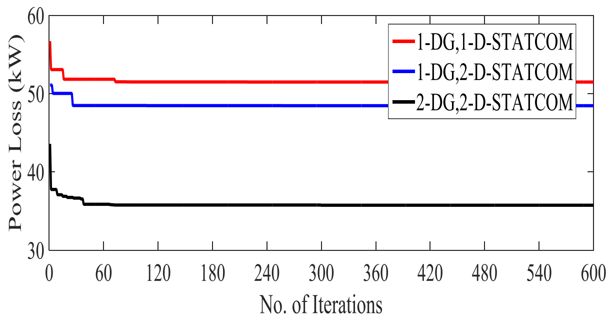

Fig. 6. Power loss versus iteration for various cases of DGs and D-STATCOMs allocation

In Table 3, the results viz. power loss, rating and position of DG/D-STATCOM, average computation time for algorithm convergence and combined effect of DG/D-STATCOM is presented in various cases

Table –III: Performance of 33-bus distribution network for DG/ D-STATCOM

Cases	Parameters	GSA (Proposed Method)	[6] BFOA
One DG With One D-STATCOM	Power loss (kW)	51.18	70.87
	DG size in kW (Location)	2.57(6)	1.09 (30)
	D-STATCOM size in MVAr (Location)	0.124(30)	0.123(10)
	Average computation time (sec.)	32.18	NA

One DG With Two D-STATCOM	Power loss (kW)	48.48	NA
	DG size in MW (Location)	2.57(6)	
	D-STATCOM size in MVAr (Location)	0.124(30)	
		0.36(13)	
	Average computation time (sec.)	30.87	
Two DG With Two D-STATCOM	Power loss (kW)	35.77	NA
	DG size in MW (Location)	0.47(15)	
		2.57(6)	
	D-STATCOM size in MVAr (Location)	0.124(30)	
		0.36(13)	
	Average computation time (sec.)	30.87	

The best location obtained is at bus 6th. The comparison of the results is also given. The results obtained for the combined placement of one DG and one D-STATCOM with the proposed algorithm are best as compared to the other algorithms. The results of GSA for the combined placement of one DG/D-STATCOM are also compared with existing methods and also mentioned in Table 3. Consequently, It is observed that the proposed algorithm is excellent compared to other algorithms.

69-bus Distribution Network

In order to check the effectiveness of GSA for analysis of DN, the single line diagram of 69 bus distribution network has taken which shown in Fig.7.

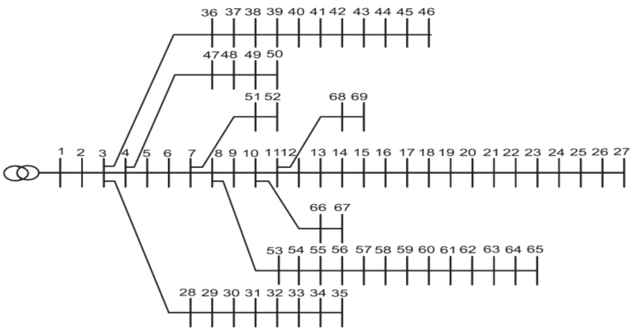

Fig. 7. Single line diagram of 69-bus distribution network

In this paper, the various cases have been considered to find out the performance of proposed optimization algorithm for IEEE 69 bus system.

Case Study: Analysis of DN with DG

In this case study, the GSA has been applied for different case of DG in distribution system: (i) One DG, (ii) Two DGs, and (iii) Three DGs for optimal placing and sizing. It has been found that the locations of three DGs are 49th bus, 60th bus and 66th bus with capacities of 0.51 MW, 1.87 MW and 0.55 MW respectively. After placing of one, two and three DGs, power loss has been observed as 63.13 kW, 59.22 kW and 0.51kW respectively.

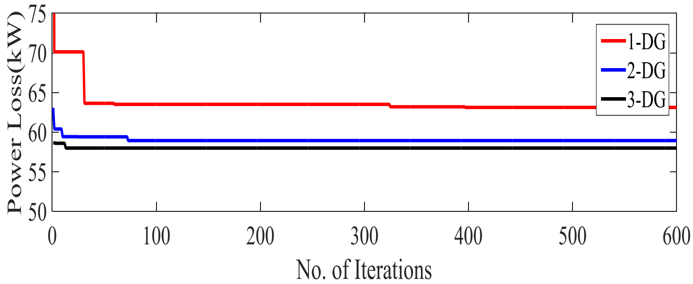

Fig. 8. Power loss versus iteration for different case of DGs for 69 bus system

Average computation time obtained for convergence in each case is 48.66 sec., 35.84 sec., and 34.73 sec. respectively. The results for optimal allocation of DGs in different case are illustrated in Table 4. Figure 8 represent the power loss versus iteration for different condition viz. with position of one DG, two DGs and three DGs in DN.

In the Table 4, the results of power loss, size of DG, location of the device, average computation time for algorithm convergence has been presented for various cases. The best location obtained is at bus 60th. The comparison of the results is also given. The results obtained with the proposed algorithm are best as compared to the other algorithms.

Table-IV: Performance of 69-bus test system for different condition of DGs

Cases	Parameters	GSA (Proposed Method)	[6] BFOA	[9] ORCSA
Only One DG	Power loss (kW)	63.13	83.21	NA
	DG size in MW (Location)	1.87 (60)	1.8727 (61)	
	Average computation time (sec.)	48.66	12.54	
Simultaneous Two DG	Power loss (kW)	59.22	NA	NA
	DG size in MW (Location)	1.87 (60)		
	Average computation time (sec.)	0.55 (66)		
Simultaneous Three DG	Power loss (kW)	35.84	NA	70.7091
	DG size in MW (Location)	1.87 (60)		0.6311 (11)
		0.55 (66)		0.4263 (20)
		0.51 (49)		1.8516 (61)
	Average computation time (sec)	34.73		NA

Case Study: Analysis of DN with D-STATCOM

In this case study, the GSA has been applied for different case of D-STATCOM in DN: (i) One D-STATCOM, (ii) Two D-STATCOMs, and (iii) Three D-STATCOM s for optimal placing and sizing. It has been found that the locations of three D-STATCOMs are 11th bus, 49th bus and 60th bus with capacities 0.51 MVAr, 0.38 MVAr and 1.32 MVAr respectively

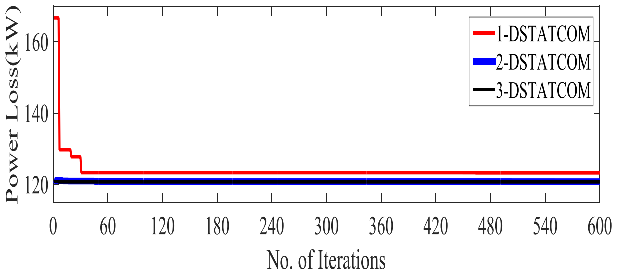

Fig. 9. Power loss versus iteration for different case of D-STATCOMs

After placing of one, two and three D-STATCOMs, power loss have been observed as 123.21 kW, 121.10 kW and 120.76 kW respectively. Average computation time obtained for convergence in each case is 51.34 sec., 49.71 sec., and 48.22 sec. in each case respectively. The results for optimal allocation of D-STATCOMs in different case are shown in Table 5. Figure 9 shows the power loss versus iterations for different cases viz. with position one D-STATCOM, two D-STATCOMs and three D-STATCOMs in RDS.

Table- V: Performance of 69-bus test system for different case of D-STATCOM

Cases	Parameters	GSA (Proposed Method)	[14] IA
Only One D-STATCOM	Power loss (kW)	123.21	158.5
	D-STATCOM size in MVAr (Location)	1.32(60)	1.70(61)
	Average computation time (sec.)	51.34	32,305
Simultaneous Two D-STATCOM	Power loss (kW)	120.76	NA
	D-STATCOM size in MVAr (Location)	0.51(11)	
		1.32(60)	
	Average computation time (sec.)	49.71	
Simultaneous Three D-STATCOM	Power loss (kW)	120.76	NA
	D-STATCOM size in MVAr (Location)	0.51(11)	
		0.38(49)	
		1.32(60)	
	Average computation time (sec.)	48.22	

In the Table 5, the results viz. power loss, size of D-STATCOM, location of the device, average computation time for algorithm convergence has been presented for various cases. The best location obtained is at bus no. 60, 11 and 49 for considered case. The comparison of the results is also given. The results obtained for one D-STATCOM placement with the proposed algorithm are compared to the other algorithm.

Case Study: Analysis of DN with DG/ D-STATCOM

In this case study, allocation of one DG and one D-STATCOM is obtained by GSA. It is observed that DG and D-STATCOM has been position at bus 60th and 60th buses respectively and size is 1.87 MW and 1.32 MVAr respectively. Figure 10 shows the power loss versus no. of iterations for combined placement of DG/D-STATCOM.

In the Table 6, the results of power loss, size of DG and D-STATCOM, location of the devices, average computation time for algorithm convergence and combined effect of DG/D-STATCOM in various cases has been presented.

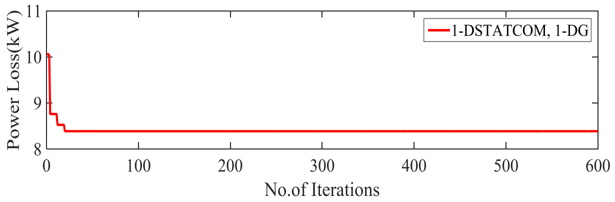

Fig. 10. Power loss versus iteration for single DG and single D-STATCOM for IEEE 69 bus system

The best location obtained is at 60th bus. The comparison of the results is also given. The results obtained for the combined placement of one DG /D-STATCOM in DN with the proposed algorithm are best as compared to the other algorithms.

Table-VI: Performance of 69 bus Distribution Network for placement of one DG/D-STATCOM

Cases	Results	Proposed Method (GSA)	[7] LSA
One DG With One D-STATCOM	Power loss (kW)	8.46	24.15
	DG size in MW (Location)	1.87(60)	1.15 (61)
	D-STATCOM size in MVAr (Location)	1.32(60)	1.75 (61)
	Average computation time (sec.)	48.48	12.35

V COMPARATIVE PERFORMANCE ANALYSIS FOR DIFFERENT CASES

33-bus Distribution Network

In present paper, the optimization technique GSA has applied for the same cases and same IEEE bus system for optimal allocation of D-STATCOM and DG. Therefore, it is observed that GSA is more effective besides existing optimization techniques for distribution network. The proposed results are compared with [6], which shown in Table 1.

However, the location of DG is same in existing techniques (BFOA) but ratings of DGs are not similar for simultaneous placement of three DGs in DN for the same power loss which shown in Table 2. The obtained results are validated and compared with [14] for location of one D-STATCOM and multiple location of D-STATCOMs and compared with [7]. Therefore, the results show that the proposed techniques are more efficient. Table 3 shows the combined placement of different combination of D-STATCOM and DG in DN, the power loss and size is also reduced for economically operation of DN. Moreover, it is also observed that due to combined placement of one DG/D-STATCOM in DN, the power loss is minimize. The outcome is compared with [6]. Table 7 provide the information about the annual energy saving and its comparison has been also done with existing literature.

Table-VII: Performance of 33-bus test system for annual energy saving for different cases

Proposed Cases	Power Loss (kW)	% Loss Reduction	Loss Saving (kW)	Annual Energy Saving (KWh)
Base case	210.9824	-	-	-
Only One DG	111.03	76	99.95	875583.02
Simultaneous Two DG	95.81	91	115.17	1008910.22
Simultaneous Three DG	88.20	98	122.78	1075573.82
Only One D-STATCOM	141.63	45	69.35	607527.02
Simultaneous Two D-STATCOM	138.59	48	72.392	634157.42
Simultaneous Three D-STATCOM	137.86	49	73.1224	640552.22
One DG With One D-STATCOM	51.18	135	159.8024	1399869.024
Existing Method				
[6] BFOA 1-DG	111.17	75	99.8124	874356.624
[14] IA 1-D-STATCOM	171.79	15	39.1924	343325.424
[7] LSA Simultaneous Three D-STATCOM	138.35	48	72.6324	636259.824

IEEE 69-bus test system

In present paper, effectiveness of GSA is validated for individual DG, individual D-STATOM, and combined placement of one DG/D-STATOM for 69 bus test system. In table 4, three different conditions are considered. By increasing the DGs in DN, the power loss is quite reduced. However, it is observed that no effect on power loss by increasing the more than two DGs in DN.

Table –VIII: Performance of 69-bus test system for annual energy saving for different cases

Proposed Cases	Power Loss (kW)	% Loss Reduction	Loss Saving (kW)	Annual Energy Saving (KWh)
Base case	186.6332	-	-	-
Only One DG	63.13	195.63	124	1081888.032
Simultaneous Two DG	59.22	215.15	127	1116139.632
Simultaneous Three DG	58.62	218.38	128	1121395.632
Only One D-STATCOM	123.21	51.48	63	555587.232
Simultaneous Two D-STATCOM	121.10	54.11	66	574070.832
Simultaneous Three D-STATCOM	120.76	54.55	66	577049.232
One DG With One D-STATCOM	8.46	2106.07	178	1560797.232
Existing Method				
[7] LSA 1-DG and 1-D-TATCOM	24.15	672.81	162	1423352.832
[9] ORCSA Simultaneous Three DG	70.7091	68.57	115.92	1015495.116

The results are shown in table 5, for different location of D-STATCOM. The proposed results are compared with [13] for location of one D-STATCOM. No good impact by multiple positions of D-STATCOM in DN for smooth operation of distribution system. The results for combined location of one DG and one D-STATCOM are shown in table 6 and compared with [8]. Though, it is clear from this proposed research; there is no benefit of multiple DG, multiple D-STATCOM and combination of multiple DG and D-STATCOM. Table 8 provide the information for annual energy saving.

VI. CONCLUSION

In this research paper, the nature inspired metaheuristic optimization techniques Gravitational Search Algorithm has been applied for various cases viz. the individual placement of D-STATCOM, and DG, combined placement of DG/D-STATCOM. Consequently, it is found that GSA technique very is effective. By placing of combination of DG and D-STATCOM, the more power loss is reduced. However, two different methods are required to find the location and capacity of compensating device as per existing literature. But proposed technique "GSA" is capable alone to obtain the allocation of DG/D-STATCOM for optimized outcome.

The proposed method has tested on 33 and 69-bus distribution network with various cases of DG/D-STATCOM. The results have been simulated using GSA with embedded of power flow analysis. Consequently, the proposed method is better than existing techniques for power loss minimization and to save more annual energy with optimal allocation of D-STATCOM/DG.

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AUTHORS PROFILE

Aadesh Kumar Arya received his B. E degree in Electrical and Electronics Engineering from Dr. B. R. Ambedkar University, Agra and M.Tech degree in Communication Engineering from Shobhit University, Meerut in 2003 and 2009 receptively. Presently he is pursuing Ph. D in Electrical Engineering in Department of Electrical Engineering at National Institute of Technology, Kurukshetra. His main interests focus on Smart Grid technology Distributed Generation, FACTS applications, DR and DSM and smart appliances.
E-mail: adeshkumararya@coer.ac.in , adeshkumararya1982@gmail.com

Ashwani Kumar received B.Tech degree in Electrical Engineering from G. B. Pant University of Agriculture and Technology, Pant Nagar and M.Tech degree in Power System from Punjab University, Chandigarh and Ph. D from IIT Kanpur, India in 1988, 1994 and 2003 respectively. He is also having the Post-Doctoral Fellow, USA during Jan. 2008-May 2008. He has joined the National Institute of Technology, Kurukshetra, India in the 1994. Presently, Dr. Ashwani Kumar is Professor in the Department of Electrical Engineering at National Institute of Technology, Kurukshetra. He has his interests in power system restructuring, FACTS applications, power systems dynamics, distributed generation, demand side management, price forecasting and Smart Grid. He has published more than 80 research papers in Refereed international journals/national journals. Also he has published 84 research papers in proceedings of international and national conferences. In past, he has been investigated many Industrial project. Currently, he is handling DST project.
He is the member of various societies' viz. ISTE, Institution of Engineers India (IEI) and IEEE, IEEE-PES society. **E-mail**-ashwa_ks@yahoo.co.in, ashwaks@gmail.com

Saurabh Chanana received B. Tech degree in Electrical Engineering, M. Tech in Power System and Ph.D in Electrical Engineering in 1996, 2002 and 2011 receptively in the Department of Electrical Engineering at National Institute of Technology, Kurukshetra, India. Dr. Saurabh Chanana is a member of IEEE and ISTE. Presently, he is Associate Professor in the Department of Electrical Engineering at National Institute of Technology, Kurukshetra, India. He has his interests in power system restructuring, FACTS applications, power systems dynamics, Demand Side Management; price forecasting, Smart Grid and Distributed Generation. He is principal Investigator of Industrial project for DRDO. He is the member of IEEE.**E-mail:** s_chanana@rediffmail.com, saurabh@nitkkr.ac.in