OPTIMAL LOCATION OF COMBINED DG AND CAPACITOR FOR REAL POWER LOSS MINIMIZATION IN DISTRIBUTION NETWORKS

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ABSTRACT

Nowadays, because of development of distributed networks and increase in electricity demand, the use of distributed generation (DG) sources and capacitors banks in parallel is increasing day-by-day. Determining the DG/capacitor optimal location and capacity is extremely important for network loss reduction and improving network performance. The purpose of power loss minimization in transmission and distribution release capacity for both utility and the customer. In this paper, Genetic Algorithm (GA) and Particle swarm optimization (PSO) algorithms are applied for optimal placement and sizing of DG and capacitor simultaneously. GA and PSO are population based stochastic search techniques used for optimization. The performance of GA and PSO has been compared by applying these approaches to standard 12-Bus Radial Distribution System. Test results show that the proposed techniques are more effective and are capable of providing better results than analytical method in finding optimum solutions.

Keywords: Distributed Generation (DG), Genetic Algorithm (GA), Loss Minimization, Optimal Siting, Optimal Sizing, Optimum Location, Particle Swarm Optimization (PSO), Power Distributed Network, Radial Distribution Systems (RDS), Shunt Capacitor.

I. INTRODUCTION

The electric power distribution networks usually supply power to customers at low voltage and are connected to the high voltage transmission systems. The total power losses in the distribution network lines is high because of low voltage and high current in comparison to high voltage network, which in turn, causes increase in the cost of power and poor voltage profile along the distribution feeder. The total power loss in the distribution network is composed of two parts: real power loss and reactive power loss. The real power loss is due to the flow of active component of current required by the load, while the reactive power loss is due to the flow of reactive component of current required to compensate the reactive power requirement of network components. Among these losses, the effect of active power loss is very important because it reduces the efficiency of power transfer and deteriorates the voltage profile. The minimization of real power loss in the distribution networks is therefore of much significance compared to the transmission system. The task of power loss reduction and enhancement of energy efficiency of electric power delivery system mostly goes to electric power distribution. It is reported that as much as 13% of total power generated is wasted in the form of power losses at the distribution level [1]. The capacity of radial line is often limited, it is therefore, necessary to consider some alternative methods so that the future load demands can be supplied ensuring supply quality and reliability.

Most distribution network components like motors and transformers are inductive in nature, so the network power factor is lagging, and this result in reduction of the system's capacity, increase in the system losses, and reduction in bus voltage. Shunt capacitors are used to alleviate some of these problems [2-4]. Apart from reduction in power losses, the shunt capacitor enhances the voltage profile, improves power factor and voltage stability of the system. Distributed Generation (DG) units can play an important role in distribution system planning as DG integration into the distribution system defers major system upgrade, reduces overall energy loss and improves the supply quality and reliability [5]. Even though, DG technologies have positive impacts on distribution system, there might be certain technical challenges with the inclusion of active DG units in conventional passive system. It is important to place DG units at proper location to improve reliability, system operation and supply quality. On the other hand, shunt capacitors, commonly installed for reactive power compensation, can also be considered in parallel with DG units for distribution system expansion planning. It is clear that any loss reduction is beneficial to distribution utilities, which is generally the entity responsible to keep the losses at low levels. Loss reduction is therefore most important factor to be considered in planning and operation of DG [6].

II. PROBLEM FORMULATION

The problem of combined DG and capacitor allocation in distribution network with their appropriate size is very important, because their improper allocation may cause an increase in the system operating costs and power loss, and reduction in the energy efficiency. The main aim of the proposed work is to minimize the total real power loss (P_L) in the distribution network as given in Equation (5), subjected to equality and inequality constraints in Equation. (1), (2), (3), (7)–(10). During DG allocation, the voltage at different buses should be maintained at proper limits for safe and reliable operation of the power distribution system and the current flow in the line conductor must be within the permissible limit.

Consider a branch connected between nodes p and q of a radial distribution network as shown in Fig. 1. The real and reactive power flow through the branch and the terminating node (q) voltage (neglecting shunt conductance and susceptance) are given by Equation (1)–(3), respectively as [15], [27] and [35]:

$$P_{pq} = P_q^F + P_q^L - P_q^{DG} + \frac{R_{pq}}{V_p^2}\left(P_{pq}^2 + Q_{pq}^2\right) \quad (1)$$

$$Q_{pq} = Q_q^F + Q_q^L - Q_q^{DG} + \frac{X_{pq}}{V_p^2}\left(P_{pq}^2 + Q_{pq}^2\right) \quad (2)$$

$$V_q^2 = V_p^2 - 2\left(P_{pq}R_{pq} + Q_{pq}X_{pq}\right)\frac{R_{pq}^2+X_{pq}^2}{V_p^2}\left(P_{pq}^2 + Q_{pq}^2\right) \quad (3)$$

$$\text{Where } P_q^F = \sum\nolimits_{\forall j l i=q} P_{ij} \text{ and } Q_q^F = \sum\nolimits_{\forall j l i=q} Q_{ij}$$

Here P_{pq} (Q_{pq}) are the sending end active (reactive) power flows and R_{pq} (X_{pq}) are the series resistance (reactance). P_q^{DG} (Q_q^{DG}) are the active (reactive) power injections by DG; Q_q^C is the reactive power injection by capacitor and P_q^L (Q_q^L) are the total active (reactive) demand load at bus q. P_q^L (Q_q^L) are the sum of active (reactive) power flows through all the downstream branches connected to bus q. V_q is the magnitude of voltage at bus q. S_B is a set of buses containing all the buses in the system. The value of current flowing through a branch connected between nodes p and q is given as:

$$I_{pq} = \sqrt{\frac{P_{pq}^2 + Q_{pq}^2}{V_p^2}} \quad (4)$$

Mathematically, the objective function is given as:

$$\text{Min } P_L = \sum_{\forall p Iq, q \epsilon S_B} I_{pq}^2 R_{pq} \quad (5)$$

The above objective function is subjected to the set of equality and inequality constraints as given below:

1. Equality constraints

Power balance: The flow of active and reactive power in all the branches of the system must satisfy Eq. (1) and (2), respectively.

Voltage equation: For all branches of the system, the voltage magnitudes at sending and receiving end nodes must satisfy Eq. (3).

DG power factor: The power factor of DG connected at bus q must satisfy the following eqn.

$$\frac{P_q^{DG}}{\sqrt{(P_q^{DG})^2 + (Q_q^{DG})^2}} = \cos \varphi_q \quad (6)$$

2. Inequality constraints

Bus voltage: The voltage at each bus must lie within the prescribed limits

$$V_q^{min} \leq V_q \leq V_q^{max} \quad q \in S_B \quad (7)$$

Line current: The flow of current through each branch should not exceed its thermal limit

$$I_{pq} \leq I_{pq}^{rated} \quad \forall \text{ pandq} \in S_q \quad (8)$$

DG capacity: The DG capacity should not exceed certain percentage of total feeder load of network

$$\sum_{q \in S_q} \sqrt{(P_q^{DG})^2 + (Q_q^{DG})^2} \leq 0.5 \times \sum_{q \in S_q} \sqrt{(P_q^L)^2 + (Q_q^L)^2} \quad (9)$$

Capacitor capacity: The capacity of capacitor should not go over the total reactive power load of network

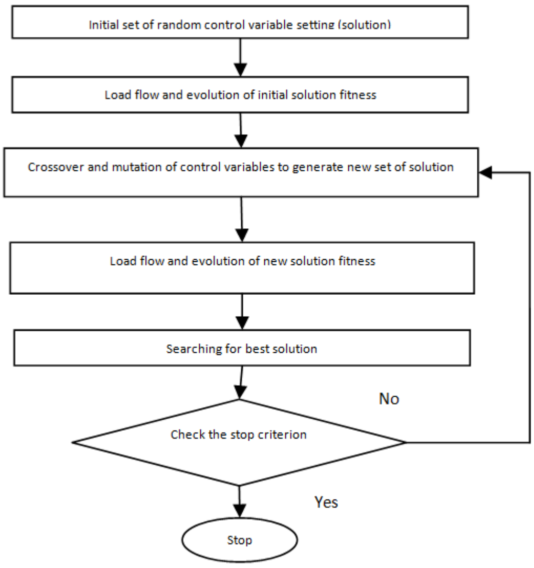
$$\sum_{q \in S_q} Q_q^c \leq 1.0 \times \sum_{q \in S_q} Q_q^L \quad (10)$$

Where V_q^{min} and V_q^{max} are the minimum and maximum value of the voltage at bus q (i.e. 0.95–1.05), respectively I_{pq}^{rated} is the thermal limit of a branch between nodes p and q, $\cos \varphi_q$ is power factor of DG at qth bus.

III. PROPOSED METHODOLOGY

3.1 Genetic algorithm (GA)

In GA algorithm [11], the population has n chromosomes that represent candidate solution; each chromosome is an *m* dimensional real value vector where *m* is the number of optimized parameters.



Flow Chart of GA

Therefore each optimized parameter represents a dimension of the problem space. The Genetic Algorithms can be described in the following steps which also flow chart of GA.

Step 1 (initialization): sets the time counter t = 0 and generates randomly 'n' chromosomes. [$x_j(0)$, j = 1,. . . ,n], where $x_j(0)$ = [x_j,1(0), x_j,2(0), . . . ,j_am(0)]. x_j, k(0), will generate in searching gap [X_k^{min}, X_k^{min}] randomly .

Step 2 (fitness): evaluating each chromosome in the initial population using the objective function J and will search for the best value of the objective function J_{best}. This step will to finish sets the chromosome proportionally to the J_{best} as the best.

Step 3 (time updating): updates the point in time counter t = t + 1.

Step 4 (new population): create a new population by repeat the following steps until the new population is completed:

- Selection: selecting parent chromosomes from a population according to their suitability.
- Crossover: by means of a crossover probability, crossing over the parents to produce a new child.
- Mutation: by means of a mutation probability, process mutates new child at each chromosome.
- Acceptance: situate new child in a new population.

Step 5 (replacement): Using of the fresh generates population for a further run of algorithm.

Step 6: If one of the stopping criteria was detected, the operation will stop, otherwise going back to step 2

3.2 Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) was first introduced by Kennedy and Eberhart as an optimization method for continuous nonlinear functions. It is a stochastic optimization technique based on individual improvement, social cooperation and competition in the population. PSO is inspired of the behaviors of social models like bird flocking or fish schooling. Since its introduction, PSO become an important tool for the optimization problems [34].

PSO technique finds the global best solution by simply adjusting the trajectory of each individual toward its own best location and toward the best particle of the entire swarm at each time step (iteration) [27]. The PSO method is becoming very popular due to its simplicity of implementation and ability to quickly converge to a reasonably good solution. In the PSO algorithm, the trajectory of each individual in the search space is adjusted by dynamically altering the velocity of each particle, according to its own flying experience of the other particles in the search space.

The position vector and velocity vector of the i^th particle in the d-dimensional search space can be represented as X_i $[x_{i1}, x_{i2}, x_{i3} ... x_{id}]$ and $V_i = [v_{i1}, v_{i2}, v_{id}]$ respectively. According to a user define fitness function, say the best position of each particle (which corresponds to the best fitness value obtain by that particle at iteration k) is $P_i = [p_{i1}, p_{i2}, ..., p_{id}]$, and the fitness particle found so far at iteration k is $P_g = [p_{g1}, p_{g2}, p_{g3}, ... p_{gd}]$, than the new velocities and the position of the particle for the next fitness evaluation are calculated using the following two equations.

Therefore each optimized parameter represents a dimension of the problem space. The Particle Swarm Optimization can be described in the following steps which also shown in Fig. 2.

Step – 1 Initialization

Initially the particle is defined as a vector which contains the randomly selected Distributed generation location (the bus number at which a statcom is placed) and its size as shown below.

Particle: [λ,η], λ: is the Distributed generation but location number, η: is the DG size in MW

Step – 2 Calculation of fitness function

The controlled optimization problem is changed into unconstrained optimization problem using penalty factor as given below.

Fitness function = Objective function J + Penalty factor (F(x) = J + PF)

The fitness function used in PSO algorithms consists of two terms: J the original fitness function and the penalty factor PF corresponding to the constrain violation.

Step -3 searching of the local and global best solutions.

On the basis of fitness function the local and global best solution are identified.

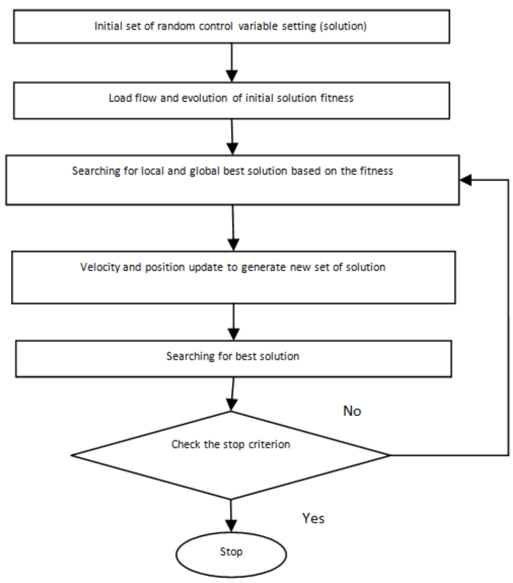
Step – 4 updating of the velocity and position

New velocity and position for every particle is calculated using (1) and (2).

Step – 5 Repeat step (2) to (4) until certain termination (stopping) condition is met.

Step – 6 Stop the optimized solution is obtained

Thus the optimal location and size of DG is evaluated using PSO algorithms implemented through step 1 to 6.



Flow Chart of PSO

IV. SIMULATION RESULTS AND DISCUSSION

The algorithm given above is implemented in the MATLAB. To demonstrate the effectiveness of the proposed algorithm, the following cases are considered for the test system:

Case 1: Only the capacitor is placed at the optimal location.

Case 2: Only the DG operating at unity power factor (upf) is placed at the optimal location.

Case 3: Combined DG operating at upf and the capacitor are placed at their optimal location.

Case 4: Combined DG operating at 0.9 power factor lag and the capacitor are placed at their optimal location.

Case 5: Combined DG operating at the pf equal to total feeder load pf and the capacitor were placed at the optimal location.

4.1 12 – Bus Distribution Network

The proposed algorithm is tested on 12-bus radial distribution networks. The Gauss-Seidel load flow method is used to find voltage magnitude and phase angle at various buses, line flow and line losses. The type of DG model considered in this study is a controllable synchronous generator based which delivers both real and reactive power at fixed power factor mode [14].The 12-bus network is an 11kV radial distribution system (RDS) consisting of 11 branches with total feeder load of 435kW and 405kVAR. The line and load data are given in [30]. The combined load power factor of this system is 0.75 lag.

Genetic algorithm and Particle swarm optimization algorithms have been applied for finding the optimal location of DG and shunt capacitor for the 5 cases as discussed below.

Case 1: Only the capacitor is placed at the optimal location. In this case the maximum capacity of capacitor is taken equal to total MVAR loading of the network, i.e. $0.405 \approx 0.4\text{MVAR}$.

Case 2: Only DG operating at unity power factor is placed at the optimal location In this case the maximum capacity of the DG is taken equal to 50% of the total MW loading of the network, i.e. $0.5 \times 0.435 \approx 0.25\text{MW}$.

Case 3: Combined DG operating at upf and capacitor were placed at their optimal locations. In this case the maximum capacity of DG and capacitor are selected same as in Case 1 & 2 i.e. 0.25MW and 0.4 MVAR respectively and are simultaneously considered for placement.

Case 4: Combined DG operating at 0.9 pf and the capacitor were placed at their optimal location. In this case the maximum DG capacity is selected equal to 50% of the total MVA loading of the network at 0.9 pf. So, the maximum DG capacity is 0.3MW and 0.15 MVAR (with capacitor value set to zero, i.e. $Q_c = 0$), respectively.

Case 5: Combined DG operating at power factor selected equal to the total feeder load power factor and the capacitor were placed at their optimal location. In this case the maximum DG capacity is selected equal to 50% of the total MVA loading of the network at 0.75 pf lag. So, the maximum DG capacity is 0.25MW and 0.2 MVAR (with capacitor value set to zero).

The results obtained for these five cases using GA and PSO toolboxes of MATLAB are shown and compared with reported results in Table 1. As can be observed from Table 1, the results obtained using GA and PSO are almost the same and better than those obtained using analytical method. The convergence characteristics as obtained using GA toolbox for the 5 cases are shown in Fig.1-5 and using PSO toolbox in Fig. 6-10 respectively.

Table 1- 12 BUS RDS Using GA, PSO and Analytical Approach

Device	Genetic Algorithm (GA)				Particle Swarm Optimization (PSO)				Analytical approach [1]		
	Size MW/MVAR	P_{loss} (kW)	VD	Lowest Voltage (p.u.)	Size MW/MVAR	P_{loss} (kW)	VD	Lowest Voltage (p.u.)	P_{loss} (kW)	Size MW/MVAR	Lowest Voltage (p.u.)
QC Only	0.210298(b9)	12.5842	0.313766	0.956298 (b12)	0.210223(b9)	12.5842	0.313795	0.956294(b12)	134.3	0.16 (b12)	0.95596(b11)
DG Only	0.235504(b9)	10.7744	0.143276	0.983531 (b7)	0.235472(b9)	10.7744	0.143310	0.983529(b7)	109.2	0.2 (b12)	0.98032(b8)
DG & QC Both	0.232224(b9) 0.212299(b9)	3.1520	0.060396	0.990805 (b7)	0.232434(b9) 0.212087(b9)	3.1520	0.060257	0.990815(b7)	71.93	0.12(b12) 0.24(b12)	0.9815(b8)
DG 0.9 pf	0.272535 0.131998 (b9)	4.49288	0.052760	0.991213 (b6)	0.2725 0.1320 (b9)	4.5000	0.05281	0.991213(b12)	57.41	0.2 0.1 (b12)	0.9847(b7)
DG 0.75 pf	0.226722 0.199939 (b9)	3.18572	0.071185	0.989928 (b7)	0.226792 0.200000 (b9)	3.1850	0.711089	0.98990 (b12)	47.56	0.2 0.16 (b12)	0.9867(b7)

Fig 1 Convergence Characteristic of GA for QC only

Fig 2 Convergence Characteristic of GA for DG only

Fig 3.Convergence Characteristic of GA for DG and QC both

Fig 4.Convergence Characteristic of GA for DG at 0.9 pf

Fig 5.Convergence Characteristic of GA for DG at 0.75 pf

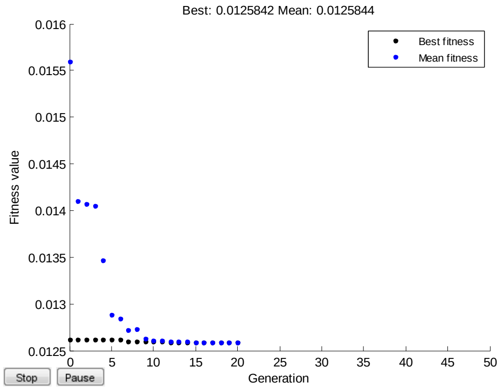


Fig 1

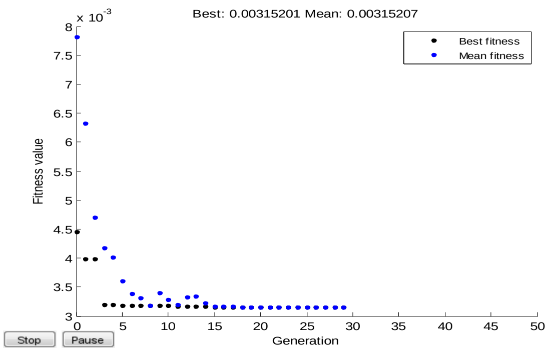


Fig 2

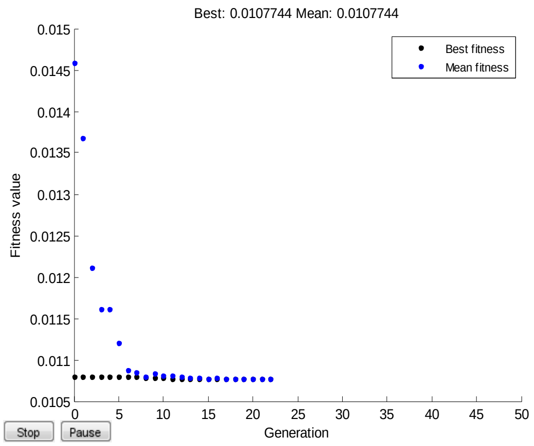


Fig 3

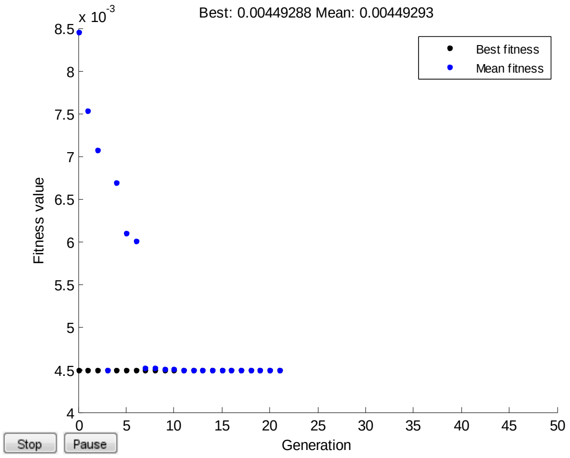


Fig 4

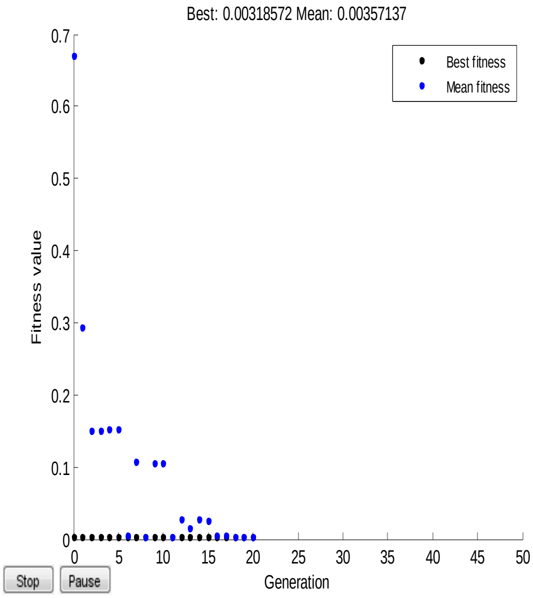


Fig 5

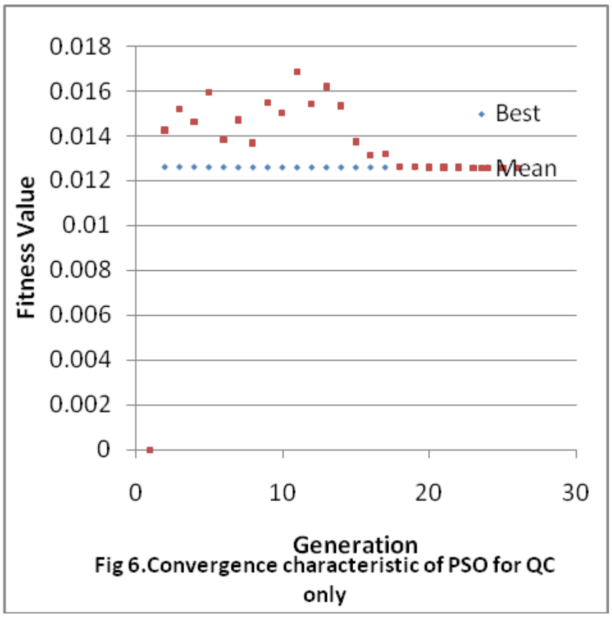


Fig 6.Convergence characteristic of PSO for QC only

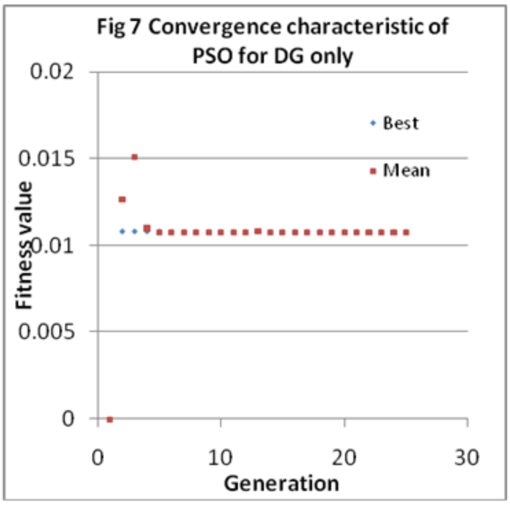


Fig 7 Convergence characteristic of PSO for DG only

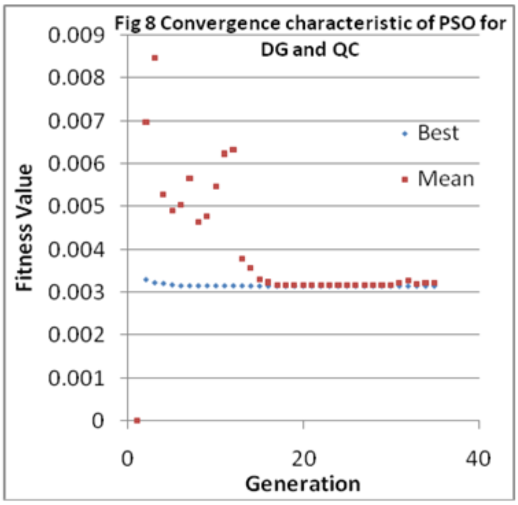


Fig 8 Convergence characteristic of PSO for DG and QC

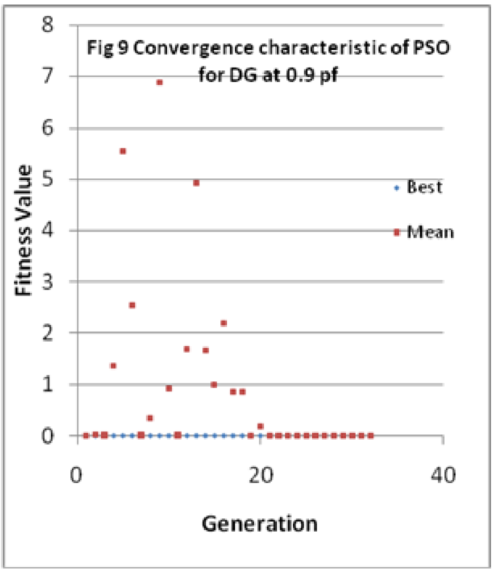


Fig 9 Convergence characteristic of PSO for DG at 0.9 pf

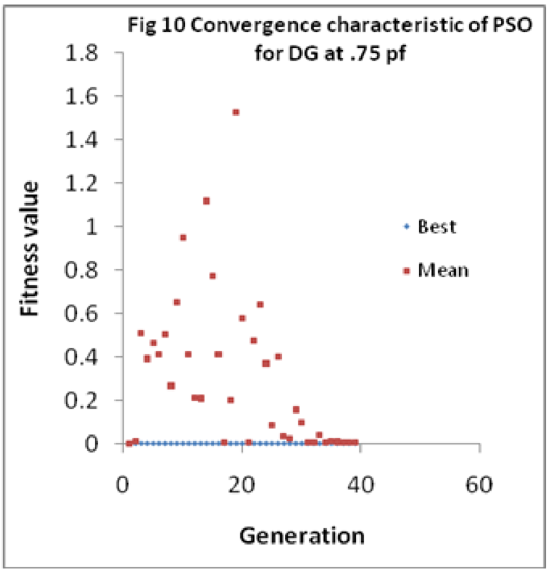


Fig 10 Convergence characteristic of PSO for DG at .75 pf

The voltage profile for 12-bus RDS for the 5 cases considered above is depicted in Fig. 11 and also in Table 2. It can be seen from the figure and Table that improvement in the voltage profile by optimal placement of DG operating at 0.9 pf lagging (case 4) is somewhat superior to combined DG operating at upf and capacitor (Case3).

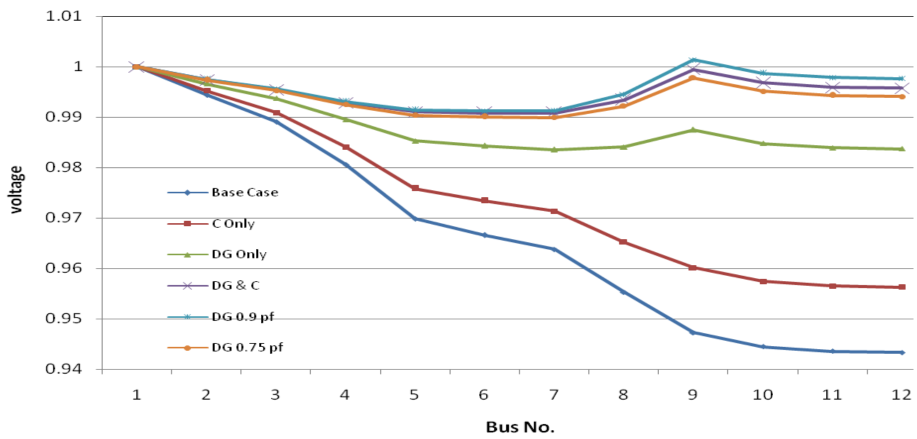


Fig 11 Voltage Profile of 12-Bus RDS

Table 2 Voltage Profile of 12 - RDS

Bus No.	Base Case	QC Only	DG Only	DG & QC Both	DG 0.9 pf	DG 0.75 pf
1	1.00000	1	1	1	1	1
2	0.99433	0.995207	0.996566	0.997416	0.997461	0.997315
3	0.98903	0.990849	0.993687	0.995449	0.995545	0.99524
4	0.98058	0.984056	0.989528	0.992884	0.993077	0.992484
5	0.96982	0.975808	0.985311	0.99105	0.991399	0.99036
6	0.96654	0.973374	0.984265	0.990808	0.991213	0.99002
7	0.96375	0.971367	0.983531	0.990805	0.991264	0.989928
8	0.95531	0.965215	0.984052	0.993385	0.994495	0.992182
9	0.94728	0.960168	0.987452	0.999424	1.001335	0.997802
10	0.94446	0.95739	0.984752	0.996761	0.998673	0.995129
11	0.94356	0.956504	0.98389	0.995911	0.997823	0.994277
12	0.94335	0.956298	0.98369	0.995713	0.997626	0.994079

V. CONCLUSIONS

This paper presented GA and PSO based techniques for optimal placement and sizing of combined DG and capacitor in the distribution system. It can be concluded that allocation of capacitor alone can improve the voltage but may not reduce the loss as expected. On the other hand, allocation of DG can reduce the power losses and also improves the system voltage profile. If the DG, with both real and reactive power generation capability is combined with the capacitor and is optimally allocated, can result in substantial reduction in real power loss of the distribution network and also improves the voltage profile along the feeder. In comparison to the conventional planning methods, the application of combined DG unit and capacitor can largely reduce the investment besides improving supply quality and reliability. The GA and PSO both algorithms provided the same results and better results obtained using analytical approach.

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