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Optimal Placement and Sizing of DG in Capacitor Compensated Distribution Networks Using Binary Particle Swarm Optimization

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Abstract: *This paper presents a binary particle swarm optimization for optimally determining the size and location of distributed generation (DG) and capacitor in distribution systems. The main innovation of this paper is using both of 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 compared with genetic algorithm method. The results obtained show appreciable reliability improvement and loss reduction while simultaneously using DG and capacitor.*

Keywords**:** *Distributed generation, Capacitor bank, Loss reduction, Reliability improvement, Binary particle swarm optimization.*

1. Introduction

Distribution system is one of the main three parts of a power system. Studies have indicated that as much as 13% of total power generated is wasted in the form of losses at the distribution level [1]. Also, analysis of the fault rate in different sections of power systems indicates that the most important section in reliability assessment is the distribution networks [2]. These signify the importance of reliability improvement and loss reduction in distribution systems. Several papers have been published that address the use of various approaches in order to achieve the minimum power losses and reliability enhancement. Khalesi and his coauthors in [3] proposed dynamic programming as an optimization tool to find best location for distributed generation installation in the network with variable load model, in order to loss reduction and reliability enhancement.

Authors in [4] were presented an innovative approach to increasing reliability and reducing power loss with placing DG resources in an actual network. In this work, the ITHD index was calculated for determination of the effect of a DG resource on power quality. A harmony search (HS) algorithm proposed to solve best solution for problem capacitor placement and reconfiguration with objectives loss reduction and reliability improvement in [5]. The impacts of capacitor placement on distribution system reliability enhancement and loss reduction are considered in [6] by defining two objective functions.

Many researches have been done in the field of optimal placement of distributed generation and capacitor with the different objectives in distribution network. Authors in [7, 8] proposed a direct search algorithm to solve optimal placement of DG and capacitor in order to maximum possible reduction in real power loss. In [9-11] the capacitor and DG are used to reduce the power loss and voltage profiles improvement in radial distribution networks. Sadighmanesh and authors [12] considered both the available transfer capability (ATC) of the distribution network in placement. Reliability improvement and loss reduction are two important goals of power utilities. None of the above mentioned works has been considered both objectives together in displacement of DG and capacitor.

In this paper a comprehensive objective function which including the costs of DG and capacitor investment, reliability and power loss is considered. DG and capacitor placement is solved individually and simultaneously to minimize objective function by BPSO. In this study, despite works devoted to evaluate reliability, DG is not considered as supporting source but it is investigated from the viewpoint of its effect on reduction of failure rate in cables and overhead lines. In order to demonstrate the effectiveness, 10 and 33 buses test systems are considered and results compared with genetic algorithm method, which suggested an improved saving in annual total cost in DG and capacitor planning problem.

In the following sections, Section 2 presents Problem description for reliability assessment and effects of DG and capacitor installation on reliability indices in distribution systems, briefly. Problem formulation for the objective function for minimization of losses in distribution system by DG and Capacitor is explained in Section 3. In section 4, the Binary Particle Swarm Optimization is described. The results of application of DGs and capacitor placement on 10-bus and 33-bus test systems are presented and discussed in section 5. Finally, section 6 summarizes the main points and results of this paper.

2. Problem Description

2.1. Reliability Analysis of Distribution System

Generally distribution systems have received considerably less of the attention devoted to reliability modeling and evaluation than have generating systems. The main reasons for this are that generating stations are individually very capital intensive and that generation inadequacy can have widespread catastrophic consequences for both society and its environment [2]. Consequently 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 very 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 supply to a customer. This is illustrated by the statistics shown in TABLE I which relate to a particular distribution utility in the UK [2]. Statistics such as these reinforce the need to be concerned with the reliability evaluation of distribution systems.

In Most distribution systems are operated as 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:

$$\lambda_s = \sum_i \lambda_i \tag{1}$$

$$U_s = \sum_i \lambda_i r_i \tag{2}$$

$$r_s = \frac{U_s}{\lambda_s} \tag{3}$$

TABLE I: 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

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. Evaluating ECOST enables the system planners to determine the acceptable level of 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. ECOST at bus i is calculated as follows [6]:

$$\text{ECOST}_i = L_{a(i)} C_i \lambda_i \tag{4}$$

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 ith bus which is evaluated using composite customer damage function (CCDF). CCDF shows the cost of interruption as a function of interruption duration. A typical CCDF [6] 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.

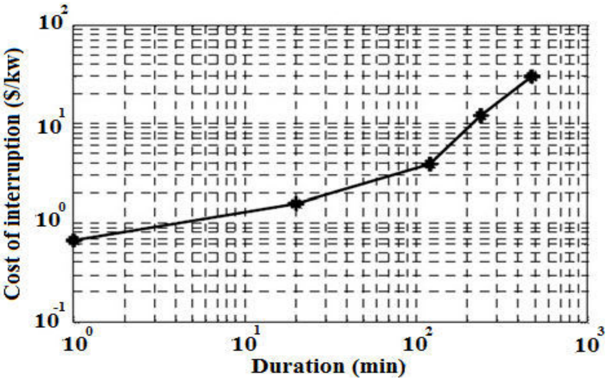

Fig. 1: Typical CCDF

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

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

where NB is the 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 which can be calculated for each load bus i using the following equation:

$$\text{ENS}_i = L_{a(i)} U_i \tag{6}$$

2.2. Impact of DG and Capacitor Placement on Reliability Enhancement

A considerable portion of customer interruptions are caused by equipment failures in distribution systems consisting of underground cables and overhead lines [6]. Resistive losses increase the temperature of feeders which is proportional to the square of the current magnitude flowing through the feeder. For underground cables, there is a maximum operating temperature which if exceeded would cause the insulation problem and an increase in component failure rates [6]. The life expectancy of the insulation material decreases exponentially as the operating temperature raises [14]. On the other hand, a major reliability concern pertaining to underground cables is water treeing. Treeing occurs when moisture penetration in the presence of an electric field reduces the dielectric strength of cable insulation. When moisture invades 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 dielectric breakdown increases, and consequently, the failure rate of the cable is increased. The severity of treeing is strongly correlated with thermal age since moisture absorption occurs more rapidly at high temperatures [15]. Temperature also has impacts on the reliability of overhead lines. High currents will cause lines to sag, reducing ground clearance and increasing 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 occurring [16].

DG and Capacitor placement can supply part of the active and reactive power demands, respectively. Therefore, due to the reduction of the magnitude of current, the resistive losses decrease. As a result, destructive effects of temperature on the reliability of overhead lines and underground cables are moderated. These impacts on reliability take into consideration as a failure rate reduction of 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 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:

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

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 before and after compensation, respectively. The new failure rate of the ith branch is computed as follows:

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

3. Problem Formulation

The problem select of the best places for installation and the preferable size of DG unit and capacitor bank is a complex discrete optimization problem. The aim of 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 which includes the cost of reliability, cost of peak power loss, cost of energy loss and cost of investment. The total cost due to placement is expressed as:

$$TCOST = ECOST + K_P L_p + K_E L_E + C(P\&C) \tag{10}$$

where TCOST is the total cost of the system ($/year), L_P is the peak active power losses (kW), L_E is the energy losses (kWh), C(P&C) is total costs of DG and Capacitor ($), 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 value of K_P is set to 168 [6] and that for K_E is set to 0.07 in this paper.

3.1.1. DG and Capacitor Costs Evaluation

The cost of DG is split into fixed cost and variable cost. Fixed cost is a one-time cost that is spent during construction and installation. On the other hand, variable cost exists when the system is in service and depends mainly on the loading requirement. The variable cost consists of the cost of operation and maintenance of the DG unit. These costs can be formulated as following equation [17]:

$$C(P_{DG}) = a + b \times P_{DG} \tag{11}$$

where a and b are defined as follows:

$$a = \frac{\text{Capital cost}(\$/\text{kW}) \times \text{Capacity}(\text{kW}) \times \text{Gr}}{\text{Life time}(\text{Year}) \times 8760 \times L_F} \tag{12}$$

$$b = \text{Fuel cost } (\$/\text{kWh}) + \text{O \& M cost } (\$/\text{kWh}) \tag{13}$$

P_{DG} is the power generated from DG unit, L_F is the load factor, G_r is the annual interest rate and the O & M cost is the operation and maintenance cost.

TABLE II: Possible choices of capacitor sizes and cost/kVar

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

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, capacitors of larger size have lower unit prices. The available capacitor size is usually limited to:

$$Q_c^{max} = LQ_o^c \tag{14}$$

where L is an integer number. Therefore, for each location for capacitor installation, L sizes are $\{Q_o^c, 2Q_o^c, \ldots, LQ_o^c\}$ available for capacitor. Capacitor cost has two parts, a fixed part and a variable part depending upon 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 II [18].

3.1.2. Power Losses

Loss reduction is one of the main goals of power utilities. 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:

$$P_{Loss}(i, i+1) = R_{i,i+1} I_{i,i+1}^2 \tag{15}$$

$$Q_{Loss}(i, i+1) = X_{i,i+1} I_{i,i+1}^2 \tag{16}$$

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:

$$P_{T,Loss} = \sum_{i=0}^{NB-1} P_{Loss}(i, i+1) \tag{17}$$

$$Q_{T,Loss} = \sum_{i=0}^{NB-1} Q_{Loss}(i, i+1) \tag{18}$$

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

3.2. Operational Constraints

From the point of view of 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:

$$V_{min} \leq |V_i| \leq V_{max} \tag{19}$$

$$|I_i| \leq I_{i,max} \tag{20}$$

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

3.3. Load Flow

In placement problem, distribution power flow is used as a subroutine in each iteration and plays an important role in the solution process. Thus, the load flow algorithm should be computationally efficient and numerically robust. Forward–backward sweep or ladder iteration method is used in this paper which is a simple, easy to implement and reliable method for radial feeders.

Consider the simple distribution feeder shown in Fig. 2. The load current for each node is computed by:

$$I_n = \left(\frac{S_n}{V_n}\right)^* = \left(\frac{P_n + jQ_n}{V_n}\right)^* \tag{21}$$

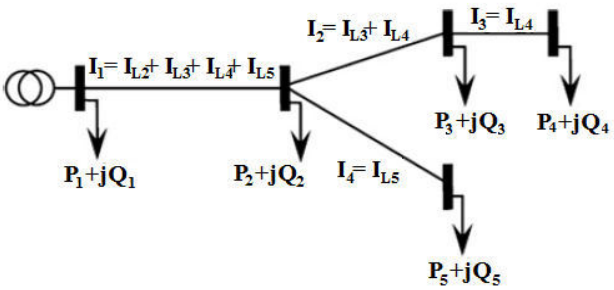

Fig. 2: Sample Distribution Feeder

For the first backward sweep, the voltage of each bus is assumed to be 1 pu and the branch currents are computed using these voltages in (21) and the Kirchhoff's current law. When the current flowing in all branches is computed, the bus voltages are updated using Kirchhoff\'s voltage law in the forward sweep. The voltage at each bus is calculated with voltage drop calculation, starting at the source bus and traversing out to the end buses using the currents calculated in the previous backward sweep. For example, voltage at Bus 2 is calculated as follows:

$$V_2 = V_1 - Z_1 I_1 \tag{22}$$

where Z_1 is the impedance of Branch 1. The backward sweep will be repeated with the updated bus voltages and the process is continued iteratively until the algorithm is terminated based on the convergence criterion as shown below:

$$\max\left|V_i^k - V_i^{k+1}\right| < \varepsilon\,, i = 1, \ldots, NB \tag{23}$$

where V^k_i and V^{k+1}_i are the voltage of bus i in two successive iterations and ϵ is the specified tolerance for voltage mismatch.

4. Particle Swarm Optimization Algorithm

4.1. Classical Approach

In this paper, BPSO is used to find the best solution of the problem of placing and sizing of DG and capacitor. PSO is an evolutionary computation technique that was first introduced by Eberhart and Kennedy [19]. In classical PSO, a number of particles form a swarm that evolve or fly throughout the problem hyperspace to search for an optimal or near optimal solution. The coordinates of each particle represent a possible solution with two vectors associated with it, the position (X_i) and velocity (V_i) vectors. In N-dimensional search space, $X_i = [x_{i1}, x_{i2}, \ldots x_{iN}]$ and $V_i = [v_{i1}, v_{i2}, \ldots v_{iN}]$ are the two vectors associated with each particle i. During their search, particles exchange information with each others in a certain way to optimize their search experience. There are different variants of the particle swarm paradigms but the most commonly used one is the Gbest model where the whole population is considered as a single neighborhood throughout the optimization process. During each iteration, the particle with the best solution shares its position coordinates (Gbest) information with the rest of the swarm. Then, each particle updates its coordinates based on its own best search experience (Pbest) and Gbest according to the following equations:

$$\begin{aligned} V_i^{k+1} &= wV_i^k + c_1 r_1\left(\mathrm{Pbest}_i^k - x_i^k\right) \\ &\quad + c_2 r_2\left(\mathrm{Gbest}^k - x_i^k\right) \end{aligned} \tag{24}$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \tag{25}$$

where c_1 and c_2 are two positive acceleration constants, which are used to weight the particle individual knowledge and the swarm social knowledge, respectively. r_1 and r_2 are two randomly generated numbers with a range of [0, 1] and w is the inertia weight factor, which represents the weighting of a particle’s previous velocity, which linearly decreasing function of the iteration index:

$$w(k) = w_{\max} - \left(\frac{w_{\max} - w_{\min}}{\mathrm{Max.Iter}}\right).k \tag{26}$$

k is the iteration index.

4.2. Binary Particle Swarm Optimization

In order to solve optimization problems in discrete search spaces, Kennedy and Eberhart in 1997 developed a binary version of PSO [20], which in it, the particle is characterised by a binary solution representation and the velocity must be transformed into the change of probability for each binary dimension to take a value of one. Basically, particles are represented by binary variables and without using w. Furthermore, the velocity is constrained to the interval [0, 1] by using the following sigmoid transformation:

$$\mathrm{sig}\left(V_{i,j}^k\right) = \frac{1}{1 + \exp\left(-V_{i,j}^k\right)} \tag{27}$$

where $\mathrm{sig}(V_{i,j}^{k})$ denotes the probability of bit $V_{i,j}^{k}$ taking 1. To avoid $\mathrm{sig}(V_{i,j}^{k})$ approaching 0 or 1, a constant V_{max} is used to limit the range of velocity. BPSO updates the velocity according to:

$$V_{i,j}^k = \begin{cases} V_{\max} & \text{if } V_{i,j}^k > V_{\max} \\ -V_{\max} & \text{if } V_{i,j}^k < -V_{\max} \\ V_{i,j}^k & \text{otherwise} \end{cases} \tag{28}$$

Each bit of particles, at each time step, changes its current position according to Eq. (29) instead of Eq. (27) based on Eq. (28) as follows:

$$X_{i,j}^k = \begin{cases} 1 & \text{if } P_i^k < sig\left(V_{i,j}^k\right) \\ 0 & \text{otherwise} \end{cases} \tag{29}$$

Fig. 3 presents a flowchart of the proposed approach. The algorithm is terminated if the iteration number is reached to the prespecified maximum number of iterations or the objective function is not improved after a specified number of iterations. In this optimization problem, the number of particles and the maximum number of iterations are selected 40 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 this optimization, the following cases were considered to validate the proposed approach:

Case 1: Optimal size and location of only capacitor in the distribution network is to be determined such that the objective function given in (10) minimized.

Case 2: In this case only DG is placed to minimize objective function.

Case 3: Optimal placement and sizing of both capacitor and DG is to be determined, simultaneously, such that the objective function minimized.

For the calculation of reliability indices and determination of 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 [6]. Based on this assumption, failure rates of other sections are calculated linearly proportional to these two values according to their resistances [2].

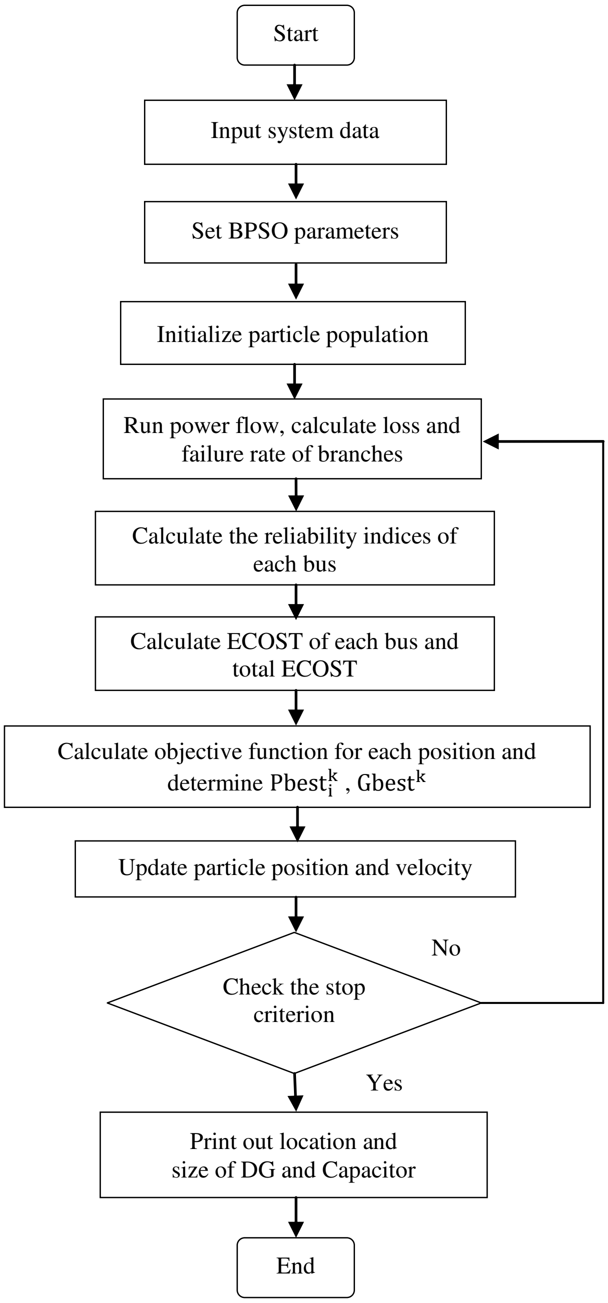

Fig. 3: Flowchart of the Proposed Approach

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 [6] and for partial compensation; the failure rate is calculated using (8). In both of 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 hours and 0.5 hours, respectively. Also, other components such as transformers, busbars, breakers and disconnects are assumed to be fully reliable, in this paper. Moreover, it is assumed that DG does not operate in islanding mode and must be disconnect from the system during fault until the fault is cleared. For testing of proposed technique, distributed generation has been considered as negative load. Also, distributed generation has been considered that supply only active power to the network without consuming any reactive power. However, it is obvious that from the economical point of view reactive power production by capacitor is cheaper than DG.

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 [21]. The total load of the system is considered as (12368+ j 4186) kVA.

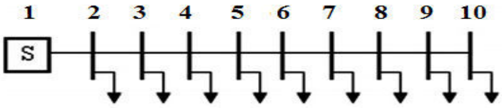

Fig. 4: 10-bus Radial Distribution System

The results of optimum DG and capacitor planning by BPSO method have been collected in TABLE III. Also, this TABLE gives the DG and capacitor simultaneous sizing results by GA. In order to indicate the effects of DG and capacitor placement on different parameters in the test system, the results are presented in TABLE IV. It can be seen from this table that the optimal placement of DG and capacitor either alone or together in the system caused both an improvement in reliability indices and reduction in active and reactive power losses and a considerable improvement of voltage in all buses. However, it is noted that value of improvement in all parameters in alone DG placement more than alone capacitor placement. The percentage of improvement in the mention's parameters for different cases is also shown in Fig. 5.

TABLE III: Optimum size and location of single DG unit and single capacitor bank in 10-bus system.

Method	Different Cases		Location	Size
BPSO	Case 1	Capacitor	Bus 5	4050 kVar
	Case 2	DG	Bus 10	1770 kW
	Case 3	Capacitor	Bus 5	3900 kVar
		DG	Bus 10	1696 kW
GA	Case 3	Capacitor	Bus 5	3750 kVar
		DG	Bus 10	1607 kW

TABLE IV: Results in different cases of placement in 10-bus system.

Method	Different Cases	TCOST ($)	ECOST ($)	ENS (kWh)	$P_{T,Loss}$ (kW)	$Q_{T,Loss}$ (kVar)	Minimum Voltage (pu)
	Base Case	884939	272650	89933.6	783.78	1036.6	0.8375
BPSO	Case 1	805139	255621	84346	702.5	904.9	0.8640
	Case 2	739123.8	252803	82982	353.36	580.2	0.9089
	Case 3	688177.2	240842	79120	313.8	498	0.9295
GA	Case 3	688310.1	241338	79283	326.9	513.7	0.9255

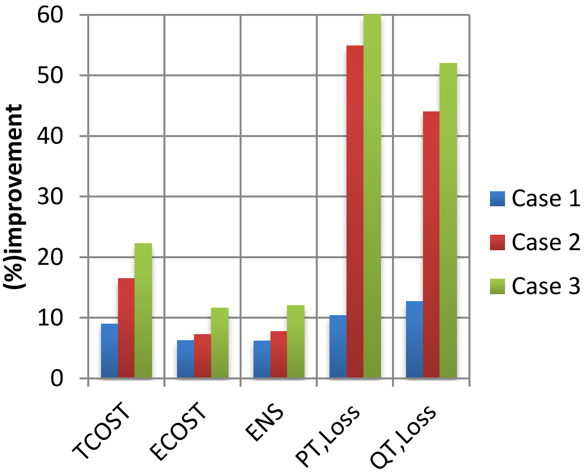

Fig. 5: Comparison between (%) improvement of parameters in different cases of placement in 10-bus system.

It is clear from the results obtained that the proposed BPSO method can obtain better solution. The percentage of improvement in different parameters for both methods is shown in Fig. 6.

Fig. 7 shows the voltage profile of buses in different installation cases and base case in the 10-bus test system. It is observed that from this figure, the voltage profile has been improved significantly in all installation cases. Though must rise is obtained in third case of placement.

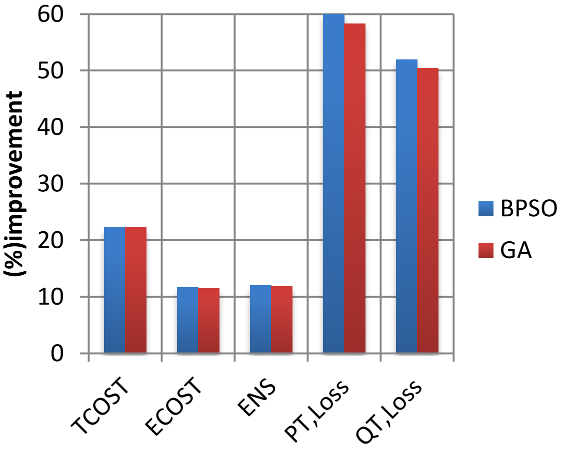

Fig. 6: Comparison between (%) improvement of parameters in 10-bus system by BPSO and GA.

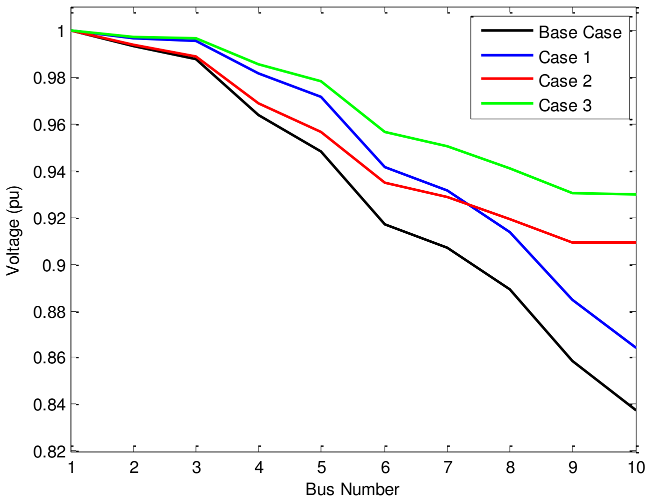

Fig. 7: Voltage profile for three installation cases and base case in 10-bus distribution system.

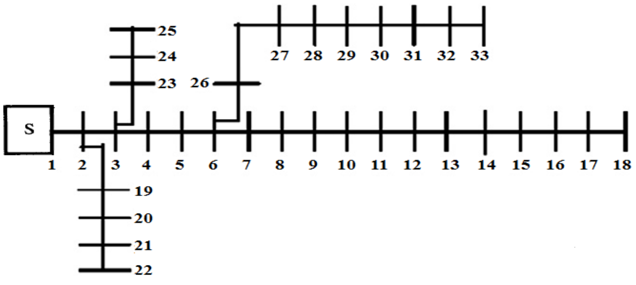

Fig. 8: Single line diagram of a 33-bus system.

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 [22]. In this paper assumed that load level is in peak condition (4458+ j 2760) kVA. The single line diagram of the 33-bus is shown in Fig. 8.

The results of DG' and capacitor installation in 33-bus test system by both method are presented in TABLES V and VI. Similar to 10-bus test system, the results obtained in these tables shows that DG and/or capacitor installation may result in loss reduction, voltage and reliability improvement, significantly. In order to a clear comparison, (%) improvement in TCOST, ECOST, ENS, $P_{T,Loss}$ and $Q_{T,Loss}$ for different installation cases illustrated in Fig. 9.

TABLE VI: Results in different cases of placement in 33-bus system.

Method	Different Cases	TCOST ($)	ECOST ($)	ENS (kWh)	$P_{T,Loss}$ (kW)	$Q_{T,Loss}$ (kVar)	Minimum Voltage (pu)
	Base Case	408608.4	162960	69338	314.45	213.3	0.8823
BPSO	Case 1	328861.8	153884	65951	223.6	153.4	0.8980
	Case 2	398128.5	157601	67316	260.6	174.5	0.9033
	Case 3	324438.7	149630	64345	178.5	120.7	0.9242
GA	Case 3	324773.6	150583	64613	184.4	124.8	0.9201

TABLE V: Optimum size and location of single DG unit and single capacitor bank in 33-bus system.

Method	Different Cases		Location	Size
BPSO	Case 1	Capacitor	Bus 30	1500 kVar
	Case 2	DG	Bus 17	311 kW
	Case 3	Capacitor	Bus 29	1650 kVar
		DG	Bus 18	295 kW
GA	Case 3	Capacitor	Bus 29	1650 kVar
		DG	Bus 17	251 kW

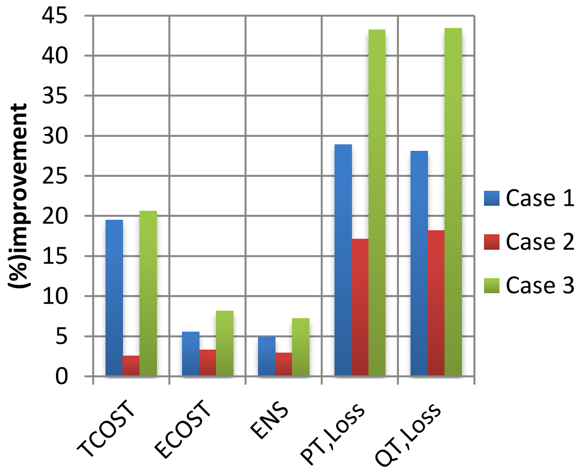

Fig. 9: Comparison between (%) improvement of parameters in different cases of placement in 33-bus system.

From this figure, though expectedly, it is clear that there is a more improvement on the reliability indices, active and reactive power losses, finally in annual total cost with optimal placing of both DG and capacitor in comparison to the alone them placement. Also, value of improvement in parameters mentioned above in alone capacitor placement more than alone DG placement. However, similar previous test system, BPSO also generates more suitable results that illustrated in Fig. 10. Moreover, Fig. 11. shows that voltage profile of each bus in 33-bus test system has been improved by DG and/or capacitor installation. However, it can be seen that most increase in overall voltage profile is obtained in the simultaneous installation of them.

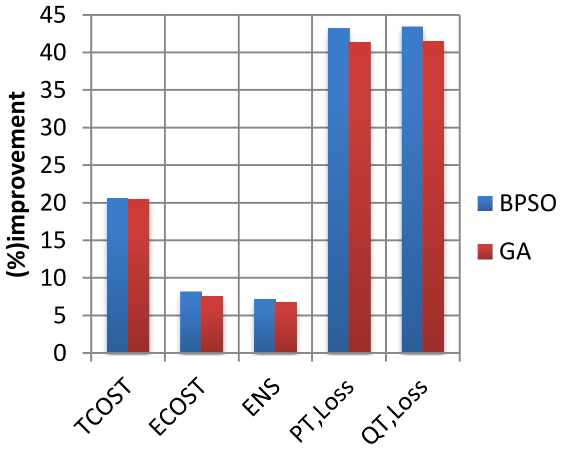

Fig. 10: Comparison between (%) improvement of parameters in 33-bus system by BPSO and GA.

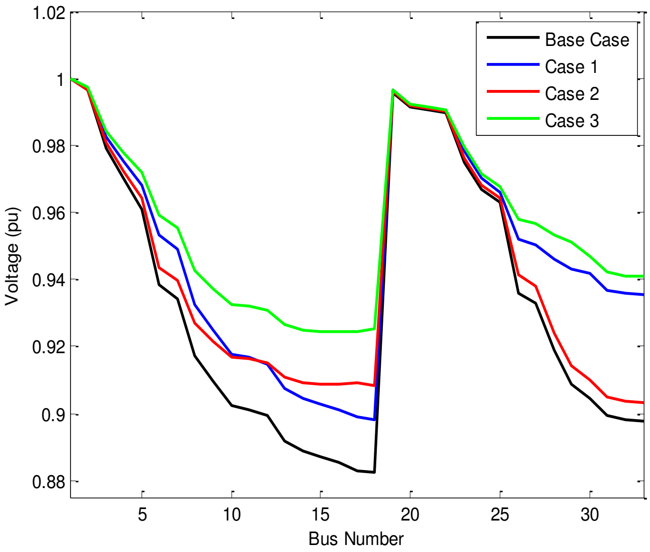

Fig. 11: Voltage profile for three installation cases and base case in 33-bus distribution system.

In generally speaking, the results obtained show that proper sizing and sitting of DG and/or capacitor in the distribution network does enhance the reliability and power losses and decrease total costs. It was found that simultaneous placement is the best scenario for installation.

6. Conclusion

In this paper a Binary Particle Swarm Optimization has been implemented to solve optimal placement and sizing of DG and capacitor in order to improving reliability and decreasing loss in distribution system. It is clear from the results obtained that optimal installation DG and capacitor can cause to improvement in loss and reliability level in test systems. The analysis indicated that the best solution is obtained when both DG and capacitor are allocating, simultaneously. The comparison is shown the effectiveness of proposed method in finding a better quality solution. Also, results have shown that locating DG and capacitor in the most suitable places lead to voltage profile improvement.

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