Optimal Allocation and Sizing of Distributed Generation in Radial Distributed System Using Ant Colony Search Algorithm

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Abstract. The majority of system losses are caused by the distribution system, hence distribution utilities are embracing new technologies and investigating other options, such as placing distribution generation (DG) in a radial distribution system to reduce losses and maximize benefits. Finding the best solution for optimal DG allocation and sizing, is therefore necessary.. In this paper, the Ant colony search algorithm (ACSA) is used to optimize distributed generation (DG) allocation and sizing in radial distribution networks. Various IEEE radial distribution systems such as 15 bus, 33 bus and 85 bus are analyzed for optimal allocation and sizing duly mentioning the required number of distribution generators. The objective function is to keep the voltage at various nodes close to unity and to minimize losses. The simple and efficient method for load flow studies in radial distribution system is used for conducting load flow studies and evaluating voltage at each bus. The ACSA method is used for 15 bus, 33 bus, and 85 bus IEEE radial distribution systems with multiple numbers of DGs in order to determine the best distribution and sizing of DGs. The results of the 15 bus and 85 bus systems are then compared to those obtained by taking into account an objective function to reduce losses.

Keywords: Ant Colony Search Algorithm (ACSA) · Load flow in Radial Distribution System (RDS) · Optimal Allocation of Distributed Generation (DG) · Heuristic Optimization Technique · Loss Reduction

1 Introduction

The generation, transmission and distribution systems are three main components of power systems. In this, the distribution systems are typically radial in nature and major portion of losses belongs to this system. Around 13% of generated power in power system is lost as a result of losses in distribution system [1]. These significant power losses will have a negative influence on distribution system's overall performance and the financial health of the distribution utilities. The overall losses in the power systems can be decreased and voltage regulation can be enhanced by minimizing power losses in this distribution system.

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Growing load demand and the level of competition in the electricity market are the two biggest issues facing distribution utilities. Additionally, increasing the capacity of the transmission and distribution system could not be economical. These challenges push distribution companies to carefully plan and build their networks in order to fulfil the demand for power. Distributed generating offers a solution to this issue.

The typical structure of a distribution system includes a main feeder, laterals, and sub-laterals to which the loads are connected. The major portion of losses takes place in main feeder because it carries the current of all the loads. These losses in the main feeder, laterals and sub-laterals can be reduced by connecting DGs at various buses in distribution system. However, the positioning and sizing of DGs should carefully considered, as DG installation is not simple. The placement of DGs at non-optimal locations can result in increase in losses, system design cost, unhealthy voltage profile and finally leads to effects opposite to the desired. Solution strategies for DG allocation and size should be used to optimize the gains in order to enhance the voltage profile, reduce system losses and lower costs.

The usual DG problem effectively involves the placement of buses and the size of DGs, therefore it combines discrete and continuous problems. All calculus-based optimization techniques are severely hampered by this combination. This widens the window for heuristic and population-based approaches to develop. The heuristic optimization strategy, which employs population-based search algorithms, was more recently proposed. Heuristic is a technique designed for solving the problems, when conventional method are slow or fails to find the nearest optimum solutions. The process of arriving at a solution involves trial and error, using only stated or general rules of thumb. A meta-heuristic is a sophisticated algorithm that might provide a workable solution to an optimization issue, especially when there is incomplete or imperfect information or limited processing capacity. The most widely utilized methods for resolving these issues include optimization, evolutionary computation, and artificial intelligence (AI). Because of their effectiveness and superiority in solving optimization issues, heuristic techniques like Bacterial Foraging Algorithms (BFA), Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), etc. are gaining popularity.

2 Objective

This paper's primary goal is to obtain the following in IEEE radial power distribution systems using the Ant Colony Search Algorithm (ACSA) for 15-Bus, 33-Bus, and 85-Bus with varying numbers of distributed generators. This is done by taking objective function into account to improve the voltage at each node and minimize the system losses.

i. To determine the distribution generators' ideal size and allocation (DGs).
ii. To determine the apparent, real and reactive power losses with and without DGs in the suggested radial distribution systems.
iii. Finding the voltages in p.u. at each bus in the suggested radial power distribution system with and without DGs.

3 Distribution Generation

The phrase "distribution generation" is used to describe generating units that are connected to the distribution system rather than the high voltage grid or transmission system. It is sometimes referred as embedded generation also because they are embedded to distribution system. Technology advancements have produced a new pattern for the expansion of Distribution Generation(DG). The renewed popularity of DG is creating many new opportunities for increasing the diversity of DGs and to improve the efficiency of electrical power systems.

Renewable (such as solar and wind turbine technologies) and non-renewable (such as fossil fuel technologies) are the two main categories used to describe DG technologies. When choosing the right DG unit size and location to connect to a distributed system or client loads, DG technologies play a vital role.

Diesel, gas turbines, reciprocating gas engines account for the majority of the DG capacity deployed to date. Concurrently, more traditional DG technologies like reciprocating engines are being developed, new ones like micro turbines are being introduced. Fuel cells are the technology of the future. Over the next decade, it is anticipated that photovoltaic system costs would decrease steadily. All of this reinforces the statement that DG is the future of power generation.

Furthermore, the expanding open electric power market encourages greater use of DGs in radial power distribution systems. Benefits of DG installation could only be realized with careful size and placement planning.

The use of distributed generation (DG) improves system reliability, service continuity, voltage profile, protection sensitivity, reduces congestion and expansion of transmission and distribution networks, reduces power losses, lowers energy costs, and improves overall system performance. Further, DG technologies cause lower rate of pollution to the environment.

4 Load Flow Solution in Radial Distributed Network

Traditional load flow methods in power transmission networks, such as Newton Raphson and Gauss Siedel methods, can't be applied in distribution systems because the distribution network's R/X ratio is substantially higher than the transmission system. Load flow studies in distribution systems are not much popular compared to load flow studies in transmission system. In this paper, "Simple and efficient method for load flow solution in distribution network" [2] was used to conduct load flow studies for proposed IEEE-15, IEEE-33, and IEEE-85 bus systems in order to obtain the best DG allocation and size solution.

In contrast to standard load flow solutions, this suggested method just evaluates a straightforward algebraic equation of voltage magnitudes and does not involve any trigonometric equations. This approach uses little computer memory and is reliable and effective. Convergence is always guaranteed. The assumptions are that the distribution system is balanced and the line shunt capacitance is essentially nonexistent.

4.1 Solution Methodology

The ant colony optimization technique is applied for allocation and sizing of DGs. The state transition rule used here in the ant system is given in the Eq. (13). The deposit and evaporation of pheromone that is applied in the ant system is given in the Eq. (14) and Eq. (17) respectively.

For conducting load flow studies to find real and reactive power losses and voltages at each nodes, the "Simple and efficient method for load flow solution in distribution network" [2] is used.

From the above electrical equivalent shown in Fig. 2, we can right

$$I(1) = \frac{|V(1)|\delta(1) - |V(2)|\delta(2)}{R(1) + jX(1)} \tag{1}$$

$$P(2) - jQ(2) = V^{*}(2)I(1) \tag{2}$$

$$(1) = \frac{P(2) - jQ(2)}{V^{*}(2)} \tag{3}$$

From Eqs. (1) and (3), we get

$$\frac{|V(1)|\delta(1) - |V(2)|\delta(2)}{R(1) + jX(1)} = \frac{P(2) - jQ(2)}{V^{*}(2)} \tag{4}$$

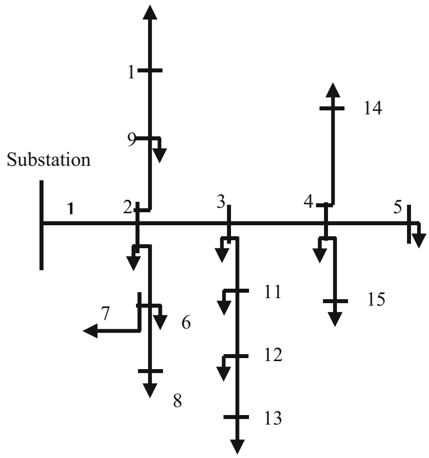

Fig. 1. SLD of 15 Bus IEEE System

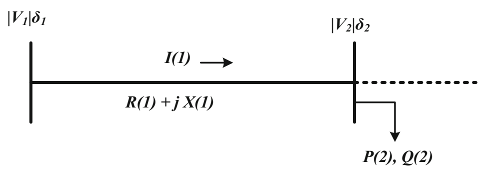

Fig. 2. 15 Bus IEEE System Electrical equivalent

By solving the above equation we get,

$$|V(2)| = \Big\{\Big[(P(2)R(1) + Q(2)X(1) - 0.5|V(1)|^2 \\ -(R^2(1) + (X^2(1))(P^2(2) + \Big(Q^2(2)\Big)\Big]^{1/2} \\ -(P(2)R(1) + Q(2)X(1) - 0.5|V(1)|^2)\Big\}^{1/2} \quad (5)$$

where

P(2) = total real power loads of all buses beyond bus 2 + total real power load of bus 2 itself + total real power losses of all branches beyond bus 2.

Q(2) = total reactive power loads of all buses beyond bus 2 + total reactive power load of bus 2 itself + total reactive power losses of all branches beyond bus 2.

The above Eq. (5) in generalized form can be written as

$$V(m2) = [B(j) - A(j)]^{1/2} \quad (6)$$

where

$$A(j) = P(m2)^* R(j) + Q(m2)^* X(j) - 0.5^* |V(m1)|^2 \quad (7)$$

$$B(j) = [A^2(j) - (R^2(j) + X^2(j)^* (P^2(m2) + (Q^2(m2))]^{1/2} \quad (8)$$

where j is the branch number and m1 & m2 are the sending and receiving end buses, respectively.

Branch 1's real and reactive power losses are given as

$$LP(1) = \frac{R(1)^*[P^2(2) + Q^2(2)]}{|V(2)|^2} \quad (9)$$

$$LQ(1) = \frac{X(1)^*[P^2(2) + Q^2(2)]}{|V(2)|^2} \quad (10)$$

Equations (9) & (10) can written in generalized form as

$$LP(j) = \frac{R(j)^*[P^2(m2) + Q^2(m2)]}{|V(m2)|^2} \quad (11)$$

$$LQ(j) = \frac{X(j)^*[P^2(m2) + Q^2(m2)]}{|V(m2)|^2} \quad (12)$$

where LP(j) and LQ(j) are real power loss and reactive power loss in branch j.

Two independent algorithms are used, one for identifying buses and branches beyond specific bus and to determine the precise load passing through the particular bus. Another algorithm is used to compute load flow.

5 Ant Colony Optimization

5.1 Overview of ACSA

Ant Colony Optimization (ACO) draws inspiration from inherent behaviour of real ants in ant colonies to study artificial systems that are employed to address discrete optimization issues. Marco Dorigo first used it in 1992. It was initially used to solve the Traveling Salesman Problem. Ants' natural behaviour has motivated researchers to apply insect operational techniques to address difficult optimization issues in the real world. Scientists have begun to study ant behaviour in order to better understand their modes of communication.

The ACSA is a path-finding algorithm modeled on how ants search for food. The ants initially wander aimlessly in search of food, then return to the colony, leaving "markers" (pheromones) that indicate the trail holds food for other ants. Other ants are more likely to follow the path and fill it with their own markers when they carry the food back when they come across the markers. The path becomes stronger and stronger as more ants find it, imitating streams of ants going to nearby food sources.

Strengthening of shorter pathways is more likely because the ants release pheromones whenever they deliver food, which optimizes the "solution". The pathway slowly deteriorates after the food source is exhausted because there are no longer any pheromones present. Because ant colony technique relies on dynamic system, it performs exceptionally well in networks with shifting topologies. Computer networks and simulations of workers made with artificial intelligence are two examples of such systems.

5.2 Convergence in ACO

The pheromone update may prevent ACO algorithms, which use stochastic search techniques, from ever finding an optimum. There are at least two different types of convergence that can be taken into account when thinking about a stochastic optimization algorithm [3]:

i. Value convergence.
ii. Solution convergence.

The assessment of the likelihood that the algorithm will at least once produce an ideal answer is known as value convergence. Contrarily, convergence in solution refers to the assessment of the likelihood that the algorithm will eventually reach a state where the same optimal solution will continue to be produced.

5.3 Mathematical Formula for ACSA

Equation (13), which provides the likelihood that ant k at node r would select the destination node s with a probability $P_k(r, s)$, is the state transition rule that the ants system uses [4]. This rule is known as a random proportional rule..

$P_k(r, s) = \frac{\tau(r,s)^{\alpha}\eta(r,s)^{\beta}}{\Sigma_{u\epsilon M_k}\tau(r,u)^{\alpha}\eta(r,u)^{\beta}}, for\ S\epsilon M_k.$

$$P_k(r, s) = 0 \qquad (13)$$

otherwise.

where α = Pheromone degree.

β = Visibility degree.

$u \epsilon M_k$ = a option that every ant k made when it was at node r.

The nodes that are immediately connected to node *r* will all be accessible to ant *k* at node *r*. Visibility is substituted with 1/(distance between node r to node s).

When moving through his trail, the ant will leave some pheromone behind. The formula (14) [4] provides the quantity of pheromone present in the path segment *i–j* left by ant *k*.

$$\tau_{i,j} \leftarrow \tau_{i,j} + \Delta\tau^{k} \tag{14}$$

With the increased value of pheromone quantity in the path segment *i-j*, the probability of choosing this path segment by other ants will increases.

Each ant adjusts the pheromone as it builds its tour according to its local updating rule. Once a node has been passed, the local updating rule in formula 15 [5] will apply, causing the pheromone to evaporate.

$$\tau_{i,j} \leftarrow (1-\rho)\tau_{i,j} + \rho\tau_0 \tag{15}$$

where τ_0 is initial pheromone value and ρ is parameter defined heuristically known as evaporation parameter. Most ACO algorithms uses variations of update rules mentioned by Marco Dorigo[3].

After completion of tours by all the ants, the global updating rule or iteration best (IB) can be applied for best ant tour. This is given by formula (16) [5].

$$\tau_{i,j} \leftarrow (1-\delta)\tau_{i,j} + \sigma\delta^{-1} \tag{16}$$

where δ= Shortest distance of all tours or iteration best tour.

σ= Pheromone decay parameter.

This rule aims to give shorter tours a higher amount of pheromone. The IB-update rule adds a far stronger bias in favour of best solutions. However, this increases the danger of premature convergence [3].

The Eq. (14) is applied after completion of tour by each ant and the evaporation of pheromone is applied by Eq. (17) [4] which applied after completion of each iteration.

$$\tau_{i,j} \leftarrow (1-\rho)\tau_{i,j} \tag{17}$$

5.4 Research Gap

There is much research work has been done for finding optimal allocation and sizing of DGs in distribution system with multiple objective functions for different optimization techniques. However, it is felt that the application of local updating and global updating rules for early convergence is observed in most of the ACO techniques. So, to imitate the natural behaviour, the deposit and evaporation of pheromone is considered without applying global updating rule by considering objective function to maintain the voltage profile near to unity and minimize the losses.

Table 1. Considerations

	IEEE 15-Bus	IEEE 33-Bus	IEEE 85-Bus
No. of Ants	150	150	300
No. of Iterations	75	75	150
Degree of Pheromone (α)	1	1	1
Degree of Visibility (β)	2	2	2
Evaporation rate (σ)	0.5	0.5	0.5
S_{max} in KVA	1000	1000	1000
S_{min} in KVA	300	300	50
V_{max} in p.u	1.05	1.05	1.05
V_{min} in p.u	0.95	0.95	0.95

6 Optimal Placement and Sizing of DGs in Radial Distribution System Using ACSA

6.1 Techniques

i. The inverse of voltage is considered as the visibility for the state transition rule such that voltage is maintained nearer to unity for reducing the line losses. The pheromone value in the paths visited by the ants are updated based on the total losses.
ii. For conducting load flow studies, “A simple and efficient method for load flow solution in radial distribution networks” [7] was applied.
iii. Ant Colony Search Algorithm was used for finding the optimum DGs allocation and sizing in proposed radial distribution system.

6.2 Consideration

The number of ants and number of iteration are taken based on the size of the distribution system. The evaporation rate (σ) is considered as 0.5, to avoid the occurrence of any possible premature convergence. The degree of pheromone (α) is taken as 1.0 to strengthen the trail path visited by the ants whereas the degree of visibility (β) is taken as 2 to increase the weight-age of visibility which is inversely proportional to voltage at each node i.e., to increase the probability of ants to choose the low voltage buses. The values and constraints that are considered in load flow calculations and in Ant colony search algorithm for different IEEE bus systems are tabulated in the Table 1 based on size of the proposed radial distribution system for faster computing time and early convergence.

6.3 Algorithm

i. Read Line, Bus and Load Data for Finding the Voltages at Each Node and Losses in All the Lines.
ii. Perform Distribution Load Flow Studies in Distribution System Without DG.

iii. For First Iteration, Generate the Ant.
iv. Among Various Buses and Sizes of DGs, Find the Probability of Pheromone Path by Using Eq. (13).
v. Calculate the Line Losses and Voltage Profile by Conducting Distribution Load Flow Studies for Complete Tour of Ant.
vi. Check the Required Constraints and Update the Pheromone Matrix.
vii. Modify the Pheromone Matrix Based on the Results of Total Power Losses.
viii. Repeat the Steps from (Iii) to (Vii) for Next Iteration.
ix. Check the Convergence Condition. If It is Satisfied, Print the Results.

7 Results

The ant colony search algorithm(ACSA) by considering objective function to improve voltage at each bus and minimize losses is used to find the optimum allocation and sizing of distribution generators in the 15-bus, 33-bus and 85-bus IEEE radial distribution network. The results are as follows.

7.1 Results in IEEE 15-Bus System

There is one main feeder and five laterals in this system. The total load demand is 1752 KVA with minimum bus voltage of 0.9445 p.u. The total real power loss is 59.58 kW and reactive power loss is 55.52kVAR respectively.

The optimal allocation & sizing of DGs, total real & reactive system losses, min and max voltages with placement of 1No, 2No, 3No and 4No DGs are shown in the Table 2.

Figure 3 shows a graphic comparison of the voltage at each node in the 15Bus IEEE radial distribution system without and with DGs. The voltage profile line at optimum solution (i.e. with 3DGs) is more straight and near to unity compared to other solutions.

The total power losses with 1No, 2No, 3No and 4No DGs are graphically compared in the Fig. 4. It is observed that the losses are reducing with increase in number of DGs up to global optimum solution, beyond further increase in number of DGs lead to increase in total power losses. From the Fig. 4, it can be observed that the global optimum solution for DGs placement and sizing in 15-Bus distribution system is obtained with 3No DGs with respective locations and sizes as shown in Table 2.

7.2 Results in IEEE 33-Bus System

There is one single main feeder and three laterals in this system. The total load demand is 4544 KVA with minimum bus voltage of 0.8772 p.u. The total real power loss is 296.74 kW and reactive power loss is 196.58 kVAR.

The optimal allocation & sizing of DGs, total real & reactive system losses, min and max voltages with placement of 4No, 6No, 8No and 9No DGs are shown in the Table 3.

The voltage at each node without and with DGs in 33-Bus IEEE distribution system are graphically compared in the Fig. 5. The voltage profile line at optimum solution (i.e. with 8DGs) is more straight and near to unity compared to other solutions.

The total power losses with 4No, 6No, 8No and 9No DGs are graphically compared in the Fig. 6. It is observed that the losses are reducing with increase in number of DGs

Table 2. Results in 15-bus radial distribution system with 1No, 2No, 3No and 4No DGs

15-BUS IEEE RDS					
	Without DG	1No DG	2No DGs	3No DGs	4No DGs
DG1 Bus No.		4	6	6	11
DG2 Bus No.			4	11	15
DG3 Bus No.				4	1
DG4 Bus No.					6
Size of DG1		1000.0	813.33	626.67	533.33
Size of DG2			860.00	346.67	440.00
Size of DG3				766.67	1000.0
Size of DG4					626.67
Min voltage in p.u	0.9445	0.9729	0.9824	0.9955	0.9933
Max voltage in p.u	1.0000	1.0000	1.0008	1.0029	1.0007
% Increase in Min Bus Voltage with DG		3.01%	4.01%	5.40%	5.17%
Real Power Loss (kW)	59.58	17.65	6.30	2.90	3.55
Reactive Power Loss (KVAR)	55.52	14.33	4.69	2.06	2.52
Apparent Power Loss (KVA)	81.44	22.82	7.88	3.56	4.36
% Total loss decreased with DG		71.98%	90.32%	95.63%	94.65%

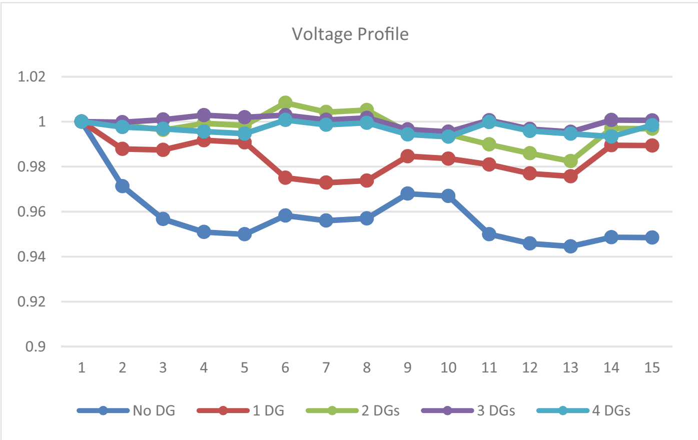

Fig. 3. Comparison of voltages with and without DGs in IEEE15-Bus System

up to global optimum solution, beyond increase in number of DGs lead to increase in total power losses. From the Fig. 6, it can be observed that the global optimum solution

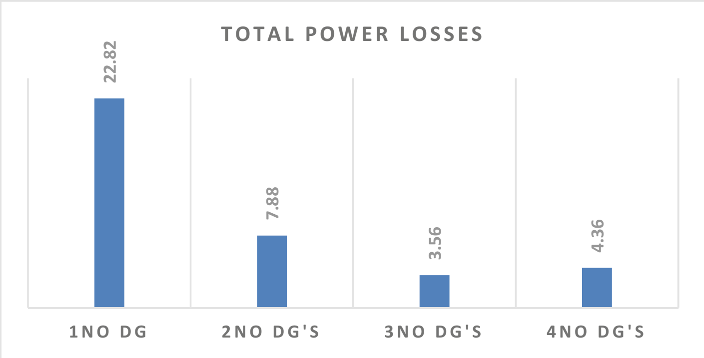

Fig. 4. Total power losses with 1No, 2No, 3No and 4No DGs in the 15-bus distribution system

for DGs placement and sizing in 33-Bus distribution system is obtained with 8No DGs with respective locations and sizes as shown in Table 3.

7.3 Results in 85-BUS IEEE Distribution System

The total load demand is 3672 KVA with minimum bus voltage of 0.8719 p.u. The total real power loss is 295.12 KW and total reactive power losses is 186.06 KVAR.

The optimal allocation & sizing of DGs, total real & reactive system losses, min and max voltages with placement of 4No, 8No, 9No and 10No DGs in IEEE 85-Bus distribution system is shown in the Table 4.

The voltage at each node with and without DGs for 4No, 8No, 9No and 10No DGs are graphically compared in the Fig. 7. The voltage profile line at optimum solution (i.e. with 9DGs) is more straight and near to unity compared to other solutions.

The total power losses with 4No, 8No, 9No and 10No DGs are graphically compared in the Fig. 8. It is observed that the losses are reducing with increase in number of DGs up to global optimum solution, beyond increase in number of DGs lead to increase in total power losses. From the Fig. 8, it can be observed that the global optimum solution for DGs placement and sizing in 85-Bus IEEE distribution system is obtained with 9No DGs with respective locations and sizes as shown in Table 4.

Table 3. Results in 33-bus radial distribution system with4No, 6No, 8No and 9No DGs

33-BUS IEEE RDS					
	Without DG	4No DG	6No DGs	8No DGs	9No DGs
DG1 Bus No		12	32	10	1
DG2 Bus No		32	7	32	14
DG3 Bus No		30	13	30	24
DG4 Bus No		24	29	25	30
DG5 Bus No			25	23	12
DG6 Bus No			24	31	31
DG7 Bus No				7	4
DG8 Bus No				14	21
DG9 Bus No					26
Size of DG1		766.67	745.45	469.70	936.36
Size of DG2		745.45	342.42	512.12	469.70
Size of DG3		745.45	745.45	384.85	469.70
Size of DG4		766.67	766.67	533.33	596.97
Size of DG5			321.21	639.39	575.76
Size of DG6			724.24	363.64	660.61
Size of DG7				596.97	554.55
Size of DG8				469.70	427.27
Size of DG9					406.06
Min voltage in p.u	0.8772	0.9661	0.9877	0.9918	0.9870
Max voltage in p.u	1.0000	1.0000	1.0035	1.0057	1.0077
% Increase in Min Bus Voltage with DG		10.13%	12.60%	13.06%	12.52%
Real Power Loss (kW)	296.74	21.46	9.16	6.98	10.51
Reactive Power Loss (KVAR)	196.58	16.17	7.69	6.44	7.80
Apparent Power Loss (KVA)	360.72	27.36	12.14	9.64	13.24
% Total loss decreased after DG connection		92.42%	96.63%	97.33%	96.33%

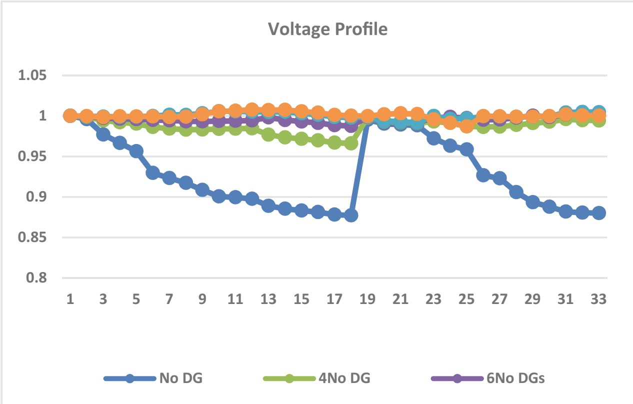

Fig. 5. Comparison of voltages without and with DGs in 33-Bus distribution system

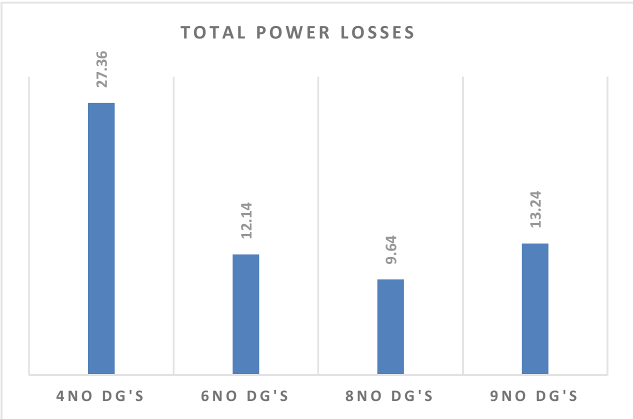

Fig. 6. Total power loss with 4No, 6No, 8No and 9No DGs in the 33-bus distribution system

Table 4. Results in IEEE 85-bus radial distribution system with 4No, 8No, 9No and 10No DGs

85-BUS IEEE RDS					
	Without DG	4No DG	8No DGs	9No DGs	10No DGs
DG1 Bus No.		29	69	33	11
DG2 Bus No.		67	53	70	10
DG3 Bus No.		10	58	54	69
DG4 Bus No.		48	10	46	54
DG5 Bus No.			13	28	55
DG6 Bus No.			80	9	4
DG7 Bus No.			32	80	44
DG8 Bus No.			67	72	29
DG9 Bus No.				61	45
DG10 Bus No					1
Size of DG1		765.29	284.71	497.06	61.18
Size of DG2		843.53	284.71	206.47	932.94
Size of DG3		742.94	307.06	217.65	284.71
Size of DG4		608.82	228.82	172.94	83.53
Size of DG5			262.35	362.94	228.82
Size of DG6			307.06	452.35	675.88
Size of DG7			787.65	385.29	307.06
Size of DG8			307.06	441.18	351.76
Size of DG9				441.18	385.29
Size of DG10					709.41
Min voltage in p.u	0.8712	0.9904	0.9883	0.9917	0.9784
Max voltage in p.u	1.0000	1.0024	1.0000	1.0073	1.0075
% Increase in Min Bus Voltage with DG		13.68%	13.44%	13.83%	12.30%
Real Power Loss (kW)	295.12	12.99	9.96	7.83	20.56
Reactive Power Loss (KVAR)	186.06	6.40	5.23	3.83	9.87
Apparent Power Loss (KVA)	350.02	14.55	11.31	8.75	22.91
% Total loss decreased after DG connection		95.84%	96.77%	97.50%	93.45%

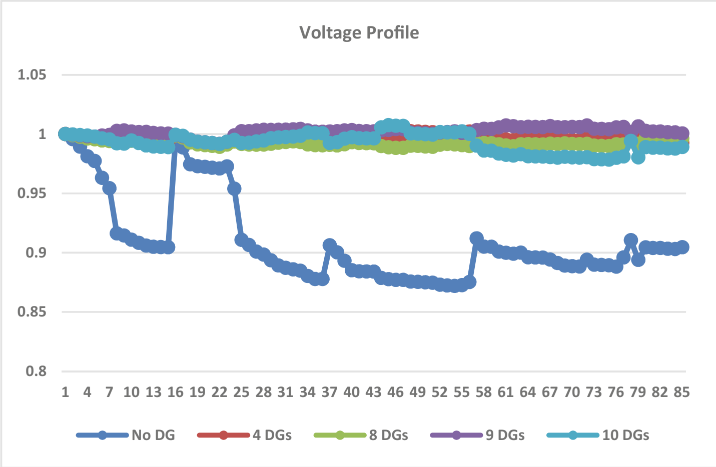

Fig. 7. Comparison of voltages without and with DGs in 85-Bus IEEE System

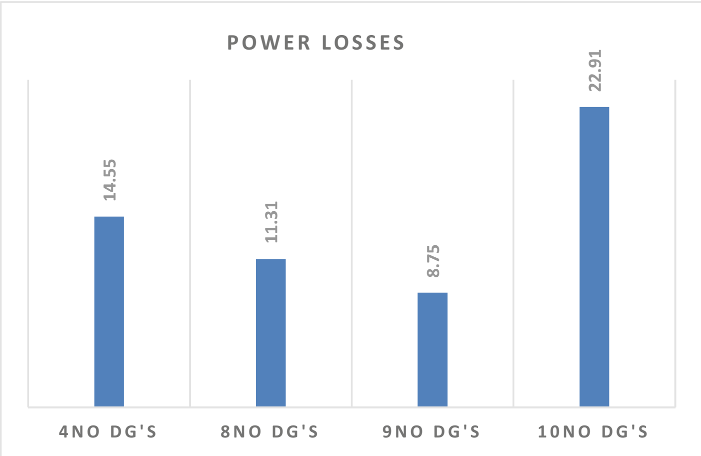

Fig. 8. Total power loss with 1No, 2No, 3No and 4No DGs in the IEEE 15-bus system

8 Conclusion

The ACSA are used to treat the 15-Bus, 33-Bus and 85-Bus IEEE radial distribution systems with varying numbers of DGs in order to determine the global optimal allocation and sizing of DGs. It is noticed that real and reactive system losses have significantly decreased and voltage at each node had also been improved.

It is observed that as the number of DGs is increasing the voltage at each node is also increasing and the voltage profile at optimum solution is near to straight line compare to other solutions. Also, the average of minimum and maximum voltage in each radial distribution system with DGs at optimal solution is very close to unity compare to other solutions, which indicates that the voltage profile is nearer to unity at optimal solution.

The increase in minimum bus voltage, reduction in both real as well as reactive system losses with objective function to maintain the voltage profile close to unity and to minimize the losses are observed to be 1.01%, 1.29% and 0.79% respectively compared to objective function to minimize the losses in 15 Bus IEEE radial distribution system [6].

The increase in minimum bus voltage, reduction in both real as well as reactive system losses with objective function to maintain the voltage near to unity and to minimize loss are observed to be 4.19%, 5.72% and 5.24% respectively compared to objective function to minimize the losses in 85 Bus IEEE radial distribution system [7].

The objective function to maintain the voltage profile near to unity and minimize the losses may be applied for finding optimum allocation of sizing of capacitor bank to minimize the losses and improve the voltage in distribution system and possibility of its application in placement of reactors in transmission system to reduce the system voltage may also be explored.

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