Locating and sizing of capacitor banks and multiple DGs in distribution system to improve reliability indexes and reduce loss using ABC algorithm

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ABSTRACT

DG sources have been introduced as one of the most widely used and effective methods among various methods providing losses reduction in power systems. In this paper, the artificial bee colony algorithm has been employed with the aim of determining location and capacity of distributed generations (DGs) and capacitor banks (CBs) in distribution systems. The proposed objective function includes power losses and ENS reliability index, which is used by deploying weight coefficients as objective function in the algorithms. Accordingly, the standard 37-bus networks have been used for studies. The simulation results demonstrate that the artificial bee colony algorithm is more effective in all sections and has higher capability in reducing losses and improving reliability as well.

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1. INTRODUCTION

Increasing production and fuels costs in power plants have made electrical system designers to minimize losses in electrical networks as much as possible. Distribution systems are also involved in this scope as a very important section enabling connection to the customers. In other words, owing to concentration of major losses in the distribution systems, the power loss in these systems could be considered as an important issue, and thus most efforts have been made to reduce losses in this section. The rate of electrical energy loss across Iran distribution system is higher than global average and according to the latest data available on the World Band site, the world average energy loss in transmission and distribution is about 8%, and this is 14% for Iran. The load imbalance is one of the most important issues causing losses in distribution networks. The static imbalance refers to constant impedance loads which always have definite and certain characteristics, but the dynamic imbalance is related to the cumulative behavior of composite loads. The cumulative and composite loads in the low-voltage distribution system feeders, along with the stochastic and asynchronous behaviors of single-phase customers and non-uniform distribution of them across different phases have led to load and current imbalance [1]. The imbalance results flowing current through neutral wire and saturation of the distribution transformers. Basically, less attention is paid to the voltage imbalance by the electricity distribution companies because its negative effects will not be revealed in short term. On-site supply of loads active and reactive power requirements reduces power transmission losses, and makes it possible to maintain the voltage profile within the allowed range, which leads to improving these two reliability indices [2]. Therefore, providing appropriate solutions to reduce losses in the unbalanced distribution system is very important. In recent years, the use of distributed generation sources and capacitor banks have been considered by the researchers as the most widely used methods for reducing losses in distribution system.

Gomez-Gonzalez [1] proposed a new hybrid method that uses discrete particle swarm optimization and optimal power flow (OPF). Technical constraints are also used in the optimization process to search the best locations to link distributed generation sources to the distribution network. A comparison between power dissipation sensitivity, power stability index (PSI), and voltage stability index (VSI) has been proposed by Murty and Kumar [2] to determine the optimal location and size of distributed generation units in the radial distribution network. The location of DGs is determined by Keane and O'Malley [3] and the load is variable with time, the amount of power generated by DGs is unknown. In this paper, a linear programming method has been used which are mathematical and numerical optimization methods. Due to the fact that the capacity of distributed products has not been specified, the use of this method is not time consuming; but if the amount of DG generation is also needed, this method will not be responsive.

A combination method of genetic algorithm (GA) and particle swarm optimization (PSO) algorithms for locating distributed generation sources has been proposed to achieve the minimum losses, increase voltage stability and improve the voltage regulation index [4]. Various distributed generation sources for active and reactive power compensation have been investigated in order to minimize power losses in distribution networks using the PSO algorithm [5]. A repetitive load distribution method has been used to calculate power losses in the system [6]. The type of distributed generation used in this paper is photovoltaic. The purpose of the determination of location and photovoltaic capacity was to reduce power losses and improve the voltage profile. In addition to the locating of distributed generation sources, the system has also been rearranged.

Jamil and Anees [7] has been used an analytical method to determine the size and location of photovoltaic panels based on massive placement on the primary side of the distribution system. The main goal of this research is to reduce power losses and improve the voltage profile with economic benefits. Kayal and Chanda [8] use a multi-purpose optimization method to determine optimal location of distributed wind and solar generation units in the distribution system based on the PSO approach. The proposed method follows the voltage and power range set by the power company. The purpose of this method is to improve the voltage stability and reduce power losses of power grids by distributed generation units.

An efficient rapid convergence optimization algorithm has been presented based on the correction of the traditional firefighting method to determine the optimal size and location of distributed generation sources of controlled voltage in balanced and unbalanced distribution systems [9]. The proposed algorithm has modified the traditional firefighting method to effectively limit the optimization problems by providing formulas for adjusting the parameters of the algorithm and updating the equations. Gallano and Nerves [10] includes optimization studies with three objectives in the distribution system, namely: Minimizing power losses, improving voltage profiles and reducing line load by network redesign, capacitor locating and distributed generation sources are simultaneously performed. A new and fast multi-objective method that can be applied to a real network has been used. The proportionate non-dominated sorting genetic algorithm (NSGA-II) and fuzzy decision making analysis are used to obtain the best structure of the network by simultaneously connecting capacitors and distributed generation sources. Optimal locating of capacitors and distributed generation sources is used to control the active and reactive power distribution [11]. This paper is based on three improved optimization algorithms, which are: Improved GA, improved particle swarm algorithm and improved cats community algorithm to find optimal location of capacitors and distributed generation sources in variable-load scenarios.

A new method is proposed for capacitor placement using particle swarm algorithm with Gaussian and Cauchy's probability functions based operators [12]. The proposed methods are proved by two samples. Simulation results showed that the presented method can achieve an optimal solution in global search with a very little time consumption. In order to determine optimal location of capacitor banks, an approach which integrates losses sensitivity factor (LSF) and VSI has been carried out in [13]. The bacterial foraging optimization algorithm is used to determine optimal size of capacitors. Taher and Bagherpour [14] have proposed the hybrid artificial bee optimization algorithm for locating the shunt capacitor in the 25-bus and 37-bus IEEE standard distribution systems. The objective function includes minimizing losses and maintaining total harmonic distortion (THD).

A quasi-oppositional teaching learning based optimization (QOTLBO) is used for optimal location of distributed generations, and at the same time, power loss minimization, voltage stability index improvement, and radial distribution network voltage deviation have been investigated in [15]. Hung and

Mithulananthan [16] have presented an appropriate analytical method for determining four types of cumulative distributed generation units in order to reduce losses in primary of distribution networks. This improved analytical method is a tool to calculate the optimal sizing of four different types of DGs as well as a methodology to determine suitable location for their placement. In addition, a method has been provided to achieve optimal power factor by using DGs to deliver active and reactive power. Also, the LSF and total load dissemination (ELF) methods are presented.

In Sajjadia *et al.* [17], locating the capacitor and DGs in radial distribution network with different load levels has been carried at the same time. The problem objectives are to reduce active and reactive power losses, reduce energy losses and improve the voltage profile. In addition, the effect of capacitor and DGs on voltage stability improvement has been investigated. The memetic or hybrid algorithm is used to find optimal solutions. This algorithm is a combination of local search and GA. The performance of proposed method is evaluated on a sample distribution network. In Naik *et al*. [18], a method is proposed for locating and sizing DGs and capacitor banks based on an analytical approach taking into account the equality and inequality constraints with the aim of loss reduction in distribution system. The sensitivity analysis method is used to determine the candidate locations for DGs and capacitors. In the paper, three improved optimization algorithm including improved GA, improved PSO and improved cat society algorithm, have been employed for optimal placement and sizing of capacitors and DGs in different scenarios with variable loads.

Gunda and Khan [19] have formulated a differential evolutionary algorithm for productive solution using DGs and shunt capacitors. Kalantari and Kazemi [20] have used GA for successful placement of distributed generation unit and shunt capacitor in the distribution network for real power and reactive power loss reduction and improvement of voltage profile. Wang and Zhong [21] have used heuristics method to improve the voltage profile. Karami *et al.* [22] have used GA for optimal location and sizing of DGs and shunt capacitors considering loadability. Hooshmand and Mohkami have used particle swarm optimization for the same [23]. Zeinalzadeh *et al.* [24] have proposed a multi-objective optimization problem for simultaneous placement of shunt capacitors and DGs considering load uncertainty using multi-objective particle swarm optimization. Khan *et al.* [25] have used binary collective animal behavior optimization algorithm for minimization of line losses and minimization of voltage deviation in the distribution network. Gampa and Das [26] presents a combination of fuzzy and GA-based methodology for simultaneous optimum allocation and sizing of distributed generations (DGs) and shunt capacitors (SCs) together in distribution systems. The objectives of reduction of active power and reactive power supply, reduction of real power loss and improvement of branch current capacity, voltage profile and voltage stability are considered.

The amount of active power needed in the candidate bus is of great importance, because inappropriate selection of each of these values, will lead to high cost and low efficiency [11]. All the mentioned advantages of DGs and capacitor banks depend on certain size and proper location of the equipment to be installed. Otherwise, not only the abovementioned benefits will not be met, but also the voltage at buses may be reduced, and total loss and transmission line congestion may be increased. In this paper the artificial bee colony algorithm (ABC) has been utilized to achieve demonstrated goals. The ABC algorithm is suitable for such problems with high convergence speed and accuracy. This paper is organized as follows. In section 2 the modeling of studied problem is presented. In this section objective function and constraints are defined. In section 4 the artificial bee colony optimization algorithm has been described. Finally, this paper ends with the presentation of results in section 6.

2. PROBLEM MODELING

The network structural and functional factors may lead to imbalances in distribution system. The structural factors, as its name suggests, refers to network structure and configuration which in many cases the asymmetric arrangement of a system leads to imbalance in it. Geometric asymmetry in the lines and cables impedances owing to incomplete transpositions of lines, aged fuses and capacitor banks is one of the structural causes of imbalance.

Second factor which is actually the main cause of this phenomenon is the network functional factor; in fact the unbalanced loads of system. The imbalance caused by structural factors is mainly very small hence it can be solved easily. The factors that make imbalance problems dramatic are functional ones including single-phase and two-phase loads, three-phase loads such as electric arc furnaces, imbalance equipment like high impedance connections such as loose contacts of aged contactors, imbalance winding turns of induction motors and/or imbalance caused by their incorrect repair as well as asymmetry in the rotor and stator of these class of motors. In addition, the inappropriate operation of power factor correction equipment and single line to ground faults can be mentioned. The heterogeneous and non-uniform distribution of different household, administrative and industrial customers may lead to loads imbalance. Furthermore, the stochastic and asynchronous behavior of single phase loads contributes in load imbalance. In fact, although the single phase loads are distributed almost uniformly across phases, owing to their stochastic and asynchronous characteristics there will be a possibility for load imbalance, particularly, in the case where single phase loads are in different types. Single phase customers in 400 V low-voltage distribution networks, are the major cause of load imbalance in these networks, and if it is not corrected, the imbalance may extend to medium voltage or even high voltage networks. The load imbalance is one of the power quality indices. Distribution networks lose a huge amount of capital annually because of load imbalance.

2.1. Objective function

In order to optimize the allocation of DG units and capacitor banks using optimization algorithms, it is necessary to select a proper objective function. This paper has employed an objective function including lines losses and ENS index. The goal is to minimize this function.

$$\min f = \alpha \text{x} P_{loss} + \beta \text{x} ENS \tag{1}$$

$$P_{loss} = \sum_{i=1}^{N_{branch}} R_i I_{i^2} \tag{2}$$

$$ENS = \sum_{j=i}^{N_{Load}} L_{avg(j)} U_j \tag{3}$$

In (1), P_{loss} is the active power loss, and ENS is the not supplied energy index. It is worth to notice that due to the lack of access to switches failures information in two studied network, the failure rate has been set stochastically employing a normal function with average of 0.05. The weight coefficients of $\alpha = 3.5$ and $\beta = 1$ are used for weighing these two objectives in the proposed objective function. In addition, in (2) R_i is ith line resistance and Ii is the current of that branch. In (3), $L_{avg(j)}$ is the average of loads connecting to the bus j, and U_j is the average of hours that loads have not been supplied at the bus j.

2.2. Problem contraints

DGs should be connected to the current network in such a way that the normal operation of the network is not compromised. This means that all requirements for proper network operation and load response should be considered. Consequently, this leads to limitations which are explained as (13) and (14).

- Power flow constraints: The following two equations should be satisfied at all buses (except slack bus) as power flow constraints [27].

$$P_{gi} - P_{di} - \sum_{j=1, j\neq slack}^{N} |v_i||v_j||y_{ij}| cos(\delta_i - \delta_i - \theta_{ij}) = 0 \tag{4}$$

$$Q_{gi} - Q_{di} - \sum_{j=1, j\neq slack}^{N} |v_i||v_j||y_{ij}| sin(\delta_i - \delta_i - \theta_{ij}) = 0 \tag{5}$$

where in (4) and (5), P_{gi} and P_{di} are injected and consumed active powers at bus i, v_i and δ_i are voltage magnitude and angle at bus i, v_j and δ_j are voltage magnitude and angle at bus j, y_{ij} and θ_{ij} are magnitude and angle of the admittance that connects bus i to bus j.

- Bus voltage constraints: The voltage of all buses is only allowed in the range of

$$|v_i^{min}| \leq |v_i| \leq |v_i^{max}| \tag{6}$$

where v_i^{max} and v_i^{min} are the upper and lower limits respectively, and each bus voltage should be in the range of 0.95 to 1.05 per unit.

- Maximum line current flow: The capacity of line to transfer power is limited. Therefore, the current (and/or power) flowing over the line must not exceed from following range.

$$|I_{ij}| \leq |I_{ij}^{max}| \tag{7}$$

where I_{ij}^{max} is maximum allowed current to flow between bus i and j.

- DG active power generation limit: Active power generated by DG should be in the allowed range. These constraints may also caused by DG technical or economical limits.

$$P_{DGi}^{min} \leq P_{DGi} \leq P_{DGi}^{max} \quad (8)$$

where P_{DGi} is the active power generated by DG.

– Capacitor banks reactive power constraint: The generated reactive power should be in the following range.

$$Q_{Ci}^{min} \leq Q_{Ci} \leq Q_{Ci}^{max} \quad (9)$$

where Q_{DGi} is the reactive power generated by DG installed at bus i.

– Limitation in number of DGs and capacitor banks: If there is a limitation in number of DGs and capacitor banks, it should be deployed in objective function.

$$N_{DG,}N_C \leq N^{Max} \quad (10)$$

– Network reliability constraint: after optimal placement and sizing of DGs and capacitor banks, it is necessary to recalculate the reliability indices to ensure that they have not exceeded the allowed range. Therefore, the following indices are calculated: SAIFI, SAIDI, and MAIFI. They are defined as (11):

$$SAIFI = \frac{\sum \lambda_I N_i}{N_T} \leq SAIFI^{Max} \quad (11)$$

$$SAIDI = \frac{\sum r_I N_i}{N_T} \leq SAIDI^{Max} \quad (12)$$

where N_i is the number of customers connected at bus i, N_T is sum of all customers, λ_i is fault rate at node i and r_i is the outage duration. It is worth to mention that owing to lack of access to the accurate information about outages, these values have been chosen stochastically with normal distribution.

3. ARTIFICIAL BEE COLONY OPTIMIZATION ALGORITHM

In computer science and operation research, the Bees algorithm is a population based search algorithm which was first developed in 2005. This algorithm is inspired from foraging behavior of artificial bee swarm. A colony of artificial bees can spread itself over long distances and several directions at the same time to harvest multiple food resources. The foraging process in a colony begins with sending bees namely scout bees to search for promising foods. Scout bees randomly evaluate the surrounding area. When they return to the hive, if the quality of the food source they have found is higher than a specific threshold, they will communicate information about the food source to the rest of the colony through a special dance named "waggle dance". The waggle dance path has a figure of eight shape or infinite symbol which is shown in Figure 1. The angle between bee orientation and the sun (α) indicates the direction of food source toward the hive. Duration of the dance indicates the distance to the food source, and the frequency of the waggles in the dance and buzzing convey the quality of the source [28].

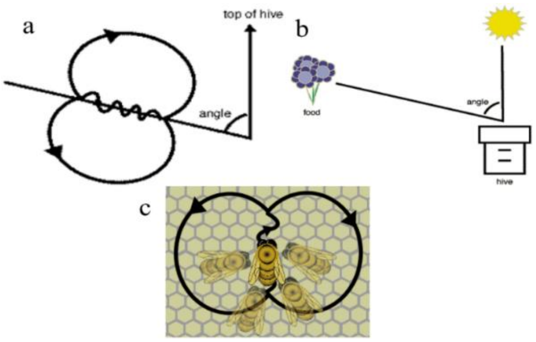

Figure 1. Waggle dance in the hive

The employed bees will be sent to the source based on profitability of food sources as well as required energy to harvest the source. Here, optimization is performed, because the bees have been decided to get the richest food source with least amount of energy. For example, between two foods sources with equal qualities the nearest source will be selected or a number of poor food sources have a higher priority than distant food sources. Based on profitability, some of the sources will be selected from initial sources that are introduced by scout bees, and then the scout bees of rest sources will be sent to discover new stochastic sources. Among selected sources, the best ones are marked as elite sources. The most employed bees are assigned to the elite sources and fewer bees are sent to the other selected sources. In the next step, the forager bees will evaluate the food sources in addition to collect food and communicate relevant information through dance to the rest of colony.

Receiving information from hive bees is not completely accurate which prevents bees to find the exact location communicated by dancing bee, thus they examine the neighboring location which leads to local search and all adjacent locations be well examined as well. At the end of each search, the best bee is determined among the bees of each source and the best bee among the selected bees [28]. Advantages of the Bees algorithm include high-speed convergence and the ability to avoid local optima.

The flowchart of artificial bee colony algorithm for placement and sizing DGs and capacitor banks is illustrated in Figure 2. In order to optimal location and sizing of capacitor banks and DG sources across distribution system using artificial bee algorithm, following steps were carried out:

Step 1: Determining artificial bee algorithm parameters including number of bees, iterations, and selected bees.
Step 2: Random initialization of bees. Each bee indicates a different location and size for two capacitor banks and DGs.
Step 3: Performing power flow and calculating power losses.
Step 4: Calculating ENS index for studied network.
Step 5: Calculating objective function using values obtained in step 3 and 4.
Step 6: Sorting bees based on the obtained values from their objective functions and selecting the best bee.
Step 7: Performing waggle dance for selected bees.
Step 8: If the determination criteria are not satisfied go to step 3.
Step 9: The end.

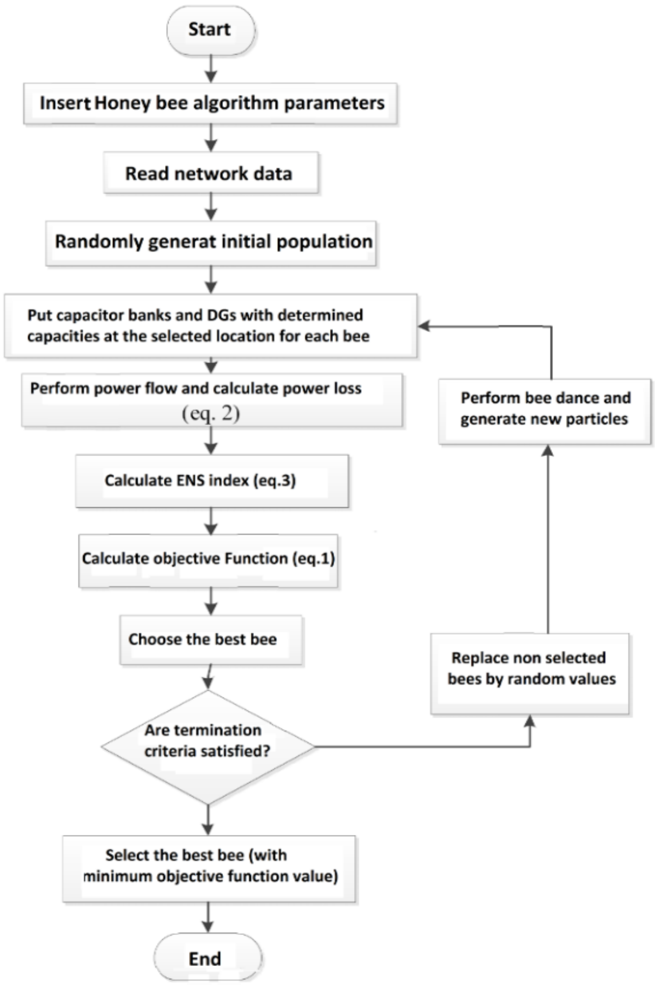

Figure 2. Flowchart of artificial bee algorithm for placement and sizing the capacitor banks and DG sources

4. SIMULATION RESULTS

Stochastic and asynchronous behavior of distribution section customers leads to inherent load imbalance in distribution network resulting adverse effect on network performance. The distribution system is required to study the location and sizing DGs under load imbalance condition. Therefore, in this paper the 37-bus IEEE standard network [9] has been employed for studies. The single line schematics of considered networks have been depicted in Figure 3. The artificial bee colony algorithm has been used in order to placement and sizing the DGs and capacitor banks across studied network. Eventually, to validate the simulation results, the results obtained from this algorithm have been compared to the GA and PSO. The parameters for these three algorithms are shown in Table 1.

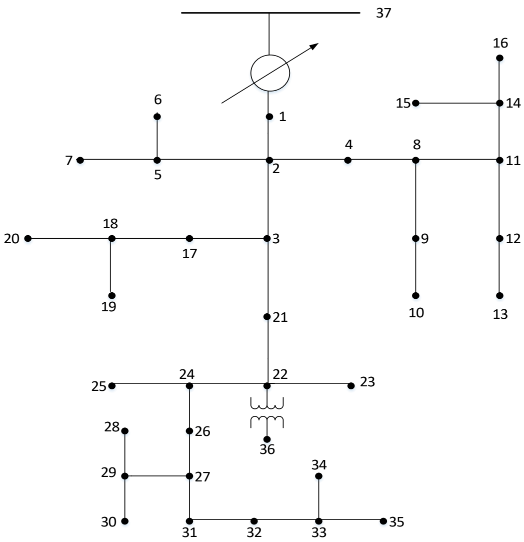

Figure 3. The IEEE 37-bus network [14]

Table 1. The algorithms parameters

ABC	Population	iteration	nSelectedSite	nEliteSite	NSelectedSiteBee	nEliteSiteBee
	50	30	30	15	30	10
PSO	Population	iteration	$C_1=C_2$	w	V_{min}	V_{max}
	50	30	2	0.7	0.4	0.9
GA	Population	iteration	P_c	P_m		
	50	30	0.2	0.8		

Due to the fact that most distribution systems are unbalanced, for more accurate examination and performance analysis of such systems, it is appropriate to use an unbalanced load model in studies to obtain more accurate and more suitable results. In this section, placement and sizing studies for capacitor banks and DGs in the 37-bus system are carried out. After performing optimization and determining the optimal capacity and location of sources in the system utilizing three algorithms of BA, GA, and PSO, the obtained results are presented in Table 2. In this table, in order to investigate the performance of each algorithm more accurately, the objective function value, total loss and ENS index are given for each one. In addition, the SAIFI and SAIDI constraints values are calculated to be in the allowed range.

Table 2. Optimization results in the first scenario

	DG I		DG II		Capacitor I		Capacitor II		Loss (kw)	ENS	The value of objective function	SAIDI	SAIFI
	Bus No.	Capacity (KW)	Bus No.	Capacity (KW)	Bus No.	Capacity (Kvar)	Bus No.	Capacity (Kvar)					
Base	-	-	-	-	-	-	-	-	0.23	0.786	1.591	5.6	0.73
GA	17	860	25	230	12	340	14	170	0.094	0.342	0.671	4.4	0.58
PSO	17	680	10	350	19	380	17	279	0.083	0.311	0.6015	4.2	0.53
ABC	10	740	18	450	19	430	12	245	0.076	0.293	0.559	3.7	0.47

According to the given results in Table 2, after optimization by ABC algorithm, buses 18 and 10 are selected for installation of DG sources, with the capacity of 740 and 450 kW respectively. In addition, the capacity of 430 and 245 kVar have been proposed for capacitor banks to be installed at buses 19 and 12 respectively. In the case where the PSO algorithm is performed, in order to achieve the minimum value for objective function, the active power capacities of 680 and 350 kW are proposed to be installed at buses 17 and 10, respectively, and the capacities of 380 and 350 kVar are assigned for buses 19 and 17 for installation of capacitor banks. Meanwhile, the GA algorithm has selected buses 17 and 25 as suitable buses for installing DGs. The active power values of each DG are 860 and 230 kW, respectively, and their reactive power sources capacities are assigned 340 and 170 kVar at bus 12 and 14, respectively. In Figure 4, the curve of objective function changes is presented for three algorithms in different iterations.

According to Figure 4, the three algorithms of ABS, PSO and GA, have converged to their final values after 18, 26 and 20 iterations, respectively. The final value of objective function is about 0.559 for ABC algorithm, whereas this value is 0.6015 for PSO algorithm and 0.671 for GA algorithm as well. The ENS value for a non-compensated system is about 0.786, while it is obtained 0.293, 0.311, and 0.342 for the three algorithms of ABC, PSO and GA, respectively.

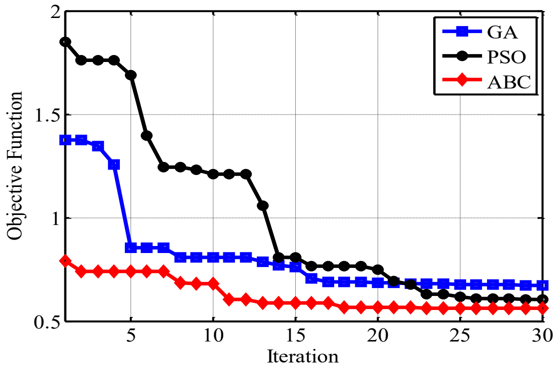

Figure 4. The objective function value for 37-bus network

The lowest ENS value corresponds to the ABC algorithm. According to the results, one can claim that after the installation of capacitor banks and DGs, the amount of unsupplied energy has decreased significantly. The power losses of each line under three conditions defined in Figure 5 are shown as follows. In the case where the capacitor banks and DGs are not used, the total losses of lines have been obtained about 230 kW. As shown in the figure, the lines losses are different in various phases. In addition, in the case where the active and reactive power sources are installed, the all lines losses across the network are shown in Figure 6 for the artificial bee colony algorithm. As can be seen in Figure 6, the losses of most lines are decreased. In the case of utilizing ABC algorithm, the total loss of system is about 76 kW, while in the case of using the two algorithms of PSO and GA the obtained losses are 83 and 94 kW, respectively.

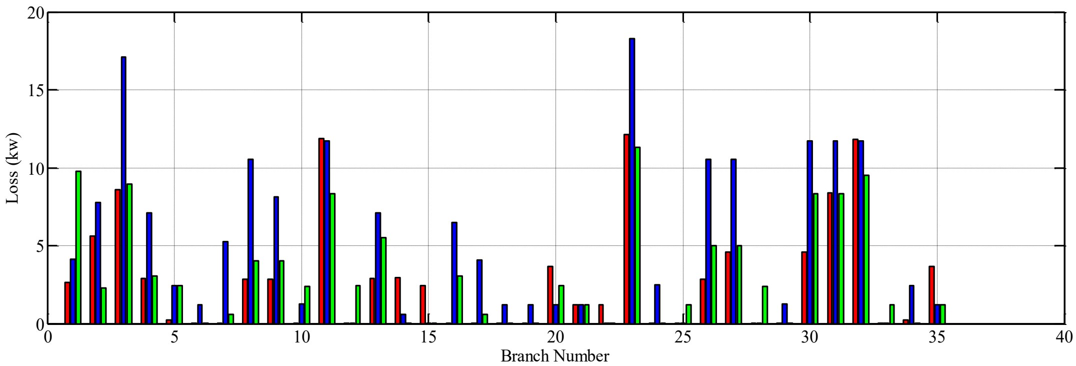

Figure 5. The line losses in 37-bus standard system (Red color---ABC, Green color---PSO, Blue color---GA)

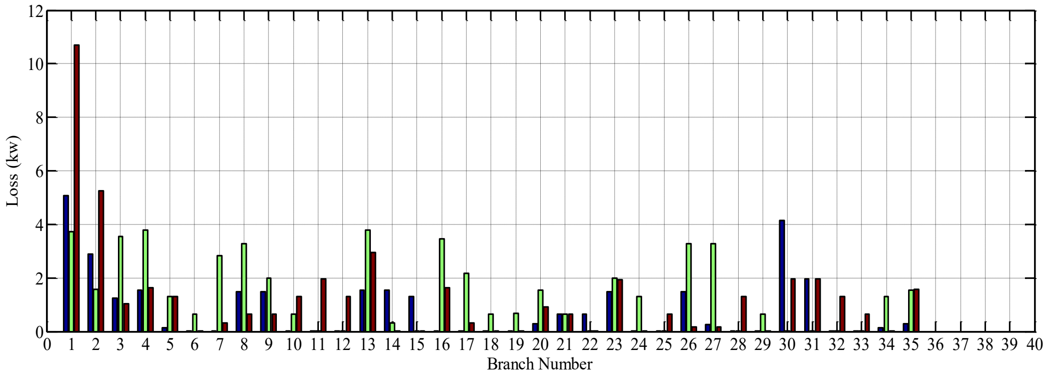

Figure 6. Losses in the Site feeder network in the case of optimization by ABC algorithm (Red color---ABC, Green color---PSO, Blue color---GA)

5. CONCLUSIONS

To the best of our knowledge, most of previous studies for placement and sizing DGs and capacitor banks across distribution systems were limited to the balanced networks. However, in distribution networks, due to the stochastic and asynchronous behavior of consumers, loads are not distributed uniformly over phases; hence distribution systems are inherently unbalanced. Consequently, it is better to employ unbalanced distribution networks to conduct studies, so that the results of studies are closer to reality. Therefore, in this paper investigations are carried out on the unbalanced network. Optimal placement and sizing of DGs are performed using the three algorithms of ABC, GA and PSO with the aim of reducing losses and improving ENS reliability index. Due to lack of access to the switches failure information, it has been set stochastically by normal distribution function. In this paper, the 37-bus standard system has been investigated. It has been assumed that there is only the possibility of installing two DG units and two capacitor banks, and each of the sources can be injected into the network in the allowed range of active and reactive power. The results obtained from ABC algorithm have been compared to the GA and PSO. The obtained value of objective function is lower than that of the other two algorithms. Therefore, the amount of network losses is reduced to a greater extent, and the lower ENS index is achieved. Before installation of sources, losses are about 230 kW and the amount of unsupplied energy is obtained equal to 0.786, while after the installation of sources, these values have been reduced by less than half. In the case where optimization is carried out by ABC algorithm, the value of objective function is obtained equal to 0.559 in which the amount of losses is 76 kW and the ENS is 0.29.

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