Optimal Allocation of DGs and Capacitor Banks in Radial Distribution Systems

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ABSTRACT

Little attention has been paid to the integration of Distributed Generators or DGs and capacitor banks in radial distribution system to meet the increased electricity demand and to improve the technical aspects like power loss reduction, voltage profile improvement, etc. Such improvements involve major concerns such as finding the optimal sizing of DGs and capacitor banks and their locations. This article presents the application of two new optimization algorithms: Firefly Algorithm (FFA) and Backtracking Search Algorithm (BSA) to solve the optimal placement of both DG and fixed capacitor banks, in order to reduce the power loss and improve voltage profile of distribution system. A detailed performance analysis is carried out on 33-bus and 69-bus radial distribution system to demonstrate the effectiveness of the proposed algorithms and the results are compared with the Genetic Algorithm/Particle Swarm Optimization (GA/PSO), Imperial Competitive Algorithm/Genetic Algorithm (ICA/GA) and Analytical approaches available in the literature.

Key Words— Optimal allocation, DGs, capacitors, radial distribution system, distribution losses minimization.

INTRODUCTION

Nowadays a wide range of research is going on the distribution system as it is the final link between the bulk power system and the consumers. Distribution system generally operates at low voltage and high currents, results in large amount of power loss and poor voltage profile when compared to the Transmission system. It is approximated that the share of distribution losses in total power generated is 13% [1].

Increasing electricity demand leads to the further increment in power losses and voltage drops. Such amount of high power losses limits the line capacity (thermal limits) and poor voltage profile causes the voltage instability of the system. Therefore, the concern is not only about the technical improvements but also to meet the future electricity demand for the existing distribution system by maintaining the line capacity and the voltage stability.

OPTIMAL CAPACITOR PLACEMENT

Normally, reactive loads on the Distribution system like motors and distribution transformers which are lagging in nature require large amount of reactive power, thus resulting in low power factor, high power losses and poor voltage profile. Capacitor is one of the equipment to alleviate up to some extent of the problems which are mentioned above and also provides reactive power support. Shunt capacitors banks reduces the power losses up to the coupling point by altering the reactive power flows up to that point. Previously shunt capacitors have been placed at the distribution sub-stations. But the possibility of pole mounted shunt capacitor makes it possible to place them at the distribution lines, which requires optimal placement and sizing of capacitor banks. Numerical methods to the optimal placement of capacitor with a view to minimize losses have been suggested in the literature based on the both traditional mathematical models and more recent heuristic approaches. Schmill [2] presented a 2/3 rule for the placement of a single capacitor assuming both load and distribution feeder are uniform. Prakash and Sydulu used Particle Swarm Optimization (PSO) [3] approach for finding the optimal sizes and locations of capacitors in radial distribution system to minimize power loss. Direct Search Algorithm (DSA) [4] to find the optimal sizes and locations of fixed and switched capacitors for constant & time varying load models in a radial distribution system to maximize the savings and minimize the power loss was presented by Raju et al. Sneha Sultana et al.[5] proposed Teaching-Learning-Based Optimization (TLBO) algorithm for the optimal placement of fixed capacitor banks along with their locations with an objective function of minimizing power losses. Iman Ziari et al. [6] proposed Modified Discrete Particle Swarm Optimization for optimal allocation and sizing of capacitors and setting of load tap changer (LTC) for minimizing line loss using estimation of the load duration curve to multiple levels. A comprehensive survey on the various heuristic optimization techniques applied to determine the optimal capacitor placement and size is presented in [7].

OPTIMAL DG PLACEMENT

Installation of DGs in the radial distribution network at the load centers can improve the voltage profile and reduce the real power losses to the significant effect as it controls the active and reactive power flows in the distribution primary lines. As the DGs can inject both real and reactive power it can reduce transmission and distribution capacity release which can be utilized for increased future demand of electricity. In decentralized electricity market installation of DGs encourages the distribution network operators, as it reduces the amount of energy taken from the transmission side. With growing concerns among the environmental impacts majorly contributed by the centrally dispatched generations, renewable energy DG sources can provide most viable alternative to the utilities. A "2/3 rule" analytical method is suggested for the installation of DG by [8]. S K Injeti et al. suggested simulated annealing (SA) method [9] for the sizing of multiple DGs and their allocation is done by using loss sensitivity factors. An ABC method is proposed for the optimal DG unit's location, size and power factor by [10], for the reduction of active power loss. PSO is applied for optimal placement of multiple DGs in distribution system with varying power load models by [11]. Optimal placement of DG is done by considers uncertainties using fuzzy numbers and is solved by a hybrid Non-dominated Sorting Genetic Algorithm II (NSGA-II) in [12]. A detailed analysis of DG placement is given by [13], which describes the different algorithms and methods of their approaches for the loss reduction and voltage profile improvement.

SIMULTANEOUS OPTIMAL ALLOCATION OF DGS AND FIXED CAPACITOR BANKS

Due to the limited DGs sources and high implementation cost, we can't have a wide usage of DG sources. Therefore, it is necessary to use another parallel element with DG which having low implementation cost, to improve the technical aspects like power loss reduction, voltage profile and power factor improvement. Since capacitor supports reactive power and improves the above mentioned technical aspects, combined optimal placement of DG and capacitor for improving the same amount of technical aspects requires less amount of real power injection by the DG against optimal placement of DG only which reduces the implementation cost of DG. Hence the simultaneous placement capacitor and DG gives the optimal operational economics of power system. Sayyid Mohssen Sajjadi et al. [14] proposed Memetic alogorithm (MA) for optimal sizing of DGs and capacitors and their corresponding location are given by voltage stability index. Mohammad H. Moradi, et al. [15-16] proposed GA/PSO and ICA/GA for the optimal sizing of DGs & capacitor banks and their locations. He considered a multi objective function for this optimization problem and explores economical advantages for corresponding technical improvements. S. Gopiya Naik et al. [17] proposed an analytical approach for optimal sizing of a DG and a capacitor and their corresponding location are given by loss sensitivity factor for loss minimization.

The various promising results reported by others to various engineering optimization problems motivated us to apply novel the Firefly Algorithm (FFA), a new nature inspired meta-heuristic algorithm proposed by Xin-She Yang in [18-20] and Back Tracking Search Algorithm (BSA), a population based evolutionary algorithm was proposed by Pinar Civicioglu in 2013[21]. However, from the literature review it is seen that the application of FFA and BSA to optimal allocation of capacitor or DGs or simultaneous placement of DG and capacitor has not been explored. This motivated the authors to use a Bio-inspired algorithm FFA and population based evolutionary algorithm BSA for the optimal placement of DG as well as capacitor. From the literature survey, different techniques has been followed to find out the location of DGs or capacitors but in this article locations are considered as one of the variable along with the sizing of DGs and capacitor banks. In order to validate the effectiveness of the proposed algorithms, they have tested on IEEE-33 and IEEE-69 radial bus systems and the results are compared with existing algorithms. The Standard Backward/Forward Sweep power flow method suggested in [22-23] is used for the load flow analysis. The rest of this article is organized as follows. Section 2 gives the objective function formulation, Section 3 gives the overview of proposed algorithms, Section 4 presents the result analysis and Section 5 presents conclusions of the work.

OBJECTIVE FUNCTION FORMULATION

Objective Function

Installation of DGs injects real and reactive power and capacitors injects reactive power causes altering of both real and reactive power flows in radial distribution system which results in the reduction of power losses and voltage profile improvement. The objective function is considered as power loss minimization which requires finding of optimal sizes and locations of both DGs and fixed capacitor banks subjected to some operational constraints. Mathematically the objective function is formulated as

$$\text{Minimize } P_{T,loss} = \sum_{i=1}^{n-1} |J_i|^2 * re(Z_i) \qquad (1)$$

Where $P_{T,loss}$ is the total active power loss, *n* is the number of buses, Z_i is the impedance of the ith branch and J_i is the branch current of the ith branch

Branch currents are obtained from the results after performing Standard backward/forward sweep power flow [22] using eq. (2).

$$J = BIBC * I \qquad (2)$$

Where J represents the branch current matrix, BIBC represents the bus injected branch current matrix and I represent the nodal current matrix.

$$I_i = \left(\frac{(P_i - P_{DGi}) + j*(Q_i - (Q_{ci} + Q_{DGi}))}{V_i}\right)^* \qquad (3)$$

Where P_i, Qi are the active and reactive power load at the ith bus, P_{DGi}, Q_{DGi} are the real and reactive power of DGs injected at the ith bus, Q_{ci} is the reactive injected by the capacitor at the ith bus and V_i is the voltage at ith node.

Constraints

The objective function is subjected to following constraints:

- The voltage magnitude must kept within the specified limits at each bus:

$$V_{min} \le V \le V_{max} \qquad (4)$$

Where V_{min}, V_{max} are the lower and upper limits of bus voltage, respectively.

- From practical limitation, maximum compensation by using DGs is limited to the total active power demand.

$$\sum_{i=1}^{N_{DG}} P_{DGi} \leq \sum_{j=1}^{N_l} P_D(j) \tag{5}$$

Where N_{DG} is the number of DGs, N_l is the number of load buses and $P_D(j)$ is the reactive power demand of load at bus j.

- From practical limitation, maximum compensation by using capacitor bank is limited to the total reactive power demand.

$$\sum_{i=1}^{N_c} Q_c(i) + \sum_{i=1}^{N_{DG}} Q_{DGi} \leq \sum_{j=1}^{N_l} Q_D(j) \tag{6}$$

Where N_l is the number of load buses and $Q_D(j)$ is the reactive power demand of load at bus j.

- Capacitors are available in discrete sizes so shunt capacitors to be dealt with multiple integers of the smallest capacitor size available and it may be mathematically expressed as

$$Q_c(i) = LQ_s \tag{7}$$

Where, Q_s is the smallest capacitor size available and L is an integer multiple.

PROPOSED ALGORITHMS

Backtracking Search Algorithm

BSA is a population-based iterative EA designed to be a global minimizer. SA can be explained by dividing its functions into five processes as is done in other EAs: initialization, selection-I, mutation, crossover and selection-II.

Algorithm General Structure of BSA

```
1) Initialization
Repeat
    2) Selection-I
       Generation of trail population
           (3) Mutation
           (4) Crossover
       End
    5) Selection-II
Until stopping conditions are met
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Initialization

BSA initializes the population P with Eq. (8):

$$P_{ij} \sim U\ (low_j, up_j) \tag{8}$$

for i = 1,2,3,…,N and j = 1,2,3,…,D, where N and D are the population size and the problem dimension, respectively, U is the uniform distribution and each P_i is a target individual in the population P.

Selection-I

BSA's Selection-I stage determines the historical population oldP to be used for calculating the search direction. The initial historical population is determined using Eq. (9):

$$oldP_{ij} \sim U\ (low_j, up_j) \tag{9}$$

BSA has the option of redefining oldP at the beginning of each iteration through the 'if-then' rule in Eq. (10):

$$\text{If } a < b \text{ then } oldP := P \mid a, b \sim U\ (0, 1), \tag{10}$$

Where, : = is the update operation. Eq. (10) ensures that BSA designates a population belonging to a randomly selected previous generation as the historical population and remembers this historical population until it is changed. Thus, BSA has a memory.

After oldP is determined, Eq. (11) is used to randomly change the order of the individuals in oldP:

$$oldP: = permuting\ (oldP). \tag{11}$$

The permuting function used in Eq. (11) is a random shuffling function.

Mutation

BSA's mutation process generates the initial form of the trial population Mutant using Eq. (12).

$$Mutant = P + F.\ (oldP - P) \tag{12}$$

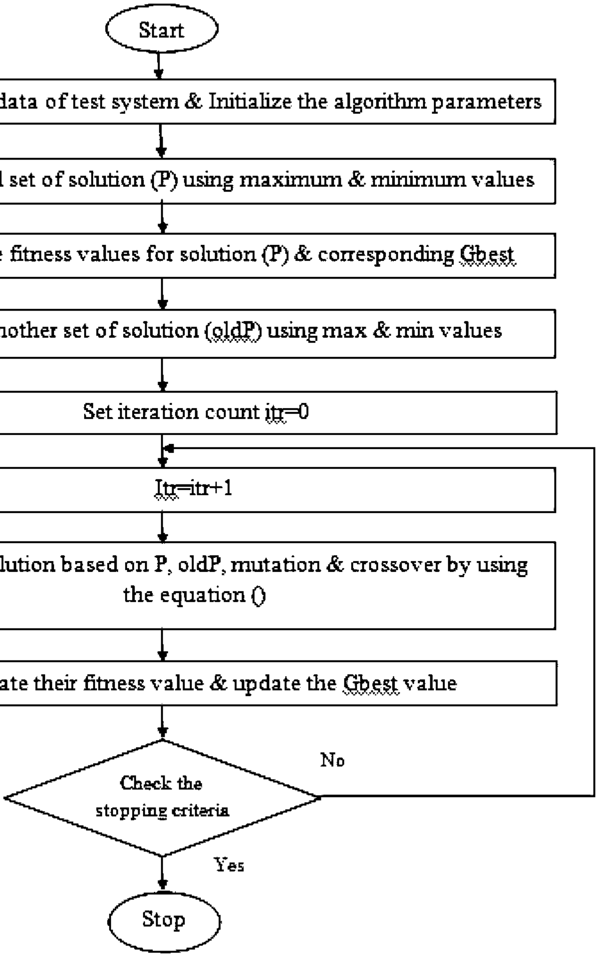

Figure 1: Flow chart of BSA

In Eq. (12), F controls the amplitude of the search-direction matrix (oldP - P). Because the historical population is used in the calculation of the search-direction matrix, BSA generates a trial population, taking partial advantage of its experiences from previous generations. This article uses the value F = 3. rndn, where, rndn ~ N (0, 1) (N is the standard normal distribution).

Crossover

BSA's crossover process generates the final form of the trial population T. The initial value of the trial population is Mutant, as set in the mutation process. Trial individuals with better fitness values for the optimization problem are used to evolve the target population individuals. BSA's crossover process has two steps. The first step calculates a binary integer-valued matrix (map) of size N*D that indicates the individuals of T to be manipulated by using the relevant individuals of P. If $map_{n,m} = 1$, where $n \epsilon \{1, 2, 3, \ldots, N\}$ and $m \epsilon \{1, 2, 3, \ldots, D\}$, T is updated with $T_{n,m} := P_{n,m}$.

Selection-II

In BSA's Selection-II stage, the T is that have better fitness values than the corresponding P is are used to update the P is based on a greedy selection. If the best individual of P (P_{best}) has a better fitness value than the global minimum value obtained so far by BSA, the global minimizer is updated to be P_{best}, and the global minimum value is updated to be the fitness value of P_{best}. The structure of BSA is quite simple; thus, it is easily adapted to different numerical optimization problems and the Figure 1 represents the flowchart for BSA.

Firefly Algorithm (FFA)

The idealized Flashing characteristics of fireflies are used to develop firefly-inspired algorithm. Firefly Algorithm (FFA) [18-20] developed by Xin-She Yang at Cambridge University, use the following three idealized rules:

- All the fireflies are unisex so it means that one firefly is attracted to other fireflies irrespective of their sex.
- Attractiveness and brightness are proportional to each other, so for any two flashing fireflies, the less bright one will move towards the one which is brighter.

- Attractiveness and brightness both decrease as their distance increases. If there is no one brighter than other firefly, it will move randomly.

The brightness of a firefly is determined by the view of the objective function. For a maximization problem, the brightness is simply proportional to the value of the objective function. Other forms of the brightness could be defined in an identical way to the fitness function in genetic algorithms.

The distance between any two fireflies i and j at xi and xj, is expressed as

$$r_{ij} = \sqrt{(x_i - x_j)^2 - (y_i - y_j)^2} \tag{13}$$

The movement of the i^{th} firefly is attracted to another more attractive (brighter) firefly jth is expressed as

$$x_i = x_i + \beta_0 e^{-\gamma r_{ij}^2}(x_j - x_i) + \alpha \text{€}_i \tag{14}$$

The problem specific implementation flow chart of FFA has been given in Figure 2.

RESULTS AND DISCUSSIONS

The performance and effectiveness of the proposed algorithms for power loss minimization have been tested on 33-bus and 69-bus radial distribution system for all the six cases. The six different cases are shown in the Table 1. A number of trails on the performance of the applied algorithms has been carried out on the test systems to determine the most suitable parameters. In this work, the tuned parameters of BSA and FFA are given in Table 2. The entire simulation is developed in MATLAB R2010a software and the simulations are carried on a computer with Intel(R) Core(TM) i5-2450M CPU @2.50GHz, 4 GB RAM.

33-bus Test System Numerical Results

The 33-bus test case consists of a main feeder and 3 sub-feeders (laterals) radial distribution system and the data of the system is obtained from [16]. The total load of the system is 3715 kW and 2300 kVAR. The

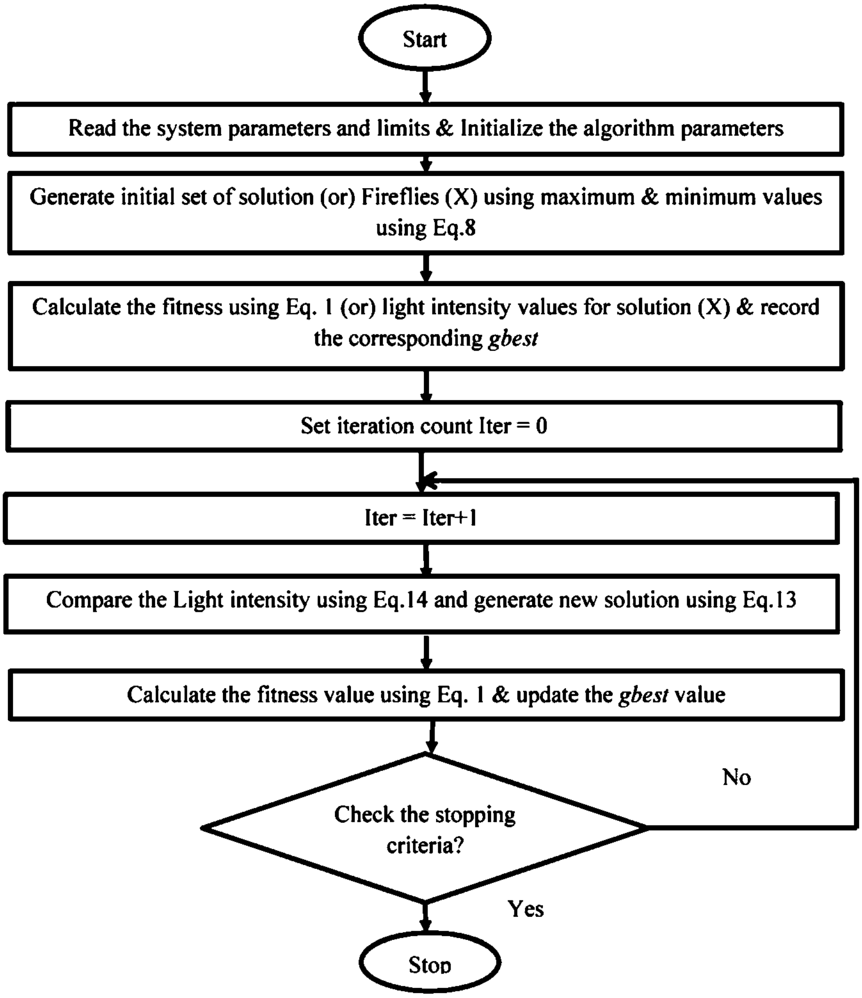

Figure 2: Flow chart of FFA

rated voltage of the system is 12.66kV. After an initial load flow run using Backward/Forward Sweep method for an uncompensated system, the active power loss is 210.9823KW and maximum & minimum voltages are 1.0 p.u and 0.9038 p.u respectively. To observe the effectiveness of the proposed algorithms, their results are compared with the other techniques like GA/PSO, ICA/GA and Analytical Approach. Table 3 & Table 4 shows, the optimal locations and sizes of DGs & capacitors, DGs operating power factors, total real power injected, total active power loss

Table 1: Description of six different cases

Case	Type of sources used for compensation
1	Single DG only
2	Single DG and single Capacitor
3	Two DGs only
4	Two DGs and two Capacitors
5	Three DGs only
6	Three DGs and three Capacitors

Table 2: Tuned algorithm parameters for BSA and FFA

Algorithm	Parameter	Description	Value
FFA	N	Population of fireflies	150
	Ndg & Nc	Dimension of a firefly	Case dependent
	βo	Initial attractiveness	1
	A	Randomness	0.25
	Γ	Absorption	1
BSA	N	Population of size	150
	D	Dimension of the search space	Case dependent
	M	Mix rate	0.8
	maxitr	Maximum number of cycles	150

and percentage of loss reduction for FFA and BSA algorithms for all the six cases respectively. The limit for the total real power injection is taken after rigorously tuning the value between 20% to 100% of the total real power demand and limit for the size of each DG is 1000kw. The percentage of real power injected for case1 & case 2 is 30%, for case 3 & case 4 is 45% and for case 5 & case 6 is 75%. The power factor for case 1, case 2, case 3 and case 4 is taken as 0.866 and for case 5 & case 6 it is varied from 0.8 to 1.0 in order to compare with existing algorithms. The maximum number of capacitors inserted is four and their sizes are integral multiple of 150kVAR. From Table 3 & Table 4 it is also observed that the reduction of power loss in case2, case4 & case6 is more when compared to case1, case3 & case5. In cases 2, 4 & 6 amount of MVA injection by DGs is same as in cases 1, 3 & 5 respectively, but difference in loss reduction of for

Table 3: Comparison of results of FFA for all the six cases of 33-bus system

Parameters	**Single DG placement**	**Single DG & Capacitors placement**	**Two DG placement**	**Two DG & Capacitors placement**	**Three DG placement**	**Three DG & Capacitors placement**
Optimal locations of DG's	30	12	14 ,30	14 ,30	30 ,14 , 24	25 ,13 , 30
Optimal sizes of DG's(KW)	1000	1000	598 ,925	597, 926	1100 ,740 ,946	866 ,836,1083
Power factor	0.866	0.866	0.866,0.866	0.866,0.866	0.866,0.866,0.866	0.905,0.88,0.9017
Total Real Power Injected(KW)	1000	1000	1523	1523	2786	2785
Optimal locations for capacitors	---------	33,25,30	---------------	29 ,31 ,6 ,25	----------------------	31 , 4
Optimal sizes of capacitors(KVAR)	----------	150,300,750	---------------	150,150,300,300	----------------------	300,300
Active power loss in KW	95.8117	64.5071	44.2303	30.2608	16.2002	12.6509
% Loss reduction	54.58	69.42	79.035	85.657	92.32	94.00
Elapsed time	**31.817749**	**46.594752**	**62.4048**	**48.9577**	**44.726108**	**85.641540**

FFA 14.84, 6.622 & 1.68 and for BSA 14.25, 5.42 & 1.74 between the cases is observed. So the simultaneous placement of DGs and capacitors has more power loss reduction than the only DG placement.

Figure 3 shows the comparison of power loss reduction of FFA and BSA for all the six cases. To check the efficiency of the proposed algorithms the results are compared with existing algorithms GA/PSO, ICA/GA and Analytical Approaches which is shown in Table 5 and Table 6. From Table 5 it is observed that both the proposed algorithms give the better result when compared with the GA/PSO and ICA/GA algorithms, among the proposed methods FFA gives the best result with a loss reduction of 94%. (Note: The results of [15] are corrected because according to specified values of DG and capacitors injection original the power loss is 14.07 kW but the authors mentioned it as 11.71 kW). From Table 6 it is observed that both the proposed algorithms give the better result when compared with the Analytical Approach, among the proposed methods FFA gives the best result with a loss reduction of 69.42%.

69-bus Test System Numerical Results

The 69-bus test case consists of a main feeder and 7 sub-feeders (laterals) radial distribution system and the data of the system is obtained from [23]. The total load of the system is 3801 kW and 2694 kVAR. The rated voltage of the system is 12.66 kV. After an initial load flow run using Backward/Forward Sweep method for an uncompensated system, the active power loss is 224.8949 kW and maximum & minimum voltages are 1.0 p.u and 0.9092 p.u respectively. To observe the effectiveness of the proposed algorithms, their results are compared with the other techniques like GA/PSO and ICA/GA. Table 7 and Table 8 shows, the optimal locations and sizes of DGs & capacitors, DG's operating power factors, total real power injected, total active power loss and percentage of loss reduction for FFA and BSA algorithms for all the six different cases respectively. The limit for the total real power injection is taken after rigorously tuning the value between 20% to 100% of the total real power demand and limit of each DG is 1000kw. The percentage of real power injected for case 1 & case 2 is 30%, for case 3 & case 4 is 40% and for case 5 & case 6 is 60%. The power factor for case 1, case 2, case 3 and case 4 is taken as 0.866 and for case 5 & case 6 it is varied from 0.8 to 1.0 in order to compare with existing algorithms. The maximum number of capacitors inserted is three and their sizes are integral multiple of 150kVAR. From Table 7 & Table 8 it is also observed that the reduction

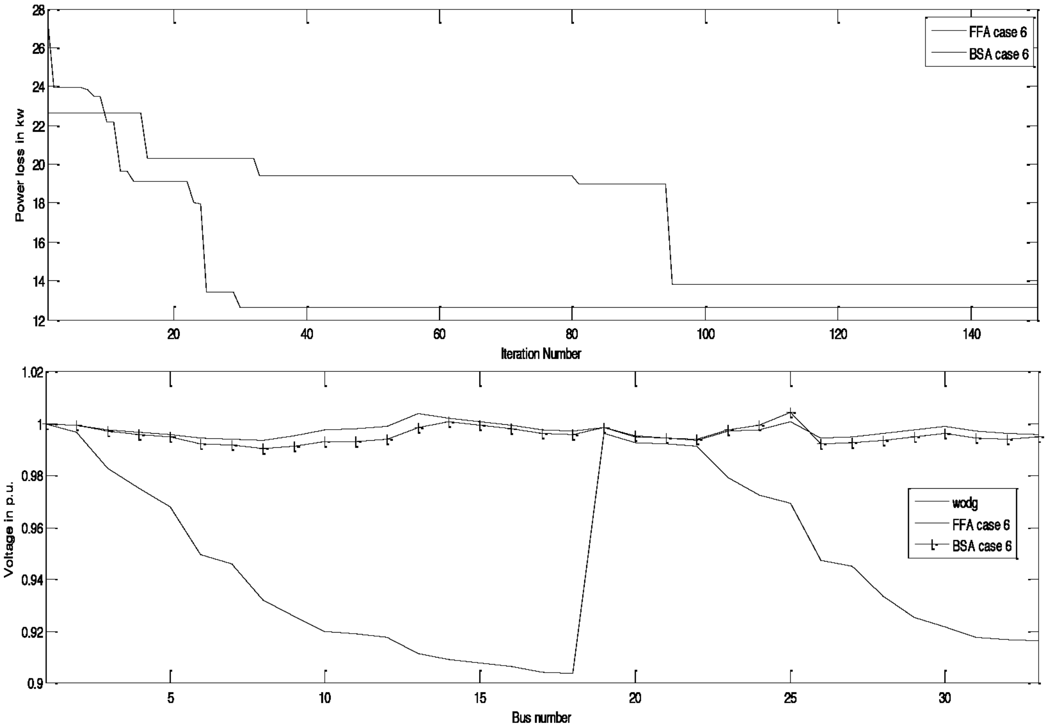

Figure 3: Comparison of loss reduction and voltage profile of FFA & BSA for case 6 of 33-bus system

Table 4: Comparison of results of BSA for all the six cases of 33-bus system

Parameters	**Single DG placement**	**Single DG & Capacitors placement**	**Two DG placement**	**Two DG & Capacitors placement**	**Three DG placement**	**Three DG & Capacitors placement**
Optimal locations of DG's	30	11	14 ,30	30, 14	30 ,12,24	25 ,14, 30
Optimal sizes of DG's(KW)	1000	1075	570,954	933,590	1000,848,938	1000 ,749,1000
Power factor	0.866	0.866	0.866,0.866	0.866,0.866	0.866,0.866,0.866	0.866,0.866,0.866
Total Real Power Injected(KW)	1000	1075	1524	1523	2786	2749
Optimal locations for capacitors	---------	23,32,30	---------------	2,24,11,33	----------------------	33,2
Optimal sizes of capacitors(KVAR)	----------	150,150,900	---------------	150,150,150,450	----------------------	300,300
Active power loss in KW	95.8117	65.7545	44.2993	32.8524	17.51	13.8543
% Loss reduction	54.58	68.83	79.00	84.42	91.69	93.43
Elapsed time	**21.270962**	**20.450268**	**17.391571**	**19.812635**	**18.444371**	**23.430**

Table 5:
Comparison of results of FFA & BSA with GA/PSO & ICA/GA for 33-bus

Parameters	Proposed Methods		Existing Methods	
	FFA	BSA	GA/PSO [15]	ICA/GA[15]
Optimal locations of DG's	25 ,13 , 30	25 ,14, 30	14,25,30	13,24,30
Optimal sizes of DG's(KW)	866 ,836,1083	1000 ,749,1000	674,670,835	794.8,1069,1029
Power factor	0.905,0.88,0.9017	0.866,0.866,0.866	0.88,0.85,0.90	0.905,0.90,0.81
Optimal locations for capacitors	31 , 4	33,2	12,30,32	8,18,30
Optimal sizes of capacitors(KVAR)	300,300	300,300	150,450,150	150,150,300
Active power loss in KW	12.6509	13.8543	17.01	14.01
% Loss reduction	94.00	93.43	91.93	93.35
Elapsed time	**85.641540**	**23.430**	N/A	N/A

Table 6:
Comparison of results of FFA & BSA with Analytical Approach for 33-bus

Parameters	Proposed Methods		Existing method
	BSA	FFA	Analytical Approach [17]
Optimal locations of DG's	11	12	18
Optimal sizes of DG's(KW)	1075	1000	800
Power factor	0.866	0.866	0.85
Optimal locations for capacitors	23,32,30	33,25,30	33
Optimal sizes of capacitors(KVAR)	150,150,900	150,300,750	800
Active power loss in KW	65.7545	64.5071	89.72
% Loss reduction	68.83	69.42	57.47
Elapsed time	**20.450268**	**46.594752**	N/A

of power loss in case 2, case 4 & case 6 is more when compared to case 1, case 3 & case 5. In cases 2, 4 & 6 amount of MVA injection by DGs is same as in cases 1, 3 & 5 respectively, but difference in loss reduction of for FFA 11.235, 5.863 & 1.94 and for BSA 10.758, 1.581 & 0.932 between the cases is observed. So the simultaneous placement of DGs and capacitors has more power loss reduction than the only DG placement.

Table 7: Comparison of results of FFA for all the six cases of 69-bus system

Parameters	**Single DG placement**	**Single DG & Capacitors placement**	**Two DG placement**	**Two DG & Capacitors placement**	**Three DG placement**	**Three DG & Capacitors placement**
Optimal locations of DG's	61	61	64 ,61	24, 61	15 ,61, 62	23,69,61
Optimal sizes of DG's(KW)	988	1000	306 ,1214	232 ,1289	514 ,936, 831	340 ,309, 1632
Power factor	0.866	0.866	0.866,0.866	0.866,0.866	0.866,0.866,0.866	0.866 ,0.866 ,0.866
Total Real Power Injected(KW)	988	1000	1520	1521	2281	2281
Optimal locations for capacitors	---------------	62 ,22 , 61	---------------	64 ,57 ,11	---------------------	60 ,32 ,49
Optimal size of capacitor(KVAR)	---------------	450 ,300 ,150	---------------	300 , 300 , 300	---------------------	300, 150 ,450
Active power loss in KW	68.0584	42.7798	31.8014	18.6034	9.5628	5.1986
% Loss reduction	69.752%	80.987%	85.867%	91.73%	95.74	97.68
Elapsed time	**75.045645**	**90.053564**	**88.819692**	**85.088916**	**86.747138**	**85.641540**

Table 8: Comparison of results of BSA for all the six cases of 69-bus system

Parameters	**Single DG placement**	**Single DG & Capacitors placement**	**Two DG placement**	**Two DG & Capacitors placement**	**Three DG placement**	**Three DG & Capacitors placement**
Optimal locations of DG's	61	61	61,23	62,9	61,20,62	19,22,61
Optimal sizes of DG's(KW)	1000	1000	1357,164	1350,170	767,514,100	294,219,1768
Power factor	0.866	0.866	0.866,0.866	0.866,0.866	0.866,0.866,0.866	0.866 ,0.866 ,0.866
Total Real Power Injected(KW)	1000	1000	1521	1521	2281	2281
Optimal locations for capacitors	----------------	62 ,22 , 61	----------------	16,2,57	-----------------------	7,2,3
Optimal size of capacitor(KVAR)	----------------	450 ,300 ,150	----------------	450, 150 , 300	-----------------------	450,300,150
Active power loss in KW	66.9526	42.7798	30.2357	26.69	9.7196	7.6047
% Loss reduction	70.229	80.987	86.55	88.131%	95.678	96.61
Elapsed time	**61.434655**	**90.053564**	**68.035410**	**69.090415**	**67.115659**	**62.518903**

Figure 4 shows the comparison of power loss reduction of FFA and BSA for all the six cases. To check the efficiency of the proposed algorithms the results are compared with existing algorithms GA/PSO and ICA/GA which is shown in Table 9. (Note: The results of [15] are corrected because according to specified values of DG and capacitors injection the original real power loss is 31.6 kW but the authors mentioned it as 3.01kw). From Table 9 it is observed that both the proposed algorithms give the better result when compared with the GA/PSO and ICA/GA algorithms, among the proposed methods FFA gives the best result with a loss reduction of 97.68%.

Convergence and Voltage Profile Analysis

The convergence and voltage profile graphs for all the six cases are shown in Figure 5, Figure 6, Figure 7 and Figure 8 for the two test systems. From the convergence graphs it is observed that, for the case 6 of 33-bus system, FFA reached to best solution at 32nd generation, whereas BSA is at 95th generation, in case 6 of 69-bus system FFA reached the better solution at 46th generation and BSA is at 39th generation.

CONCLUSIONS

In this article, two new algorithms have been proposed for the simultaneously optimal placement of DGs and capacitors in a distribution system. These two algorithms are applied on six different cases; the result shows that, cases with simultaneous placement of DG and capacitor have much improvement of voltage profile and power loss reduction when compared with cases of only DG placement. From the results it is observed that the percentage of power loss reduction is improving as the number of DGs is increasing from 1 to 3, but the rate of improvement of percentage power loss reduction is decreasing from 1DG to 3DGs. Among all cases, case 6 shows the highest loss reduction. The results of FFA & BSA algorithms with comparison of existing algorithms show that the performances of FFA & BSA are better than GA/PSO, ICA/GA and Analytical Approach. Among the two proposed algorithms, FFA gives the better solution in terms of solution quality.

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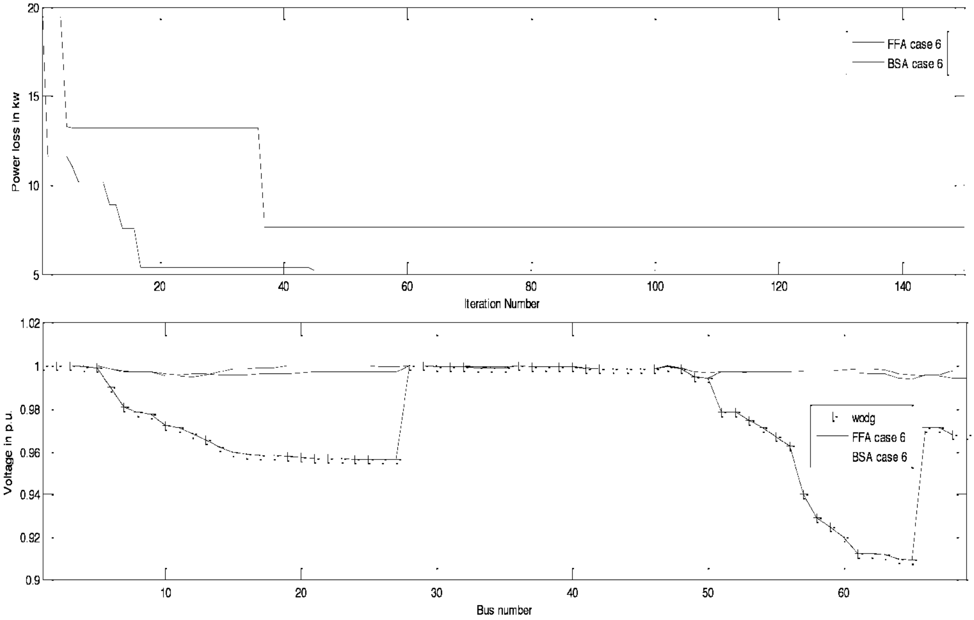

Figure 4: Comparison of loss reduction and voltage profile of FFA and BSA for case 6 of 69-bus system

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Table 9: Comparison of results of FFA and BSA with GA/PSO & ICA/GA for 69-bus

Parameters	**Proposed Methods**		**Existing Methods**	
	FFA	**BSA**	**GA/PSO [15]**	**ICA/GA[15]**
Optimal locations of DG's	23,69,61	19,22,61	18,61,64	11,18,61
Optimal sizes of DG's(KW)	340 ,309, 1632	294,219,1768	422,1184,305	490.1,386,1693
Power factor	0.866 ,0.866 ,0.866	0.866 ,0.866 ,0.866	0.85,0.88,0.83	0.99,0.98,0.91
Optimal locations for capacitors	60 ,32 ,49	7,2,3	11,49,61	21,61,64
Optimal sizes of capacitors(KVAR)	300, 150 ,450	450,300,150	150,150,600	300,1050,300
Active power loss in KW	5.1986	7.6047	8.02	31.6
% Loss reduction	97.68	96.61	96.43	85.94
Elapsed time	**85.641540**	**62.518903**	N/A	N/A

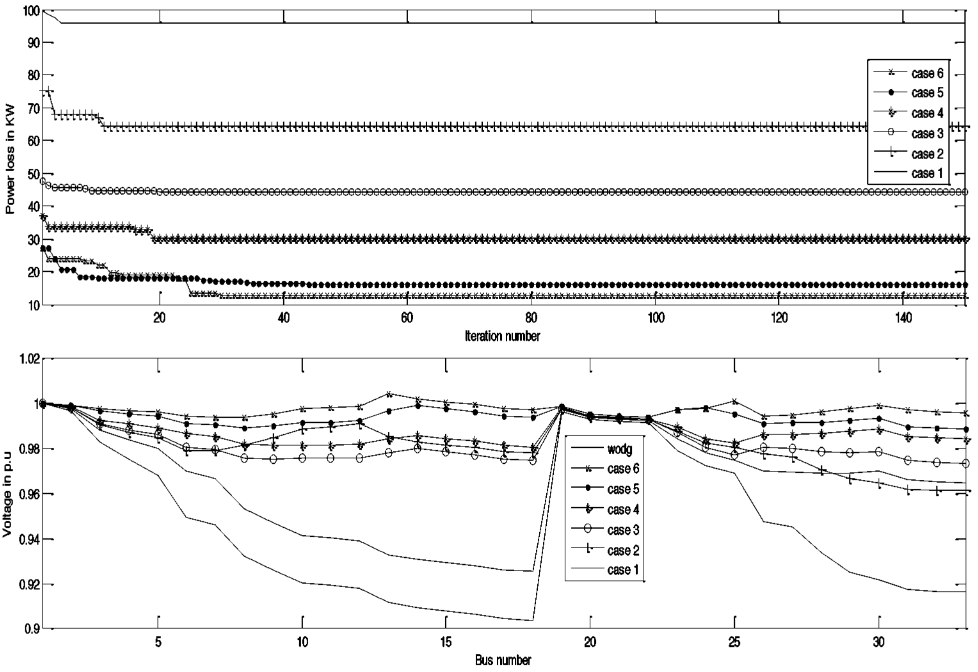

Figure 5: Convergence and voltage profile for all the six cases of FFA for 33-bus system

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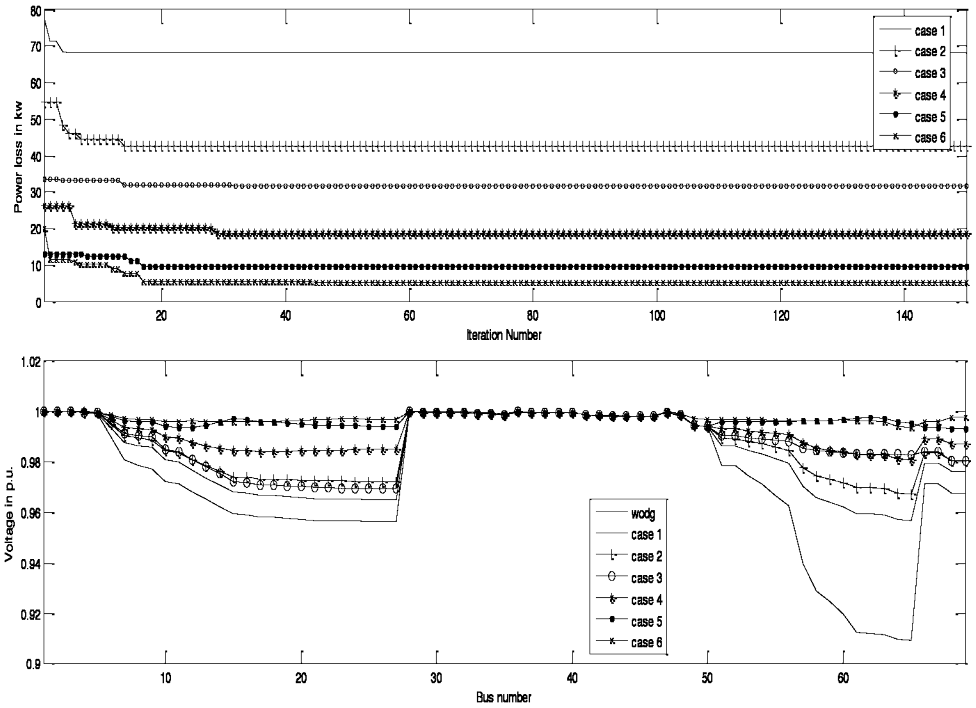

Figure 6: Convergence and voltage profile for all the six cases of FFA for 69-bus system

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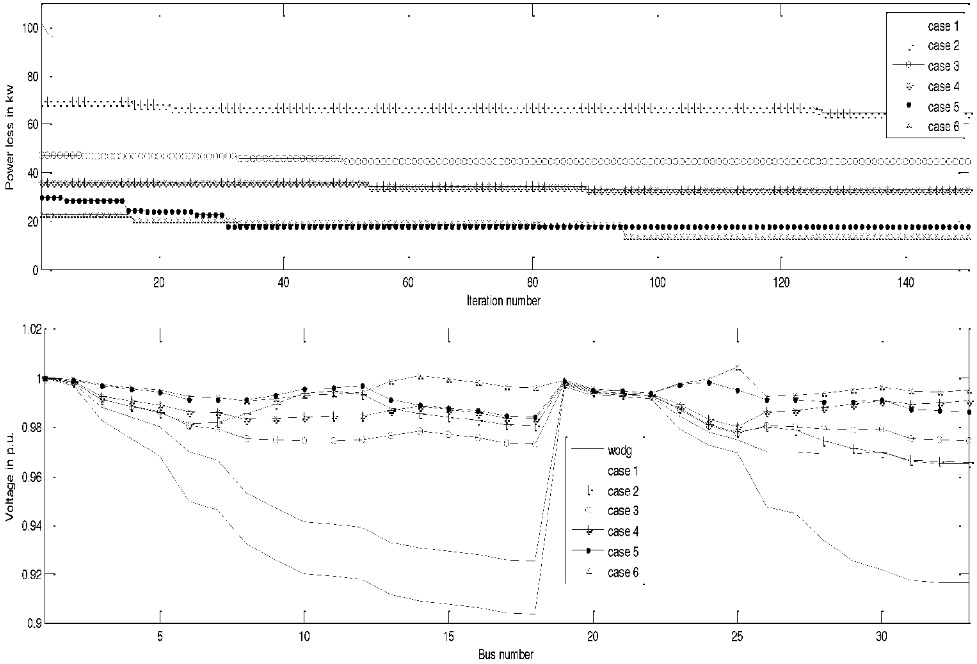

Figure 7: Convergence and voltage profile for all the six cases of BSA for 33-bus system

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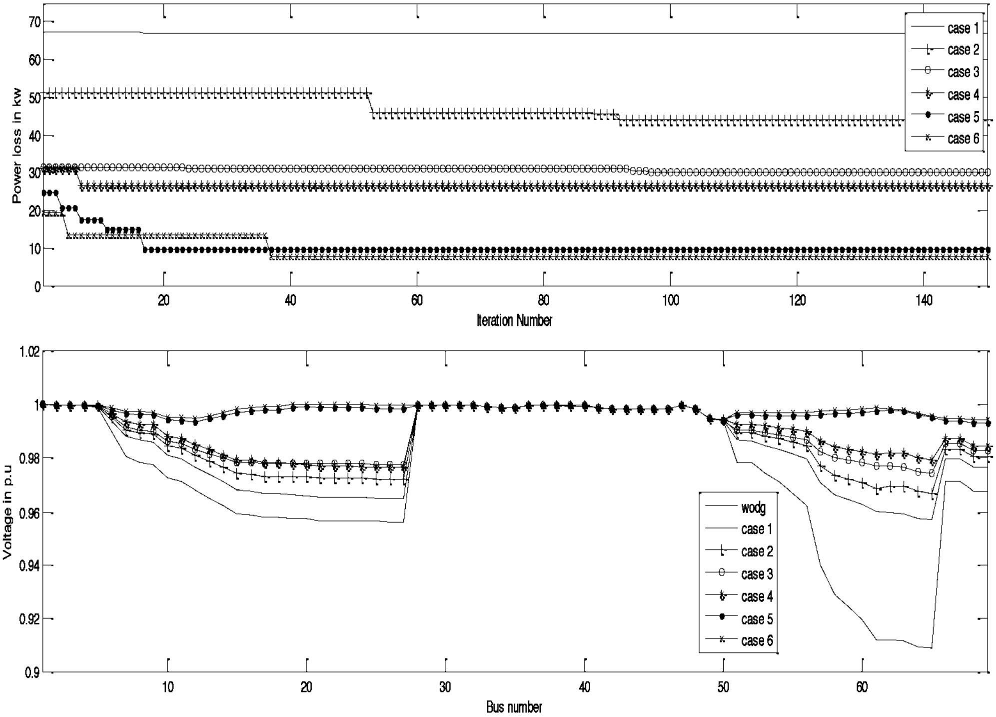

Figure 8: Convergence and voltage profile for all the six cases of BSA for 69-bus system

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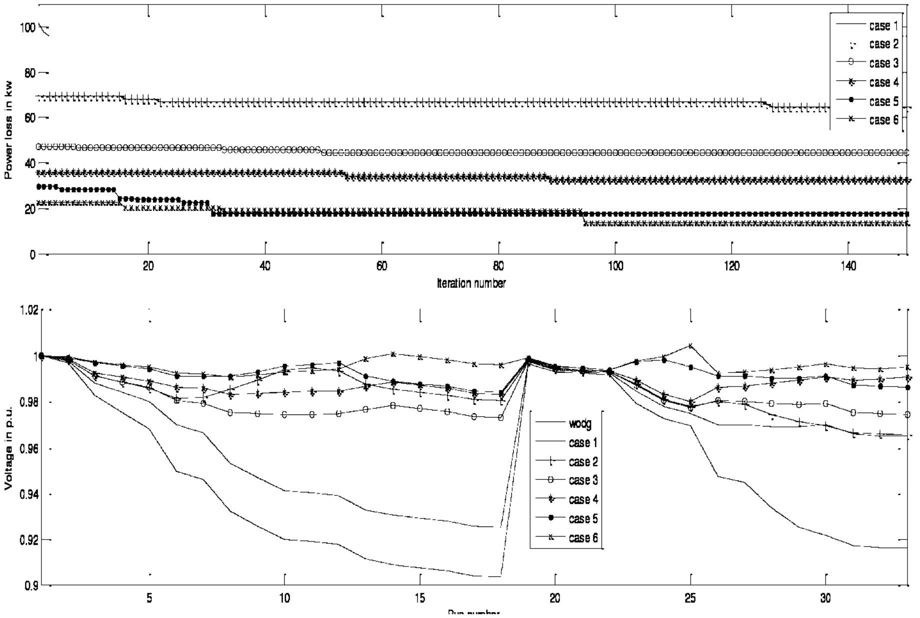

Figure 9: Convergence and voltage profile for all the six cases of BSA for 33-bus system

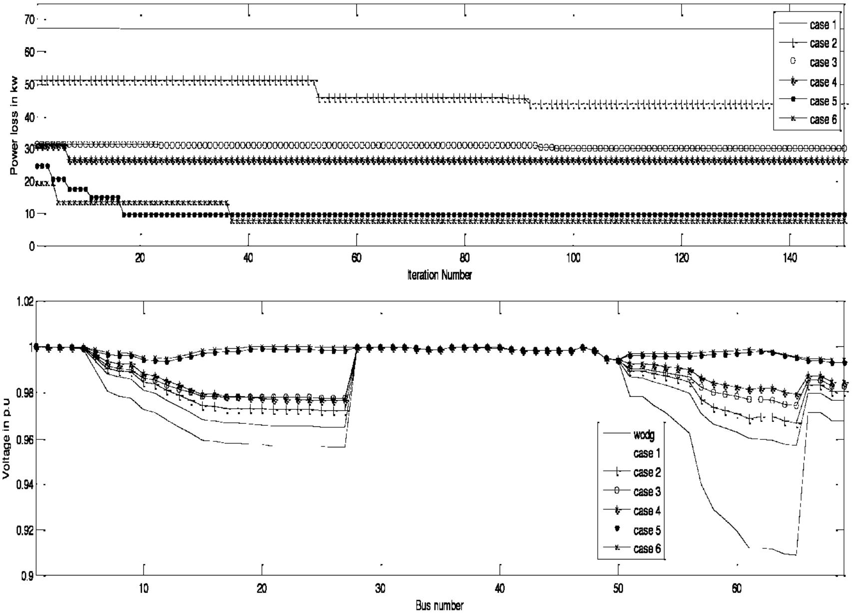

Figure 10: Convergence and voltage profile for all the six cases of BSA for 69-bus system