Reliability Improvement and Loss Reduction in Radial Distribution System by Reconfiguration using Black Hole Algorithm

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***Abstract*—This paper presents a new methodology to solve radial distribution system (RDS) reconfiguration problem to reduce the losses and to enhance the reliability of the system. Optimal reconfiguration selects the best set of feeders by changing the switching status of sectionalizing and tie switches so that the resulting RDS has improved voltage profile and minimum power loss. In addition, the impact of DG and capacitor are also considered in the problem formulation. Also in order to calculate the reliability indices such as SAIFI, SAIDI, CAIDI, AENS and ASAI, the reconfiguration technique is considered as a failure rate reduction strategy. This paper presents the application of black hole algorithm (BHA) to solve optimal network reconfiguration problem. A standard IEEE 69 bus radial system is chosen for the study. To show the effectiveness of the proposed algorithm in finding the best solution, simulations are carried out on the test system and the results are briefly compared before and after reconfiguration.**

Key words: Distributed generator, Reconfiguration, Reliability indices, Black hole algorithm, Radial distribution system

I. INTRODUCTION

An electrical distribution network consists of a group of interconnected radial networks. The configuration of RDS may be varied via switching operations to transfer loads among the feeders. In RDS, there are two types of switches; sectionalizing-switches (normally closed) and tie-switches (normally open) [1]. The reconfiguration of the distribution system is a process of opening sectionalizing switches and closing tie switches so that the radial structure of the network is maintained and all of the loads are supported. This results in balancing system load, reduced power losses, improved bus voltage profile and system reliability. The complexity of the reconfiguration problem increases as the circuit elements are switched in and out, certain variables tracking their status assume discrete values and because of the discontinuous nature of solution space. Hence it becomes difficult to solve this problem by conventional linear/nonlinear programming methods. In the past decades, a number of investigations has been carried out on reconfiguration problem. In order to minimize active power loss and voltage deviation, heuristic techniques [2], expert systems [3], brute-force approach [4], harmony search algorithm [5], evolution programming [6] have been proposed.

Capacitors are widely used in distribution networks for the purpose of reactive power compensation which results in good voltage profile. In the literature, some researchers have considered reconfiguration and capacitor placement problems simultaneously. They have used methods such as branch exchange [7], ACSA [8], modified PSO [9 and 24], deterministic approach [10] etc to solve reconfiguration problem and methods like discrete optimization [11], harmony search algorithm [5], heuristic technique [12], Imperialist Competitive Algorithm [25] Adaptive Shuffled Frogs Leaping Algorithm [26], etc to determine the optimal location and amount of capacitances to be used. In recent years, the BH algorithm and its modified versions have been used to solve optimization and engineering problems [27].

In recent years, penetration of distributed generations (DG) in the RDS has been increased widely. This increase can be justified by the factors such as environmental concerns, the restructuring of electricity market and the development in technologies for small-scale generation. If DGs are correctly installed at optimal locations and its units are correctly coordinated, they will reduce power losses in distribution system.

In the literature, many researchers have attempted to determine the optimum location and size of DG units in the distribution system. In-Su *et al* [13] described an analytical method to determine the reliability of a distribution system with DG. They considered three modes of operations of DG such as stand by unit, peaking unit and mixed mode operation. Gozel *et al* [14] determined optimal allocation and sizing of DGs using an analytical method in view of minimum line loss. Venkatesh *et al* [15] focus on the aspects of loss minimization and voltage enhancement of RDS by artificial intelligence methods. Rashidi *et al* [16] were presented an improved PSO for optimal placement of multiple DG sources to minimize real power losses. Kang *et al* [17] proposed a novel efficient population-based heuristic approach. Hamedi *et al* [18] were presented an innovative approach to increase reliability and reducing power loss with optimal placement of DG resources in an actual distribution network.

This paper emphasizes the advantage of reconfiguration of RDS in the presence of DG and capacitor for loss reduction, bus voltage improvement and reliability enhancement. The BHA is used to solve the reconfiguration problem with DG and capacitor. Standard IEEE 69 bus radial distribution system is considered as test system. The algorithm used is easy for implementation, with less number of parameters and efficient in obtaining the global best results. Expected interruption cost (ECOST) corresponding to interruption duration time is calculated using composite customer damage function (CCDF). This system is further analyzed to show the increasing reliability levels as suggested by the improvements in various reliability indices such as SAIFI, SAIDI, CAIDI and AENS.

II. Reliability Analysis of Distribution System

Reliability analysis of electrical distribution system is considered as a tool for the planning engineer to ensure a reasonable quality of service and to choose between different system expansion plans that cost wise were comparable considering system investment and cost of losses. The usual method of evaluating the reliability indices is an analytical approach which based on failure mode assessment and the use of equations for series and parallel networks. The analytical approach is based on assumptions concerned with statistical distributions of failure rates and repair times. The common indices used for evaluation are the expected failure rate (λ), the average outage time (r) and the expected annual outage times (U) which is adequate to the sample radial system. The basic reliability indices of the system are given by:

$$\lambda_{sys,i} = \sum_{k \in s} \lambda_k \qquad (1)$$

$$U_{sys,i} = \sum_{k \in s} \lambda_k r_k \qquad (2)$$

Where λ_k, and r_k are the average failure rate and average outage time of the i^{th} component respectively.

In this paper, expected interruption cost (ECOST) is included as part of the objective function. Evaluating ECOST enables the system planners to determine the acceptable level of reliability for customers, provided economic justifications for determining network reinforcement and redundancy allocation, identify weak points in a system, determine suitable maintenance scheduling and develop appropriate operation policies. ECOST is therefore a powerful tool for system planning [19]. ECOST at bus i is calculated as follows:

$$ECOST_i = \sum_{i=1} L_{a(i)} C_i \lambda_i \qquad (3)$$

Where $L_{a(i)}$ is the average load connected to load point i in kW and C_i is the cost of interruption (in $/kw) for the i^{th} bus.

The total ECOST of the distribution feeder is calculated as follows:

$$ECOST = \sum_{i=1}^{NB} ECOST_i = \sum_{i=1}^{NB} L_{a(i)} C_i \lambda_i \qquad (4)$$

Where NB is the total number of load points in the feeder. In order to submit the importance of a system outage, energy not supplied index (ENS) is evaluated. This index reflects total energy not supplied by the system due to faults during study period and is calculated for each load bus i using the following equation:

$$ENS_i = L_{a(i)} U_i \qquad (5)$$

A customer damage function (CDF) provides the interruption cost versus interruption duration for a specified group of customers. The CCDF is basically the sum of the individual customer damage functions in the customer mix. The sector customer damage function (SCDF) of the residential, commercial and industrial sectors etc. can be combined to create a composite customer damage function (CCDF). CCDF shows the cost of interruption as a function of interruption duration. A typical CCDF [19] is illustrated in Fig 1. Since it accounts for reliability worth and the reliability level, ECOST is a comprehensive value based reliability index and was used for this study.

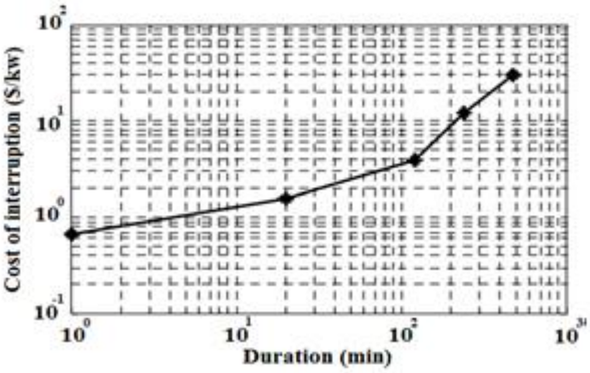

Fig. 1. Typical CCDF

III. Distribution System Reliability Enhancement Using DG and Capacitor

Majority of the customer interruptions are caused by equipment failures in distribution systems consisting of underground cables and overhead lines. Resistive losses increase the temperature of feeders which is proportional to the square of the current magnitude flowing through the feeder. Moreover increase in temperature causes insulation failure in underground cable and overhead lines which in turn increases the component failure rate. If DG and capacitors are installed at appropriate places, they can supply part of active and reactive power demands respectively. This reduces the resistive losses due to reduction of the magnitude of current.

These impacts on reliability are taken into consideration as a failure rate reduction of distribution feeder components.

Let us assume that any feeder i has an uncompensated failure rate of λ_i^{uncomp} before DG and capacitor placement. If the reactive or active component of a feeder branch is fully compensated, its failure rate reduces to λ_i^{comp}. If the reactive and active components of current are not completely compensated, a failure rate is defined with linear relationship to the percentage of compensation. Thus, the compensation coefficient of the ith branch is defined as:

$$\alpha_i = \frac{I_r^{new}}{I_r^{old}} * \frac{I_a^{new}}{I_a^{old}} \quad (6)$$

Where I_r^{new}, I_r^{old} and I_a^{new}, I_a^{old} are the reactive and active components of the ith branch current after and before compensation, respectively. The new failure rate of the ith branch is computed as follows:

$$\lambda_{i-new} = \alpha_i \left(\lambda_i^{uncomp} - \lambda_i^{comp}\right) + \lambda_i^{comp} \quad (7)$$

IV. CUSTOMER-BASED RELIABILITY INDICES

A survey by the *Electric Power Research Institute* (EPRI) has identified the most frequently used customer oriented indices are namely SAIFI, SAIDI, CAIDI, AENS and ASAI. These indices are defined as follows [21].

A. System Average Interruption Frequency Index (SAIFI):

$$\text{SAIFI} = \frac{\text{Total numbers of customer interruptions}}{\text{Total number of customers served}}$$

$$= \frac{\sum \lambda_{sys,i} N_i}{\sum N_i} \quad (8)$$

B. System average interruption duration index (SAIDI):

$$\text{SAIDI} = \frac{\text{Sum of all customer interruptions durations}}{\text{Total number of customer served}}$$

$$= \frac{\sum U_{sys,i} N_i}{\sum N_i} \quad (9)$$

C. Customer average interruption duration index (CAIDI):

$$\text{CAIDI} = \frac{\text{Sum of all customer interruption durations}}{\text{Total number of customer interruptions}}$$

$$= \frac{\sum U_{sys,i} N_i}{\sum \lambda_{sys,i} N_i} \quad (10)$$

D. Average energy not supplied (AENS):

$$\text{AENS} = \frac{\text{Sum of system annual outage duration at load point}}{\text{Sum of average load point}}$$

$$= \frac{\sum L_i U_{sys,i}}{\sum N_i} \quad (11)$$

E. Average Service Availability Index (ASAI):

$$\text{ASAI} = \frac{\text{Customer hours service availability}}{\text{Customer hours servise demand}}$$

$$= [(8760\text{-SAIDI})/8760]*100 \quad (12)$$

Where L_i is average load connected at ith load point, which may be obtained from the load duration curve, $\lambda_{sys,i}$ is the system failure rate at ith load point, N_i is the total number of customers at load point i and $U_{sys,i}$ is system annual outage duration at ith load point.

V. PROBLEM FORMULATION

The main objective of this paper is to determine the optimum location and size of DG in distribution systems in order to improve the system reliability and to reduce the power loss along with minimum installation cost of DG. Losses in the distribution feeders and voltage of all nodes are found by backward – forward sweep distribution load flow analysis. In this paper a multi objective function is considered on the basis of active power loss index, reliability index, voltage profile index and DG investment cost index which are defined as follows:

A. Multiobjective Function

The multiobjective function of the problem is described as:

$$Minimize \quad J = \sum_{m=1}^{4} K_m J_m \quad (13)$$

$$K_m \in [0,1], \quad \sum_{m=1}^{4} K_m = 1 \quad (14)$$

Where, k_m are weighting factors assigned to each objectives are K_1=0.4, K_2=0.1, K_3=0.1 and K_4=0.4 attributed to power loss, reliability, voltage deviation and DG's Investment Cost Index.

B. Real Power Loss Index (J_1)

Power losses are important factor in the design of distribution systems and are calculated by backward – forward sweep load flow method in radial distribution system. At a given time, the power loss index is given by

$$J_1 = \frac{P_{L,DG}}{P_L} \quad (15)$$

Where $P_{L,DG\&Cap}$ is the total real power loss of the distribution system in the presence of DG and P_L is the total real power loss without DG in the distribution system.

C. Reliability Index (J_2)

Reliability index is given by

$$J_2 = \frac{ECOST_{DG}}{ECOST} \quad (16)$$

Where $ECOST_{DG}$ and ECOST is expected interruption cost of systems with and without DG installation.

D. Voltage deviation index (J_3)

Bus voltage is one of the most important characteristic of the system. One of the benefits of correct selection of location and size of DG is the improvement of voltage deviation. This index indicates higher voltage deviations from 1.0 per unit. Voltage deviation index **(**VDI) is expressed as

$$J_3 = \sum_{i=1}^{NB} |V_i - 1| \quad (17)$$

Where NB is the total number of the buses
V_i is the magnitude voltage on the ith bus.

E. DG's Investment Cost Index (J_4)

DG is appropriate selections for minimizing both the line loss and improving the network reliability and voltage profile. However, the investment cost of DG is a significant problem that prevents engineers using them widely. This index is calculated with the following equation:

$$J_4 = \frac{Cost_{DG}}{Cost_{MCD}} \quad (18)$$

where $Cost_{DG}$ are costs of DG. $Cost_{MCD}$ are costs of DG in their maximum capacity.

VI. BLACK HOLE PHENOMENON

John Michell and Pierre Laplace were the first to introduce the concept of black holes in the eighteen century. They identified the absence of star by integrating Newton's law but the absence of star was not known as black hole at that time. Only in 1967, John Wheeler, an American physicist first named the phenomenon of mass collapsing or absence of star as a black hole. A black hole in space is what is left when a star or massive sized planet collapses. The gravitational power of the black hole is too high that even the light cannot escape from it. Anything that crosses the boundary of the black hole is swallowed by it and vanishes. The sphere-shaped boundary of a black hole in space is known as the event horizon. The radius of the event horizon is termed as the Schwarzschild radius. At this radius, the escape speed is equal to the speed of light, and once light passes through, even it cannot escape. The Schwarzschild radius is calculated by the following equation:

$$R = \frac{2GM}{C^2} \quad (19)$$

Where, G is the gravitational constant, M is the mass of the black hole, and c is the speed of light. If anything moves close to the event horizon it will be absorbed into the black hole and permanently disappear.

A. Black Hole Algorithm (BHA)

Similar to the other meta-heuristics algorithms, a population of randomly distributed candidate solutions for the given problem is created. All the population-based algorithms move the individuals towards the global best solution through certain techniques. For example, mutation and crossover operations are followed in GA. In PSO, the movement of the initial solution towards the global best solution is based on the individual best and global best in each iteration.

In BHA, the evolving of the population is done by moving all the candidates towards the best candidate in each iteration, namely, the black hole and replacing those candidates that enter within the range of the black hole by newly generated candidates in the search space [28 and 29]. The proposed BHA in this paper is more similar to the natural black hole phenomenon. In BHA the best candidate among all the candidates at each iteration is selected as a black hole. Then, all the candidates are moved towards the black hole based on their current location and a random number. The searching mechanism of BHA is as under:

A randomly generated population of solutions is taken as the initialization process. Then the fitness values of the population are evaluated and the best solution whose fitness value is the best one is the black hole. After initializing the black hole and stars, the black hole starts absorbing the stars around it and all the stars start moving towards the black hole. The absorption of stars by the black hole is formulated as follows:

$$x_i(t) = x_i(t-1) + rand(0,1)(x_{BH} -, x_i(t-1)) \quad (20)$$

where $x_i(t)$ and $x_i(t-1)$ are the locations of the ith star at iterations t and $t-1$, respectively. x_{BH} is the location of the black hole in the search space. rand is a random number in the interval [0, 1]. N is the number of stars (candidate solutions). While moving towards the black hole, a star may reach a location with lower cost than the black hole. In such a case, the black hole moves to the location of that star and vice versa. Then the BHA will continue with the black hole in the new location and then stars start moving towards this new location. In addition, there is the probability of crossing the event horizon during moving stars towards the black hole. Every star (candidate solution) that crosses the event horizon of the black hole will be sucked by the black hole. Every time a candidate (star) dies – it is sucked in by the black hole – another candidate solution (star) is born and distributed randomly in the search space and starts a new search. This is done to keep the number of candidate solutions constant. The next iteration takes place after all the stars have been moved. The radius of the event horizon in the black hole algorithm is calculated using the following equation:

$$R = \frac{f_{BH}}{\sum_{i=1}^{N} f_i} \tag{21}$$

where f_{BH} is the fitness value of the black hole and f_i is the fitness value of the i[th] star. N is the number of stars (candidate solutions). When the distance between a candidate solution and the black hole (best candidate) is less than R, that candidate is collapsed and a new candidate is created and distributed randomly in the search space. Based on the above description the main steps in the BH algorithm are summarized as follows:

B. Implementation of BHA for RDS

Step 1: Initialize the algorithm parameters like population size, maximum number of generations and black hole.

Step 2: Each individual is a vector of the control variables. i.e. i.e. Xi= [VG1, VG2…VG NG, TP1, TP2…TP NT, Qc1, Qc2….QNC]. NP number of agents is generated by respecting the limits of control parameters.

Step 3: Calculate the fitness function values of all candidate solution by running the NR load flow.

Step 4: Determine the center of mass which has global best fitness using equation (21).

Step 5: Generate new candidates using the center of mass, particle best and global best by adding/subtracting a normal random number according to equation (20).

Step 6: Repeat steps step 2 to step 5 until stopping criteria has been achieved.

VII. SIMULATION RESULTS AND DISCUSSION

Optimal reconfiguration, capacitor and DG placement in optimal locations are performed using the proposed BF algorithm on standard IEEE 69 bus RDS in view of loss reduction and voltage and reliability enhancement. The test system is a radial distribution network with rated voltage of 12.66KV, 100 MVA, 69 nodes, 74 lines, 5 contact switches and the total load is 3802.2 KW + j2694.6 KVAr. The test system is shown in figure 2. The test system details are found in [22].

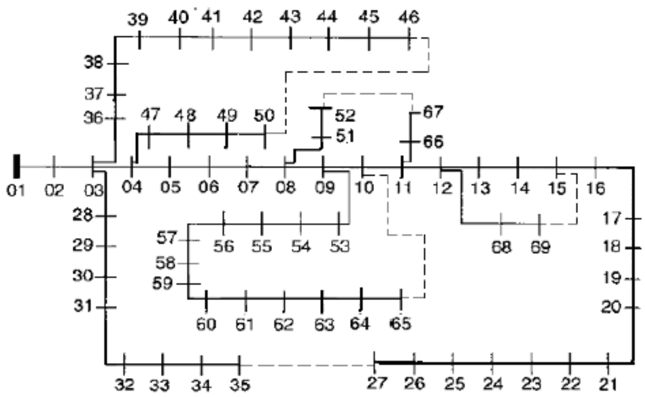

Fig. 2. IEEE 69 bus system

It is assumed that the section with the highest resistance has the biggest failure rate of 0.5 f/year and the section with the smallest resistance has the least failure rate of 0.1 f/year. Based on this assumption, failure rates of other sections are calculated linearly proportional to these two values according to their resistances.

Furthermore, it is assumed that if the reactive or active component of a distributor section current is fully compensated, its failure rate reduces to 85% of its uncompensated failure rate [23] and for partial compensation, the failure rate is calculated using (7). In this paper, some assumptions are made to evaluate the reliability indices. It is assumed that there is a circuit breaker (CB) at the substation with a sectionalizer at the beginning of each section. Since the reconfiguration strategy only affects the reliability of the feeders, the other network components, such as the transformers, busbars, and sectionalizer switches, are supposed to be fully reliable. Besides, for each line, the repair time and total isolation and switching time are considered as 8 hours and 0.5 hours respectively. Component failure rate is optimized using the compensation coefficient (7) which in turn used to calculate the customer reliability indices i.e. SAIFI, SAIDI, CAIDI, AENS and ASAI before and after reconfiguration [20]. The available DG and Capacitor sizes and their associated cost are given in table 1. Simulations were carried out on 1.86 GHz system in MATLAB 7.5 version environment.

Table 1. DG and capacitor size and costs

DG		**Capacitor**	
Size (KW)	**Cost ($)**	**Size (KVAr)**	**Cost ($)**
250	2121	150	750
500	1500	300	975
750	1225	450	1140
1000	1061	600	1320
1250	949	900	1650
1500	866	1200	2040
1750	802	-----	-----
2000	750	-----	----

The following case studies are carried out for reliability enhancement of the radial distribution system.

Case A: Before reconfiguration

1. With DG alone
2. With Capacitor alone
3. With DG and Capacitor

The topology of test system is considered as such and BF algorithm is used to find the optimum location and size of DG and capacitor by minimizing the multiobjective function given in equation (13). Table 2 gives optimum location and size of DG and capacitor obtained using proposed method. Table 3 gives the ECOST, ENS, P_{LOSS}, Q_{LOSS}, VDI and minimum voltage magnitude obtained using the BF algorithm. In this table, base case represents the system without DG and capacitor. In order to show the impact of DG and capacitor, the results are compared with base case. % improvement achieved by the black hole algorithm compared with that of base case is also given in table 3. Fig 3 shows voltage profiles in each bus of test system before reconfiguration with DG and capacitor. Fig 4 shows line loss in each segment of the distribution system before reconfiguration with DG and capacitor.

Table: 2 Optimal size and location of DG and Capacitor before reconfiguration

	Before reconfiguration	
	Installed at	**Size (KW/KVAr)**
DG	58	1500
Capacitor	61	450
DG and Capacitor	21 63	500 600

Table: 3 Results obtained before reconfiguration.

	ECOST ($)	**ENS (KWh/yr)**	**P_{Loss} (KW)**	**Q_{Loss} (KVAr)**	**VDI (p.u)**	**Minimum voltage magnitude (p.u)**
Base case	117646.37	15713.97	226.59	104.42	1.843	0.9092
With DG	97534.32	12546.12	172.12	80.25	1.239	0.9321
With capacitor	72111.00	8560.72	195.34	69.34	1.432	0.9235
With DG and capacitor	39197.45	6245.89	140.19	59.46	0.856	0.9417
% of improvement	66.68	60.25	38.13	43.05	53.55	3.45

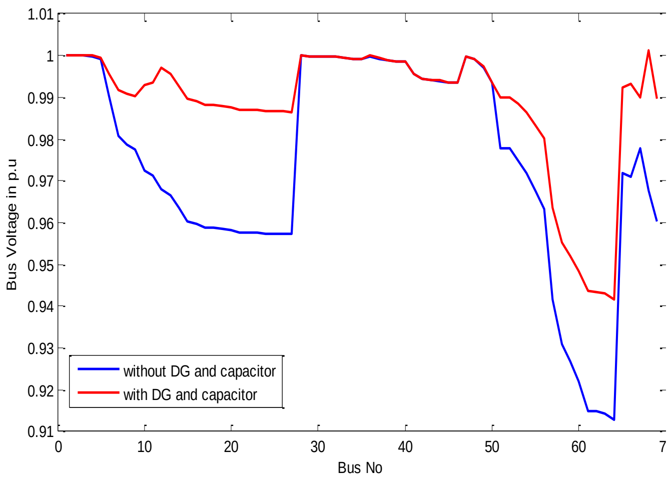

Fig. 3 Voltage profile in each bus before reconfiguration

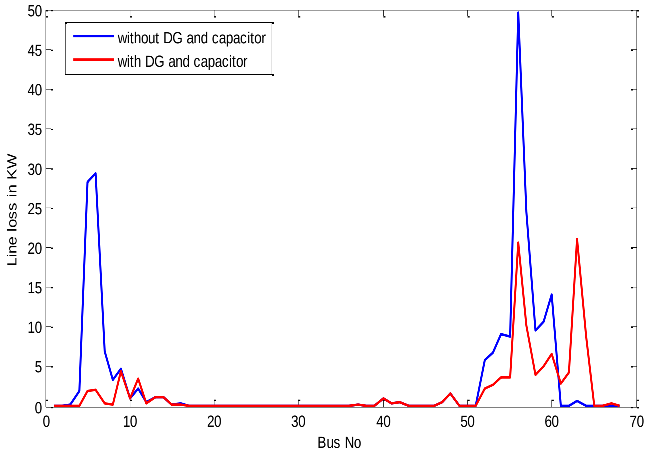

Fig. 4 Line loss in each branch before reconfiguration

Case B: After reconfiguration

1. With DG alone
2. With Capacitor alone
3. With DG and Capacitor

The reconfiguration is done on standard IEEE 69 bus distribution system. Table 4 shows the open switches in the system corresponding to before and after reconfiguration. Opening and closing of switches can change the amount of power loss which can be seen in Table 4. This shows the validity and effectiveness achieved due to reconfiguration of RDS using proposed method.

Table 4. Results of simulation for test on 69-bus system

Scenario		Base case	Optimal case (with DG and capacitor)
Open switches		69, 70, 71, 72,73	26, 50, 65, 70, 72
Before Reconfiguration	**P_{Loss} (KW)**	226.59	140.19
	Q_{Loss} (KVAr)	104.42	59.46
After Reconfiguration	**P_{Loss} (KW)**	175.01	89.23
	Q_{Loss} (KVAr)	85.61	50.21

Table 5 gives optimum location and size of DG and capacitor obtained using proposed method after reconfiguration. Table 6 gives the ECOST, ENS, P_{LOSS}, Q_{LOSS}, VDI and minimum voltage magnitude obtained using the BF algorithm. In this table, base case represents the system without DG and capacitor after reconfiguration. % improvement achieved using black hole algorithm by placing DG and capacitor in optimal locations is determined in comparison with the base case and is also given in the table 6.

Table: 5 Optimal size and location of DG and Capacitor after reconfiguration

	After reconfiguration	
	Installed at	**Size (KW/KVAr)**
DG	59	1250
Capacitor	61	900
DG and Capacitor	9 12	750 450

Table: 6 Results obtained after reconfiguration.

	ECOST ($)	ENS (KWh/yr)	P_{Loss} (KW)	Q_{Loss} (KVAr)	VDI (p.u)	Minimum voltage magnitude (p.u)
Base case	113981.56	14237.31	175.01	85.61	1.768	0.9127
With DG	95189.24	12015.82	162.91	78.13	1.467	0.9413
With capacitor	68324.76	7954.12	157.53	67.53	1.312	0.9392
With DG and capacitor	35451.01	4934.56	89.23	50.21	0.8003	0.9807
% of improvement	68.89	65.34	49.01	41.35	54.73	6.93

It may be noted from tables 3 and 6 that there is an improvement of 9.55% in ECOST, 20.99% in ENS, 36.35% in P_{LOSS}, 15.55% in Q_{LOSS}, 6.54% in VDI and 3.97 % in voltage magnitude compared with before and after reconfiguration.

This clearly shows the impact of reconfiguration of the RDS. Fig 5 shows voltage profiles in each bus of test system after reconfiguration. Fig 6 shows line loss in each branch of the system after reconfiguration.

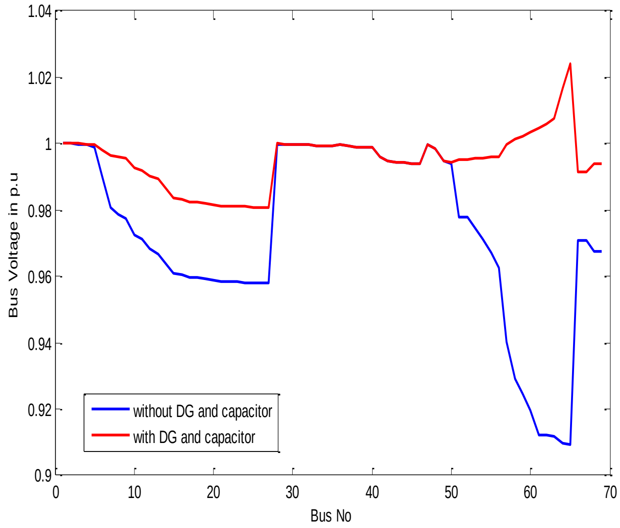

Fig.5 Voltage profile in each bus after reconfiguration

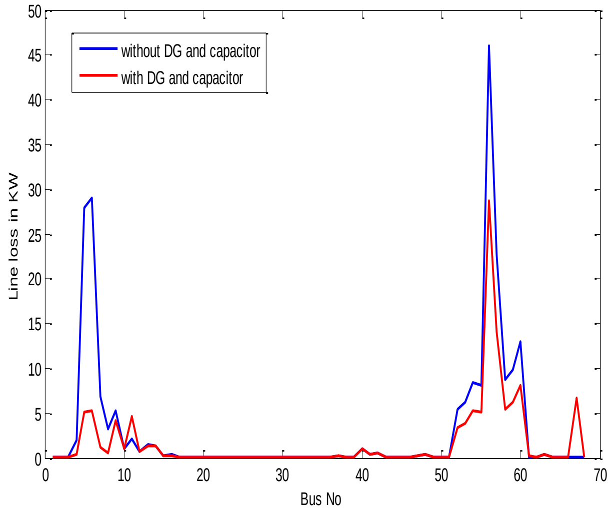

Fig. 6 Line loss in each branch after reconfiguration

Further, the customer and energy based load point reliability indices are also calculated using optimized failure rate and are given in table 7.

Table: 7 Customer and energy based reliability indices for 69 bus test system

	Before Reconfiguration				**After Reconfiguration**			
	Base case	**With DG**	**With Capacitor**	**With DG & Capacitor**	**Base case**	**With DG**	**With Capacitor**	**With DG & capacitor**
SAIFI	2.5896	1.4816	1.5894	1.1354	2.5257	2.5015	1.3288	1.8791
SAIDI	1.9824	0.8170	0.7891	0.8326	1.9853	1.9131	0.9554	1.5654
CAIDI	0.7655	0.5247	0.4356	0.7551	0.7857	0.7856	0.6511	0.7911
AENS	0.4197	0.1634	0.1798	0.1702	0.4162	0.3978	0.1752	0.3421
ASAI	99.974	99.990	99.990	99.990	99.977	99.9676	99.989	99.990

VIII. CONCULSION

In this paper, the black hole algorithm optimization technique has been used to find the most appropriate topology of the distribution system in the presence of DG and Capacitor in view of loss minimization and reliability improvement. The proposed algorithm has been applied on the standard IEEE 69 bus distribution system. Better results are obtained after reconfiguration of RDS. Finally the energy and customer based reliability indices were evaluated using the optimized failure rates and repair times of the distributor segments. It is seen that reliability indices are also improved and voltage profile of all the buses remained stable within the tolerable limits. Real and reactive power losses are also reduced and hence reliability is improved.

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