Optimal Placement and Sizing of Distributed Generation and Capacitor Bank for Loss Reduction and Reliability Improvement in Distribution Systems

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ABSTRACT

In this paper optimum size and location of the capacitors and distributed generators (DGs) are determined for reliability improvement and power loss reduction using genetic algorithm (GA). The main innovation of this paper is using both DG and Capacitor for the reliability improvement and power loss reduction. For this purpose an objective function consisting of reliability cost, power loss cost and also DG's and capacitor's investment cost are considered. The effectiveness of the proposed method is examined in the 10 and 33 bus test systems and comparative studies are conducted before and after DG and Capacitor installation in the test systems. The results obtained show the effectiveness of the proposed method.

KEYWORDS: Distributed generation, Capacitor bank, Loss reduction, Reliability improvement, Genetic algorithm.

1. INTRODUCTION

Distributed Generation (DG) has been used in some electric power networks due to the several advantages. These benefits depend on the location and the size of DG [1]. Over the past decade several techniques have been proposed to determine the optimal location of DG. The main object of these techniques is to minimize the losses of power systems. However, other objects like improving the voltage profile, reliability, cost minimization, maximizing DG capacity and etc have also been considered in different studies. Some researchers have applied the analytical approaches for optimal DG placement in terms of the different load types [2].Lalitha et al. [3] presented a methodology using fuzzy and artificial bee colony algorithm for the placement of DGs in the radial distribution systems to reduce the real power losses and improve the voltage profile. Niknam and his coauthors [4] proposed a Pareto-based multi objective optimization equipped with a Fuzzy decision making tool to determine the location of the renewable electricity generators by the improved honey bee mating optimization algorithm. In the proposed placement scheme, generation costs, losses and emission of distributed system and optimization of the voltage profile were treated as competing objective functions. The work in [5] proposed combined method to solve he location and capacity problems for DG. In this method, GA and PSO methods were used to determine the location and calculate the capacity of DG respectively. Parallel capacitors are placed on the primary networks of the distribution feeders to reduce technical losses caused by reactive energy flows. Other potential benefits of capacitors include voltage regulation, released capacity of the equipments and the deferred expenditure on the system expansions. The optimal capacitor allocation problem searches for the best compromise between cost of capacitors and their benefits to a network. Since, the optimal capacitor placement is a complicated combinatorial optimization problem, many different optimization techniques and algorithms have been proposed in the past. Schmill [6] developed a basic theory of the optimal capacitor placement. He presented his well known 2/3 rule for the placement of one capacitor assuming a uniform load and a uniform distribution feeder. The impacts of the capacitor placement on the distribution system reliability are considered in [7] by defining two objective functions. In [8] an approach employed loss sensitivity factors and PGSA for capacitor placement in the distribution system has been proposed in which the PGSA is used to estimate the required level of shunt capacitive compensation at the optimal candidate locations to enhance the voltage profile of the system and reduce the active power loss. In this paper optimal size and placement of DG unit and capacitor bank for reliability improvement and loss reduction is determined using genetic algorithm. For the optimization problem, a comprehensive objective function including the costs of DG and capacitor investment, reliability and power loss is considered. The rest of this paper is organized as follows: Section 2 presents the problem description of the reliability assessment and effects of DG and capacitor installation on the reliability indices in the distribution systems, briefly. The problem formulation of the objective function to minimize the losses and reliability enhancement in the distribution system by DG and capacitor is presented in Section 3. In section 4, the genetic algorithm is described briefly and the structure of coding to size and place the DG and capacitor in genetic algorithm is presented. The results of the DGs' application and capacitor placement on the 10-bus and 33-bus test systems are presented and discussed in section 5. Finally, section 6 summarizes the main points and the results of this paper.

2. PROBLEM DESCRIPTION

2.1. Reliability analysis of the distribution systems

Generally, the distribution systems have received considerably less of the devoted attention to the reliability modeling and evaluation of the generating systems. The main reasons are that generating stations are individually very capital intensive and generation inadequacy can have widespread catastrophic consequences for both society and its environment [12]. Consequently the great emphasis has been placed on ensuring the adequacy and meeting the needs of this part of a power system. A distribution system, however, is relatively cheap and outages have a big localized effect. Hence less effort has been allocated to quantitative determination of the adequacy of various alternative designs and reinforcements. On the other hand, analysis of the customer failure statistics of most utilities shows that the distribution system makes the greatest individual contribution to the unavailability of the supply to a customer. This is illustrated by the statistics shown in Table 1 which relate to a particular distribution utility in the UK [12].

Table 1. Typical customer unavailability statistics.

	Average unavailability per customer year	
Contributor	Time(minutes)	(%)
Generation/transmission	0.5	0.5
132 Kv	2.3	2.4
66 & 33 Kv	8	8.3
11 & 6.6 Kv	58.8	60.7
Low voltage	11.5	11.9
Arranged shutdowns	15.7	16.2
Total	96.8	100

The statistics such as the mentioned ones in Table.1 reinforce the needed concern with the reliability evaluation of the distribution systems. Most distribution systems are operated as the radial networks, consequently the principles of series systems can be applied directly to them [13]. Three basic reliability indices of the system, average failure rate, λ_s, average outage time, r_s, and annual outage time U_s are given by:

$$\lambda_s = \sum_i \lambda_i \qquad (1)$$

$$U_s = \sum_i \lambda_i r_i \qquad (2)$$

$$r_s = \frac{U_s}{\lambda_s} \qquad (3)$$

where λ_i, r_i and λ_i r_i are, respectively, the average failure rate, average outage time and annual outage time of the ith component. In this paper, expected interruption cost (ECOST) is included as part of the objective function. The evaluation of the ECOST enables the system planners to determine the acceptable level of the reliability for customers, provide 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 [7]. ECOST at the bus i is calculated as follows [14]:

$$ECOST_i = L_{a(i)} C_i \lambda_i \qquad (4)$$

Where $L_{a(i)}$ is the average load connected to the load point i in kw and C_i is the cost of interruption (in \$/kw) for the ith bus which is evaluated using composite customer damage function (CCDF). CCDF shows the cost of the interruption as a function of interruption duration. A typical CCDF [14] 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.

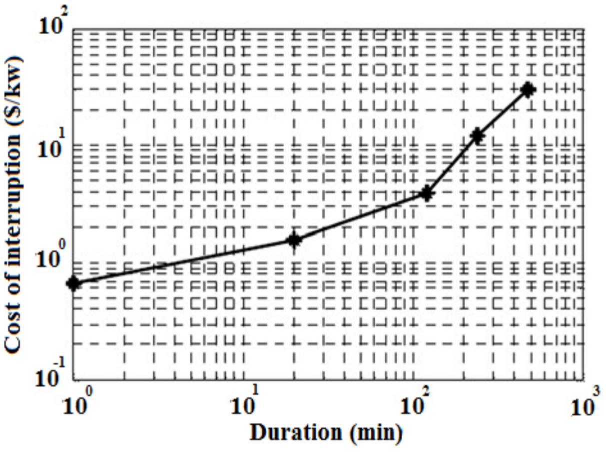

Fig.1. Typical CCDF

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

$$ECOST = \sum_{i=1}^{NB} ECOST_i = \sum_{i=1}^{NB} L_{a(i)}\, C_i\, \lambda_i \tag{5}$$

where NB is the number of the 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 the total energy not supplied by the system due to the faults during the study period which can be calculated for each load at the bus i using the following equation:

$$ENS_i = L_{a(i)}\, U_i \tag{6}$$

this index is used also in this study.

2.2. Impact of DG and capacitor placement on the reliability enhancement

The customer interruptions are caused by a wide range of phenomena including equipment failure, animals, trees, severe weather, and human error. Feeders in the distribution systems deliver power from distribution substations to distribution transformers. A considerable portion of the customer interruptions are caused by equipment failures in the distribution systems consisting of the underground cables and overhead lines [7]. Resistive losses increase the temperature of feeders proportional to the square of the current magnitude flowing through the feeder. For underground cables, there is a maximum operating temperature if exceeded would cause the insulation problem and an increase in component failure rates [7].

The life expectancy of the insulation material decreases exponentially as the operating temperature raises [15]. On the other hand, a major reliability concern pertaining to the underground cables is water treeing. Treeing occurs when the moisture penetration in the presence of an electric field reduces the dielectric strength of the cable insulation. When moisture invades, the extruded dielectrics such as cross-linked polyethylene (XLPE) or ethylene-propylene rubber (EPR), breakdown patterns resembling a tree reduce the voltage withstand capability of the cable and the probability of the dielectric breakdown increases, consequently, the failure rate of the cable is increased. The severity of treeing is strongly correlated with the thermal age since the moisture absorption occurs more rapidly at high temperatures [16].

Temperature also has impacts on the reliability of the overhead lines. High currents will cause lines to sag, reduce ground clearance and increase the probability of phase conductors swinging into contact. Higher currents can cause conductors to anneal, reducing tensile strength and increasing the probability of a break occurrence [17].

DG and capacitor placement can supply a part of the reactive and active power demands, respectively. Therefore, due to the reduction of the magnitude of the current, the resistive losses decrease. As a result, destructive effects of the temperature on the reliability of the overhead lines and underground cables are moderated. These impacts on the reliability take into consideration as a failure rate reduction of the distribution feeder components. Before DG and capacitor placement, any feeder i has an uncompensated failure rate of λ_i^{uncomp}. 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 the current is not completely compensated, a failure rate is defined with linear relation to the percentage of the compensation. Thus, the compensation coefficient of the ith branch is defined as:

$$\alpha_i = \frac{I_r^{new}}{I_r^{old}} * \frac{I_a^{new}}{I_a^{old}} \tag{7}$$

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:

$$\lambda_{i\text{-}new} = \alpha_i\,(\lambda_i^{uncomp} - \lambda_i^{comp}) + \lambda_i^{comp} \tag{8}$$

3. PROBLEM FORMULATION

The problem of the best places selection for the installation and preferable size of the DG unit and capacitor bank is a complex discrete optimization problem. The aim of the DG and capacitor placement in the distribution system is to minimize the annual cost of the system, subjected to certain operating constraints.

3.1. The objective function

Mathematically, the objective function of the problem is described as:

$$\min F = \min(TCOST) \tag{9}$$

Where TCOST is the objective function including the cost of the reliability, the cost of the peak power loss, the cost of energy loss and the cost of investment. The total cost due to the placement is expressed as:

$$TCOST = ECOST + K*ENS + K_p*L_p + K_E*L_E + C(P\&C) \tag{10}$$

where TCOST is the total cost of the system ($/year), ENS is the total energy not supplied which consists of energy not supplied because of the occurring faults in the overhead lines and underground cables (kwh), L_P is the peak active power losses (kw), L_E is the energy losses (kwh), C(P&C) is the total costs of DG and capacitor ($), K is the price of energy not supply ($/kwh), K_P is the factor to convert peak active power losses to dollar ($/kw), and K_E is the factor to convert energy losses to dollar ($/kwh). It should be noted that the value of K is set to 0.1 [18] and that for K_P and K_E is set to 168 and 0.07 in this paper [19], respectively.

3.1.1. DG and Capacitor costs evaluation

The costs of DG consist of three parts including the investment cost, the maintenance cost and operation cost of DG. The cost of DG unit, the investigation fee, the preparation of the site for DG installation, construction, monitoring equipment, etc. are included in the investment cost. Another yearly cost of DG allocation relates to the maintenance cost. Maintenance cost includes annual mechanical and electrical inquiry and renovation cost. This cost is not related to the placement of DG and is equal for all DG placements. Since the distributed generation shall trace load demands therefore it is required to have cost for its input source hence operation cost is equivalent to fuel cost. In this paper these costs are used based on [20].

Considering shunt capacitors, practically there exists a certain number of standard sizes which are integer multiples of the smallest size Q_o^c. In general, the capacitors of larger size have lower unit prices. The available capacitor size is usually limited to:

$$Q_o^{max} = L\, Q_o^c \tag{11}$$

Where L is an integer number. Therefore, for each location of the capacitor installation, L sizes $\{Q_o^c, 2Q_o^c, \ldots, LQ_o^c\}$ are available for the capacitor. Capacitor cost has two parts, a fixed part and a variable part depending on the kvar capacity. Besides, the cost per kvar varies from one size to another. In this paper the capacitor installation costs are used based on Table 2 [21].

Table 2. Possible choices of capacitor sizes and cost/kvar.

Case	1	2	3	4	5
Q_c(Kvar)	150	300	450	600	750
$/Kvar	0.5	0.35	0.253	0.22	0.276
Case	6	7	8	9	10
Q_c(Kvar)	900	1050	1200	1350	1500
$/Kvar	0.183	0.228	0.17	0.207	0.201
Case	11	12	13	14	15
Q_c(Kvar)	1650	1800	1950	2100	2250
$/Kvar	0.193	0.187	0.211	0.176	0.197
Case	16	17	18	19	20
Q_c(Kvar)	2400	2550	2700	2850	3000
$/Kvar	0.17	0.189	0.187	0.183	0.18
Case	21	22	23	24	25
Q_c(Kvar)	3150	3300	3450	3600	3750
$/Kvar	0.195	0.174	0.188	0.17	0.183
Case	26	27			
Q_c(Kvar)	3900	4050			
$/Kvar	0.182	0.179			

3.1.2. Power Losses

Losses are important in designing and planning of the distribution systems and calculated by load flow. Generally, distribution systems are fed at one point and have a radial structure. Due to its low memory requirements, computational efficiency and robust convergence characteristic, the load flow is computed by forward/backward method in radial distribution networks. The power loss of the line section connecting buses i and i+1 may be computed as:

$$P_{Loss}(i,i+1) = R_{i,i+1}\, I_{i,i+1}^2 \tag{12}$$

$$Q_{Loss}(i,i+1) = X_{i,i+1}\, I_{i,i+1}^2 \tag{13}$$

where $I_{i,i+1}$ is the magnitude of the current, $R_{i,i+1}$ and $X_{i,i+1}$ are resistance and reactance of the line section buses i , i+1 respectively. The total power loss of the feeder is determined by summing up the losses of all line sections of the feeder, which is given as:

$$P_{T,Loss} = \sum_{i=0}^{NB-1} P_{Loss}(i,i+1) \tag{14}$$

$$Q_{T,Loss} = \sum_{i=0}^{NB-1} Q_{Loss}(i,i+1) \tag{15}$$

Where $P_{T,Loss}$ and $Q_{T,Loss}$ are the total active and reactive power loss in the system, respectively.

3.2. Operational Constraints

From the viewpoint of the system stability, power quality, etc., voltage magnitude at each bus must be maintained within its limits. The current in each branch must satisfy the branch's capacity. These constraints are expressed as follows:

$$V_{min} \le |V_i| \le V_{max} \tag{16}$$

$$|I_i| \le I_{i,max} \tag{17}$$

Where $|V_i|$ voltage magnitude of bus i, V_{min} and V_{max} are minimum and maximum bus voltage limits, respectively. $|I_i|$ stands for current magnitude and $I_{i,max}$ is the maximum current limit of the branch.

4. GENETIC ALGORITHM

Genetic algorithm is stochastic meta- heuristics that mimic some features of the natural evolution and was invented by John Holland in the 1960s. To optimize a function, possible solutions are first encoded into the chromosome-like strings, in order that the genetic operators can be applied to them. Genetic algorithm usually starts with a population of randomly generated solutions.

The two main genetic operators are crossover and mutation, both loosely based on their natural counterparts. The crossover operator takes two solutions, the so-called parents, and recombines them to form one or more new solutions, the so-called children. Parents are chosen from among all the solutions of the current population. However, the selection is stochastically biased towards solutions with better objective function values. These are also known as solutions with a higher fitness in evolutionary terms. The crossover operator has a crossover probability which determines how likely it is for the crossover operator to be applied to a chromosome.

Mutation takes one solution and modifies it slightly to form a new solution. Like crossover, for every mutation there is always a defined probability that is how likely the mutation in question would be applied to an individual, this is called the mutation probability. After performing a certain number of crossovers and mutations, some of the solutions in the old population are replaced by new solutions and this concludes one generation of the algorithm. These generations are then repeated until a stopping criterion is met. In this paper, the structure of each chromosome coding is shown in Fig. 2.

Position DG	Size DG	Position Capacitor	Size Capacitor

Fig.2 Chromosome encoding.

The flowchart of the GA is shown in Fig. 3. DG unit and capacitor bank can be potentially placed in any bus other than the slack bus. By convention, bus-1 is connected to the substation and is considered as the slack bus. Hence, DG and capacitor may be connected to any location except bus-1. The iterative GA based solution attempts to obtain the best-fit chromosome for which (10) is minimum. The corresponding chromosome determines the optimum location and size of DG and capacitor. In this paper, Mutation probability and Crossover probability set as 0.2 and 0.8 respectively. The number of the initial population and the maximum number of the selected iterations are 20 and 500, respectively.

5. SIMULATION RESULTS

For simulation purpose, 10 and 33 buses distribution systems are considered for DG and capacitor installation. The presented algorithm was implemented and coded in Matlab 7.8 computing environment. In order to evaluate the proposed algorithm, the objective function given in (10) is minimized to two test systems, optimum size and location of one DG unit and one capacitor bank are determined with the proposed method. For the calculation of reliability indices and determination of the optimal DG and capacitor placement, 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 [7]. Based on this assumption, failure rates of other sections are calculated linearly proportional to these two values according to their resistances [12].

Furthermore, it is assumed if the reactive or active component of a section current is fully compensated, its failure rate reduces to 85% of its uncompensated failure rate [7] and for partial compensation; the failure rate is calculated using (8). In both of the test system, it is assumed that there is only one breaker at the beginning of the main feeder and also there is one sectionalizer at the beginning of each section. Besides, for each line, the repair time and total isolation and switching time are considered 8 and 0.5 hours, respectively. Also, other components such as transformers, bus bars, breakers and disconnectors are assumed to be fully reliable, in this paper.

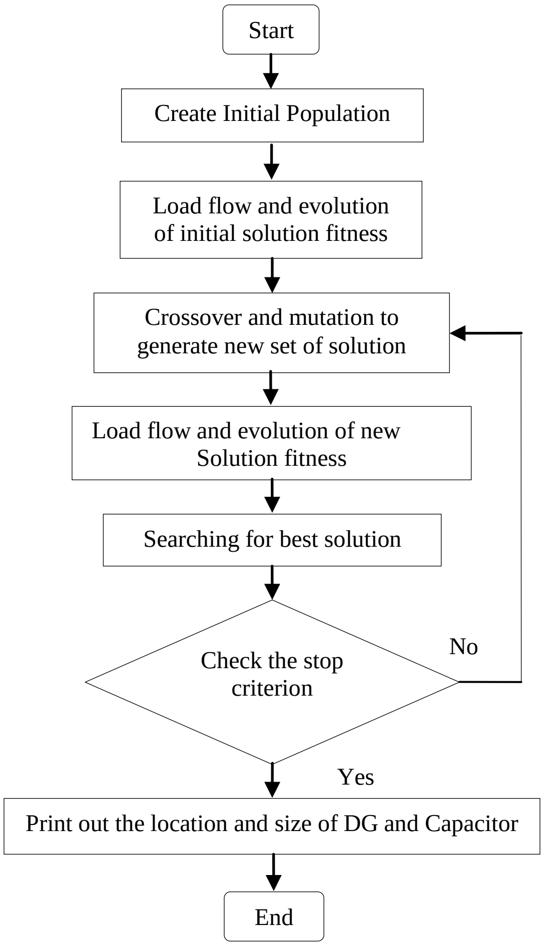

Fig. 3 Flow chart of the genetic algorithm.

In this paper, design is performed for a ten-year period and annual load growth of the system is assumed 5 percent. That is defined as follows:

$$S_n= (1.05)^{n-1}\times S_0 \qquad (18)$$

Where n is the number of year, S_0 and S_n are the initial load of the system and the load of the system in nth year, respectively. Moreover, it is assumed that DG does not operate in islanding mode and must be disconnected from the system during fault until the fault is cleared. Also, the substation voltage (bus 1) is considered as 1.0 p.u and the lower and upper limit of the voltage magnitude of the buses are assumed 0.90 and 1.10 p.u, respectively.

5.1. 10-Bus Test System

The single line diagram of the 23 kV, 10-bus, 9-section radial distribution system is shown in Fig. 4. The data of the system are obtained from [22]. The total load of the system is considered as (12368+ j 4186) kVA.

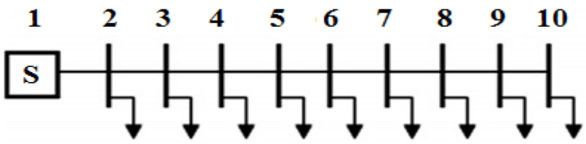

Fig. 4. 10-bus radial distribution system.

The optimal size and location of DG unit and capacitor bank are given in Table 3. In order to indicate and compare the effects of DG and capacitor placement in the test system, the results are compared to the case in which there is no DG and capacitor in the system and the results are presented in Table 4. It can be seen that the determination of the optimum size and location of the DG and capacitor has a considerable effects on the loss reduction and reliability improvement for a ten-year planning period in the test system. It is observed from Table 4 that the total cost of using DG and capacitor installation (TCOST) is decreased from 1005496227 $ to 880829888.8 $, expected interruption cost (ECOST) is reduced from 3434890 $ to 2989400 $, active power losses are reduced from 14274.4 kw to 3495 kw, reactive power losses are. reduced from 18569.7 kvar to 5838 kvar, respectively, and energy not supplied index (ENS) is decreased from 1131176 kwh/yr to 984400 kwh/yr.

Table 3. Optimum size and location of the single DG unit and single capacitor bank in 10 bus system.

	Location	Size
DG	Bus 10	3678 kw
Capacitor	Bus 5	4050 kvar

Fig.5. Shows the voltage profile of the buses before and after DG and capacitor installation in the 10-bus test system in 10th year. It can be observed that the voltage profile has been improved significantly by installing the DG and capacitor.

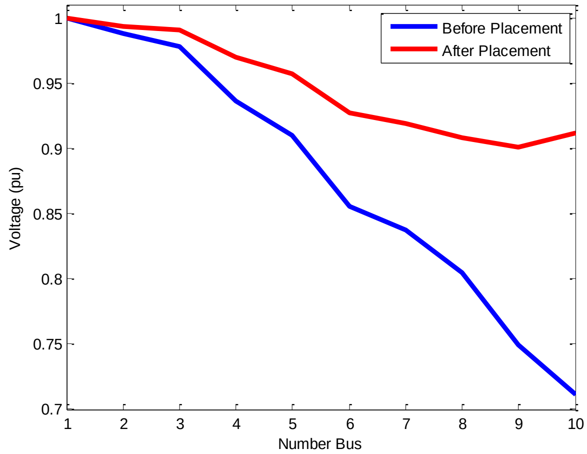

Fig. 5. Voltage profile after and before installation of DG and capacitor in the10 bus system.

5.2. 33-Bus Test System

The 12.66 kV, 33-bus, 4-lateral radial distribution system is considered as another test system. The data of the system are obtained from [23].It is assumed in this paper that the load level is in peak condition (4458+ j 2760) kVA. The single line diagram of the 33-bus is shown in Fig. 6.

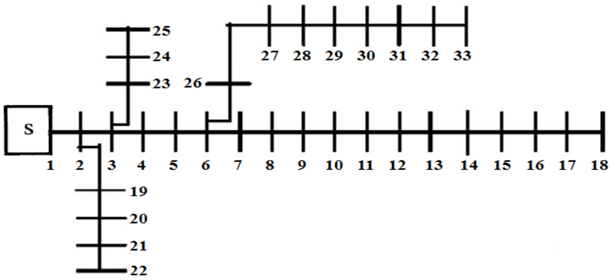

Fig. 6. Single line diagram of a 33-bus radial distribution system.

The results of DG and capacitor installation in the 33 bus test system are presented in the Tables 5 and 6. Similar to the 10-bus test system, the obtained results shown in these tables demonstrate that DG and capacitor installation may result in the loss reduction and reliability improvement, significantly. The results of the table 5 and 6 show that by using DG and capacitor with optimum sizes (941 kw for DG and 1800 kvar for capacitor) in optimum location (bus 14 for DG and bus 30 for capacitor), total cost is reduced from 773563717.7 $ to 702038690.6 $, ECOST is reduced from 2049710 $ to 1839300 $, active power losses are decreased from 5453 kw to 2244.2 kw, reactive power losses are decreased from 3704 kvar to 1505.6 kvar and ENS is decreased from 872123 kwh/yr to 793580 kwh/yr. Moreover, Fig.7 shows the voltage profile of the system in 10th year. The voltage profile of each bus in the 33-bus test system has been improved significantly by the DG and capacitor installation.

Table 4. Comparison of the results before and after DG and Capacitor installation in the 10 bus system for planning period

	TCOST ($)	ECOST ($)	ENS (kwh/yr)	$P_{T,Loss}$ (kw)	$Q_{T,Loss}$ (kvar)
Base case	1005496227	3434890	1131176	14274.4	18569.7
After DG and Capacitor installation	880829888.8	2989400	984400	3495	5838
(%) improvement	12.4	12.97	12.97	75.54	68.56

Table 5. Optimum size and location of the single DG unit and single capacitor bank in the 33 bus system.

	Location	Size
DG	Bus 14	941 kw
Capacitor	Bus 30	1800 kvar

Table 6. Comparison of the results before and after DG and Capacitor installation in the 33 bus system for planning period

	TCOST ($)	ECOST ($)	ENS (kwh/yr)	$P_{T,Loss}$ (kw)	$Q_{T,Loss}$ (kvar)
Base case	773563717.7	2049710	872123	5453	3704
After DG and Capacitor installation	702038690.6	1839300	793580	2244.2	1505.6
(%) improvement	9.246	10.265	9	58.84	59.35

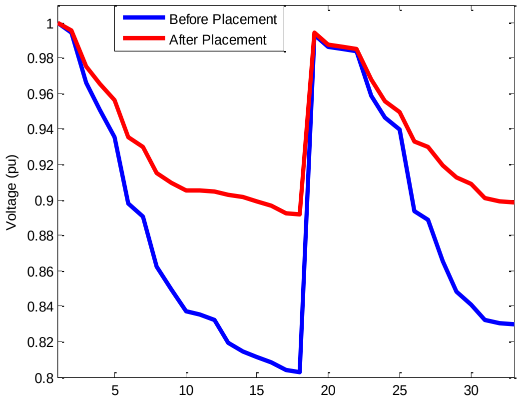

Fig.7 Voltage profile after and before installation of DG and capacitor in 33 bus system.

6. CONCLUSION

In this study, a genetic algorithm based method is used for DG and capacitor placement in distribution system. An objective function have been considered for the reliability improvement and loss reduction considering reliability cost, power loss cost and DG's and capacitor's investment cost. Two test systems are considered and the optimum size and location of DG and capacitor are determined. The obtained results show that by using DG and capacitor installation with optimum size in optimum location has considerable effects on loss reduction, voltage and reliability improvement in the test systems.

Totally, considering the comparison between the effects of DG and capacitor installation in the two cases of the test systems, it is concluded that the effects of the DG and capacitor on the loss reduction, voltage and reliability improvement of the systems as well as their effectiveness are similar.

REFERENCES

[1] H. M. Khodr, Z. A. Vale and C. Ramos, **“A Benders Decomposition and Fuzzy Multicriteria Approach for Distribution Networks Remuneration Considering DG”,** *IEEE Transactions on Power Systems,* Vol. 24, pp. 1091-1101, May. 2009.

[2] C. Wang and M. H. Nehrir, **“Analytical approaches for optimal placement of distributed generation sources in power systems”,** *IEEE Transactions On Power Systems*, Vol. 19, pp. 2068-2076, Nov. 2004.

[3] M. P. Lalitha, V. C. Reddy and N. S. Reddy, **“Application of fuzzy and ABC algorithm for DG placement for minimum loss in radial distribution system”,** *Iran. J. Electr. Electron. Eng*, Vol. 6, pp. 248–256, Dec. 2010.

[4] T. Niknam, I. Taheri, J. Aghaei, S. Tabatabaei, and M. Nayeripour, **“A modified honey bee mating optimization algorithm for multiobjective placement of renewable energy resources”,** *Applied Energy*, Vol. 88, pp. 4817–4830, Dec. 2011.

[5] M. H. Moradi, M. Abedini, **“A combination of genetic algorithm and particle swarm optimization for optimal DG location and sizing in distribution systems”,** *Electrical Power and Energy Systems*, vol. 34, pp. 66–74, Jan. 2012.

[6] J. V. Schmill, **"Optimum size and location of shunt capacitors on distribution feeders",** *IEEE Trans Power Apparat Syst*, Vol. 84, pp. 825–832, Sep. 1965.

[7] A. H. Etemadi and M. Fotuhi-Firuzabad, **"Distribution system reliability enhancement using optimal capacitor placement",** *Generation,Transmission & Distribution, IET*, Vol. 2, pp. 621-631, Sep. 2008.

[8] R. Srinivasas Rao, S. V. L. Narasimham and M. Ramalingaraju, **"Optimal capacitor placement in a radial distribution system using Plant Growth Simulation Algorithm",** *Electrical Power and Energy Systems*, Vol. 33, pp. 1133–1139, Jun. 2011.

[9] IB. Mady, **"Optimal Sizing of Capacitor Banks and distributed generation in Distorted Distribution Networks by Genetic Algorithms",** *CIRED, 20th International Conference on Electricity Distribution*, pp. 8-11, 2009.

[10] J. Gunda, N. A. Khan, **"Optimal location and sizing of DG and shunt capacitor using differential evaluation",** *International journal of soft computing*, Vol. 6, No. 4, pp. 128-135, 2011.

[11] M. Mohammadi , M. Houshyar, M. Salehi, and R. Ghadimi, **"Capacitor Bank and DG Optimal Placement in Order to Achieve the Minimum Active Power Losses by PSO",** *Journal of Basic and Applied Scientific Research.*, Vol. 2, pp. 1948-1955, 2012.

[12] R. Billinton, R. N. Allan, **" Reliability evaluation of power systems",** Plenum, New York, 2nd edn, 1996

[13] R. Biliinton, R. N. Allan, **"Reliability evaluation of engineering Systems"**, New York, 2nd edn, 1992..

[14] L. Goel, R. Billinton, **"Evaluation of interrupted energy assessment rates in distribution systems",** *IEEE Trans. Power Deliv*., Vol. 6, pp. 1876–1882, Oct. 1991.

[15] P. L. Lewin, J. E. Theed, A. E. Davies, S. T. Larsen, **"Method for rating power cables buried in surface troughs",** *IEE Proc., Gener. Transm. Distrib.*, Vol. 146, pp. 360–364, Jul. 1999.

[16] S. V. Nikolajevic, **"The Behavior of Water in XLPE and EPR Cables and Its Influence on the Electrical Characteristics of Insulation",** *IEEE Transactions on Power Delivery*, Vol. 14, pp. 39-45, Jan. 1999.

[17] R. E. Brown, **Electric power distribution reliability, Marcel Dekker Inc",** New York, Basel, 2009.

[18] M. Gilvanejad, H. A Abyaneh, and K. Mazlumi, **"Fuse cutout allocation in radial distribution system considering the effect of hidden failures",** *Electrical Power and Energy Systems*, Vol. 42, pp. 575-582, Jun. 2012.

[19] S. M. Tabatabaei and B. Vahidi, **"Bacterial foraging solution based fuzzy logic decision for optimal capacitor allocation in radial distribution system",** *Electric Power Systems Research*, Vol. 81, pp. 1045-1050, Jan. 2011.

[20] N. Khalesi, N. Rezaei, M.-R. Haghifam, **"DG allocation with application of dynamic programming for loss reduction and reliability improvement",** *Electrical Power and Energy Systems*, Vol. 33, pp. 288–295, 2011.

[21] S. F. Mekhamer, S. A. Soliman, M. A. Moustafa, and M. E. El-Hawary, **"Application of fuzzy logic for reactive power compensation of radial distribution feeders",** *IEEE Transaction on Power System*, Vol. 18, pp. 206–213, Feb. 2003.

[22] JJ. Grainger and SH. Lee**, "Optimum size and location of shunt capacitors for reduction of losses on distribution feeders",** *IEEE Trans Power Apparat Syst*, Vol. 100, pp. 1105–1118, Mar. 1981.

[23] M. A. Kashem, V. Ganapathy, G. B. Jasmon, and M. I. Buhari, **"A novel method for loss minimization in distribution networks",** In: Proceedings of international conference on electric utility deregulation and restructuring and power technologies, pp. 251–255, 2000.