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Simultaneous Optimal Placement and Sizing of Distributed Generations and Capacitor Banks in Unbalanced Distribution Networks for Reliability Improvement and Losses Reduction

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ABSTRACT: Determining location and capacity of distributed generation (DGs) and Capacitor banks (CBs) in the distribution network are two important and effective indices on power losses and improving network performance. This paper proposed artificial bee colony (ABC) algorithm for simultaneous optimal placement and sizing of DGs and CBs in the unbalanced distribution network. The proposed objective function is considered a combination of the two functions consisting of the power losses and energy not-supplied (ENS) reliability index, which is used in the algorithms in the form of an objective function by deploying the weight coefficients. for evaluation of the proposed method, this method was implemented on the IEEE 37-bus unbalanced distribution network and a real 33-bus network of Neyriz County distribution network, whose information was extracted from the GIS database. The simulation results of the proposed method were compared with the results obtained from GA and PSO algorithms to confirm the results. The simulation results show the more proper efficiency and performance and higher capability in reliability improvement and loss reduction of the proposed ABC algorithm when it is compared with other algorithms.

KEYWORDS: Distributed Generations, Capacitor Banks, Unbalanced Distribution Network, Reliability Improvement,Losses Reduction, ABC algorithm.

I.INTRODUCTION

Electricity distribution networks are the most widespread part of the power system. These networks are the interface between the consumer and the transmission and generation system and are particularly sensitive given their proximity to the consumer so that the occurrence of any disruption in this network can lead to interruption in the subscriber's service. Load imbalance is one of the most important and common problems in distribution networks that come from the lack of proper distribution of loads and subscribers between the phases and had significant consequences like an increase in electrical energy losses, network capacity occupancy, neutral voltage, unbalanced in the three phases voltages of the network and an increase in transformer losses [1-2].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. Therefore, providing appropriate solutions to reduce losses in the unbalanced distribution system is very important

The increasing load demand has led to the further development of distribution networks. Furthermore, the operation of the distribution network is mostly done radially because of security and control problems. These factors increase voltage drop, loss, load imbalance, and reduce voltage stability. Expanding and increasing the complexity of the distribution network, along with reducing the efficiency of the centralized distribution network, has made power system operators use alternative solutions to improve the electricity industry. The studies show that approximately 10% to 13% of the total energy generated is lost at the distribution level [3-4].

Among the methods of improving the efficiency of the distribution system, network rearrangement, using distributed generations (DGs) and Capacitor Banks(CBs), and changing the feed location of the system can be cited [5-6]. Using small-scale generators that connect directly to the distribution network or local consumers prevents the establishment of new power plants and transmission and distribution lines. Additionally, reducing losses, improving voltage profiles, increasing line capacity, increasing reliability and system stability are among the systemic advantages of installing DGs in distribution networks [7].

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Given the simultaneous operation of active and reactive power by consumers, the tendency to reduce costs and the need to increase and improve the power quality has caused most industrialized and developed countries in the world to expand reactive power compensators like capacitor banks. Capacitors should be next to other energy resources. distributed generation resources like doubly Fed wind turbines and solar panels can generate active and reactive power. However, the widespread use of these resources always faces a challenge due to the limited installable capacity of distributed generators, the high cost of the power electronic devices compared to the capacitor, and the uncertainty in the wind and sun. These factors have made it important for CBs to provide part of reactive power [8].
Proper use and all the advantages of DGs and CBs depend on determining the appropriate location and capacity of these devices. Otherwise, not only the above-mentioned benefits will not be met, but also the voltage at buses may be reduced, and total loss and transmission line congestion may be increased. The studies show that various methods presented in these categories can be divided into three general categories of analytical, numerical, and evolutionary methods given the type of method used to optimize the objective function [9].

Overall, analytical methods are simple to implement and have high convergence speed, but they cannot be used to examine the overall behavior of the system because of using simplification in problem assumptions. For instance, [10] has used the sensitivity analysis method to place the capacitor and distributed generation simultaneously for reducing losses considering the equal and unequal constraints in the distribution network.

Numerical methods can usually reach the best solution. However, generally, they do not perform well in optimizing large networks. [11] has used an integer nonlinear programming method to locate and determine the optimal value of the capacitor. Nonetheless, voltage stability, which is essential in controlling reactive power, has not been examined.
With the emergence of evolutionary methods in optimization problems and the ability to overcome the problems of these two methods, these methods have been widely welcomed. The algorithms used in evolutionary methods are such that the variables of the objective function are directed to the optimal points through a continuous process of repetition. In [12], a new metaheuristic method called stud krill herd has been used to locate and determine the capacity of DGs. Its purpose is to reduce line losses by considering different constraints like voltage range, real power output range DG, power balance range, and DG location range. The proposed method has been implemented on 33 and 69-bus networks. Simultaneous location of capacitors and DGs in the radial distribution network with different load levels in [13] has been done with the aim of reducing active and reactive power losses and improving voltage profiles. The Memetic or hybrid algorithm is used to find optimal solutions. This algorithm is a combination of local search and GA algorithm [14]. The optimal placement of capacitors and DGs is used to control the distribution of active and reactive power distribution networks. This paper uses three optimization algorithms, an improved GA, an improved PSO algorithm, and a cat-swarm optimization algorithm to find the optimal location of capacitors and DGs in variable load scenarios. In [15], optimization studies have been conducted simultaneously with three objectives: minimizing power losses, improving voltage profiles, and reducing line loads by restructuring the network and replacing capacitors and DGs simultaneously. A new and fast multi-objective method that can be applied to a real network has been used. Non-dominated sorting genetic algorithm II (NSGA-II) and fuzzy decision-making analysis have been used to obtain the best network structure by simultaneously connecting capacitors and DGs. In [16], a method based on an analytical approach to determine the location and size of DGs and capacitors with the aim of reducing losses is proposed by considering the equal and unequal constraints in the distribution network. The sensitivity analysis method is used to identify DG candidate sites and locating capacitors. Optimal placement and determination of DGs in the unbalanced distribution network, considering the load model and uncertainty of wind turbine and photovoltaic cells production capacity with the aim of improving voltage profile and reducing power losses and voltage imbalance coefficient of buses using algorithm the optimized PSO is performed in [17]. In [18], the water cycle algorithm is proposed to determine the optimal location and size of DGs and CBs. Simulations have been performed on three distribution systems, IEEE 33-bus, IEEE 69-bus, and the Delta East network as part of Egypt's distribution network to achieve technical, economic, and environmental benefits. [19] and [20] used binary genetic algorithm and PSO, respectively, to determine the optimal size and location of DGs to improve reliability and reduce power losses. The objective function is the reliability cost, the power loss cost, as well as the investment cost of the DG and capacitor, and the proposed method, is implemented on 10 and 33-bus test networks. Optimal placement and sizing of DGs and capacitors to improve the voltage profile and reduce losses using the loss-sensitivity factor method is stated in [21]. In [22] the hybrid Phasor PSO optimization and Gravitational Search Algorithm (PPSOGSA), is proposed to solve the problem of optimal placement and sizing of inverter-based DGs and CBs in radial distribution networks with linear and non-linear loads. The objective of the problem is the reduction of active power losses considering constraints of the fundamental frequency active and reactive power balance, RMS voltage, and total harmonic distortion of voltage (THDV) at each bus of the network, as well as the branch flow constraints. The performance of the PPSOGSA-based approach is evaluated on the standard IEEE 33- and 69-bus test networks.

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While most studies have been done on the optimal placement and sizing of DG and CB in balanced distribution networks, very little research has been done on DG and CB placement and sizing in unbalanced distribution networks. Moreover, generally, distribution networks have received considerably less attention devoted to reliability modeling and evaluation than 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 [23]. Consequently, great emphasis has been placed on ensuring the adequacy and meeting the needs of this part of a power system. A distribution network, however, is relatively cheap and outages have a big localized effect. Hence less effort has been allocated to the 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 1 which relate to a particular distribution utility in the UK [23]. The statistics such as the mentioned ones in Table.1 reinforce the needed concern with the reliability evaluation of the distribution networks.

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

In this paper, the optimal size and placement of DG units and capacitor banks for reliability improvement and loss reduction are determined using the ABC algorithm. For the optimization problem, an objective function including line losses and energy not supplied (ENS) index is considered. The main innovations and paper's contributions are listed in the following:

- Applying a novel population-based meta-heuristic algorithm called the Artificial Bee Colony (ABC) optimization to solve the problem of optimal placement and sizing of DG units and CBs in unbalanced distribution networks and results comparison of this method with the results obtained from GA and PSO algorithm.
- Appling a real radial unbalanced distribution network.
- Two technical objectives are satisfied that is: power loss reduction and ENS reliability index improvement.
- Calculation of the customer-based reliability indices (additional relationships related to other security criteria)for the performance evaluation of each algorithm from the perspective of network reliability.
- Increasing the awareness of the importance of combined penetration of DGs and CBs for enhancing the operation of electrical networks.

The rest of this paper is organized as follows:
In section 2, the modeling of the studied problem is presented. In this section, objective function and constraints are defined. In section 3, the ABC optimization algorithm is described briefly. The Simulation results of the optimal placement and sizing of DGs and CBson the IEEE 37-bus unbalanced network and 33-bus Neyriz distribution network are presented and discussed in section 5. Finally, section 6, summarizes the main points and the results of this paper.

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II. FORMULATION OF THE PROBLEM

Objective functions:

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The objective function used in this paper for optimal placement and sizing of distributed Generations and Capacitor Banks includes line losses and energy not supplied (ENS) index. Power losses are important in designing and planning distribution systems and are calculated by load flow In order to submit the importance of a system outage, the ENS index 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 k using equation (3). The goal is to minimize this function.

$$\min f = \alpha \times P_{loss} + \beta \times ENS \qquad (1)$$

$$P_{loss} = \sum_{i=1}^{N_{branch}} R_i I_i^2 \qquad (2)$$

$$ENS = \sum_{k=1}^{N_{Load}} L_{avg(k)} U_k \qquad (3)$$

WhereP_{loss} is the active power loss and ENS is the expected energy not supplied index in terms of megawatt hours per year. In the proposed objective function, the weight coefficients $\alpha = 3.5$ and $\beta = 0.01$ were used to equiponderate the two objectives. Moreover, in (2),R_i and I_i are the resistance and current value of the i-th branch. In (3), $L_{avg(k)}$ is the amount of average load connected to the bus k (load point k) and U_k is the average of the hours that loads have not been supplied at the bus k or is the annual outage time for node i. It has to be noted that because of the lack of access to switch failures percentage information in two studied networks, the failure rate has been considered stochastically by the normal function with an average of 0.05.

Operational Constraints

DGs and CBs 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 some constraints which are listed below:

Load flow constraints: The following two equations as load flow constraints must be satisfied at all buses (except slack bus) as Load flow constraints. There must always be a balance between the generation and consumption of power [24].

$$P_{gi} - P_{di} - \sum_{j=1, j\neq Slack}^{N} |V_i||V_j||y_{ij}| \cos(\delta_i - \delta_j - \theta_{ij}) = 0 \quad (4)$$

$$Q_{gi} - Q_{di} - \sum_{j=1, j\neq Slack}^{N} |V_i||V_j||y_{ij}| \sin(\delta_i - \delta_j - \theta_{ij}) = 0 \quad (5)$$

WhereP_{gi} and Q_{gi} are the active and reactive power supplied by the substation at the i-th bus respectively, P_{di}andQ_{di} are the reactive consumed active and reactive power at the i-th bus respectively. V_i and δ_i the voltage magnitude and angle at i-th bus, V_j and δ_j voltage magnitude and angle at the j-th bus, and y_{ij} and θ_{ij} are the magnitude and angle of the branch admittance between the basses i and j.

Bus voltage and maximum line current constraints: The viewpoint of the system stability, power quality, etc., voltage magnitude at each bus must be maintained within its limits. The current that flows through each branch must not exceed the thermal limit of the line for safe operation. These constraints are expressed as follows:

$$V_i^{min} \leq |V_i| \leq V_i^{max} \qquad (6)$$

$$|I_i| \leq I_i^{max} \qquad (7)$$

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Where $|V_i|$ voltage magnitude of bus i, V_i^{min} and V_i^{max} are the lower and upper limit of bus voltages, respectively. $|I_i|$ stands for current magnitude and I_i^{max} is the maximum allowable current for branch i.

DG active and CB reactive power capacity constraints: Active and reactive power generated by DG and CB should be in the allowed range. These constraints may also be caused by DG technical or economical limits.

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

$$Q_{CBi}^{min} \leq Q_{CBi} \leq Q_{CBi}^{max} \qquad (9)$$

Where P_{DGi} and Q_{CBi} are the active and reactive power generated by DG and CB installed at bus i respectively**.** P_{DGi}^{min} and P_{DGi}^{max} are the minimum and maximum permissible values of each DG capacity respectively. Q_{CBi}^{min} and Q_{CBi}^{max} are the minimum and maximum permissible values of the capacity of each CB respectively.

DG penetration coefficient: All capacity of DG units in the network is a factor of the total load in the network, called the penetration factor. This value should not exceed the permissible penetration coefficient for distributed generation units.

$$\rho_t \leq \rho_t^{std} \qquad (10)$$

Whereρ_t^{std} is the allowable penetration coefficient for the installation of distributed generation units.

DG and CB number constraint: The limitation in the number of DGs and CBs should be deployed in the objective function.

$$N_{DG}, N_{CB} \leq N^{max} \qquad (11)$$

The most widely used reliability indices are averages that weigh each customer equally. Customer-based indices are popular with electric companies since a small residential customer has just as much importance as a large industrial customer. Regardless of the limitations they have, these are generally considered acceptable techniques showing adequate measures of reliability. Indeed, they are often used as reliability benchmarks and improvement targets[25]. After optimal Placement and sizing of DGs and CBs, it is necessary to recalculate the value of reliability indices. For this aim, System Average Interruption Frequency Index (SAIFI), Customer Average Interruption Duration Index (SAIDI), Average Service Availability Index (ASAI), Average Service Unavailability Index (ASUI), Average Energy Not Supplied (AENS), System Customer Outage Costs (SCOC) are calculated. These indices can be expressed as in the following equations:

$$SAIFI = \frac{\sum_{i=1}^{n} \lambda_i N_i}{\sum_{i=1}^{n} N_i} \qquad (12)$$

$$SAIDI = \frac{\sum_{i=1}^{n} U_i N_i}{\sum_{i=1}^{n} N_i} \qquad (13)$$

$$ASAI = \frac{\sum_{i=1}^{n} N_i \times 8760 - \sum_{i=1}^{n} U_i N_i}{\sum_{i=1}^{n} N_i \times 8760} = 1 - \left(\frac{SAIDI}{8760}\right) \quad (14)$$

$$ASUI = \frac{\sum_{i=1}^{n} U_i N_i}{\sum_{i=1}^{n} N_i \times 8760} = \left(\frac{SAIDI}{8760}\right) \qquad (15)$$

$$AENS = \frac{\sum_{i=1}^{n} L_{avg}(i) U_i}{\sum_{i=1}^{n} N_i} \qquad (16)$$

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$$SCOC = (ECOST)\sum_{i=1}^{n} L_{avg}(i)U_i = (ECOST)(ENS) \quad (17)$$

Whereλi is the failure rate of node i and Ni is the number of customers connected to the node i. n is the Number of all nodes in the network.
It has to be noted that because of the lack of access to accurate information of the determinants, the values of the parameters for calculating the reliability limit are considered randomly and with normal distribution.

III. ARTIFICIAL BEE COLONY ALGORITHM (ABC) OPTIMIZATION

The ABC algorithm is an optimization algorithm based on the collective intelligence and intelligent behavior of the bee population that was first developed by Karabogaas in 2005 [23]. This algorithm is founded on the foraging nature of the swarm of honey bees. A colony of artificial bees can spread itself over long distances and in 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. The Bees use a sophisticated communication system, and the communication between bees is done through a special dance; Known as the "waggle dance". this dance transmits information about the direction of the food source (relative to the hive), distance, and quality to other bees. This system enables them to obtain the necessary information about the food outside the hive. In this method, each solution indicates a potential food area and the quality of the solution is equivalent to the quality of the food source. According to this method, there are three groups of bees: employed bees, onlooker bees, and scout bees.

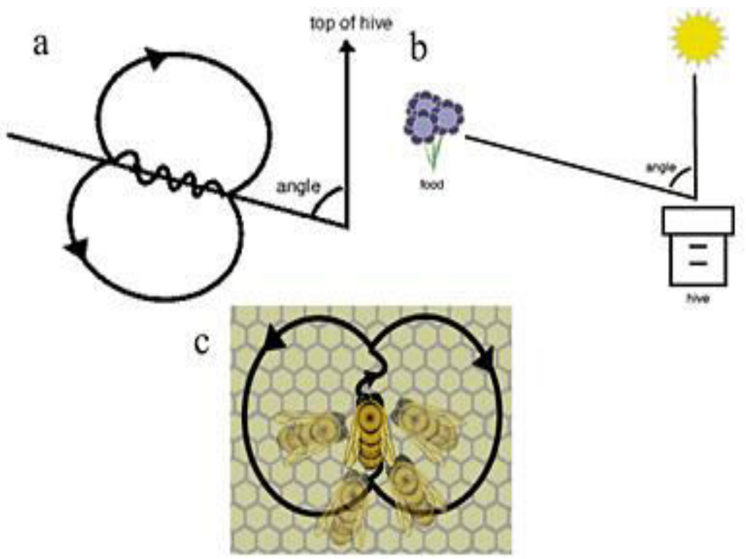

Figure 1. Waggle dance of bees

The basic steps of the ABC algorithm are as follows:
Initialization: At the initialization stage, the populace of X_{ij} is initialized in the range of parameter j, where X_{ij} is the solution. The purpose is served by the following equation:

$$X_{ij} = X_{minj} + rand\left(X_{maxj} - X_{minj}\right) \quad (18)$$

Where X_{minj} and X_{maxj} are the minimum and maximum limits of parameter j.
Employed bee phase: Each employed bee determines a source of food V_{ij}, inside the food source neighborhood in her memory X_{ij} using (19)

$$V_{ij} = X_{ij} + \emptyset_{ij}\left(X_{ij} - X_{kj}\right) \quad (19)$$

Where, $\emptyset_{ij}$ is a random number in the range of [-1, 1], solution X_k is selected randomly, $and\, j$ is a parameter also chosen randomly.After V_i, a new solution is produced, and a greedy selection process is applied between X_i and V_i.

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The information gained by employed bees is shared with bees waiting in the hives using probability values P_i as calculated using (20) [24].

$$P_i = \frac{fit_i}{\sum_{i=1}^{SN} fit_i} \qquad (20)$$

Where SN is the number of food sources and $fit_i$is the value of the fitness of solution x_i or the value of fitness of the food source searched by the employed bees calculated using the following equation:

$$fit_i = \begin{cases} \frac{1}{1+f(x_i)} & f(x_i) \geq 0 \\ 1+|f(x_i)| & f(x_i) < 0 \end{cases} \qquad (21)$$

where $f(x_i)$ is the cost value of the objective function.

Onlooker bee phase: The amounts of the nectar of a source of food represent the solution fitness of the position of the food source. A selection technique based on the solution fitness is used to place the onlooker bees onto the site of food source. For the onlookers (20) is used to find the new solutions V_i from X_i. They are selected based on the value of pi and the solutions thus obtained are assessed. Like the case of employed bees, a greedy selection process is applied between X_i and V_i

Scout bee phase: The food source discarded employed bees become scout bees and they start randomly to search for a fresh food source. Scout bees are the colony's explorers. They look for food without any guidance. The "abandonment criteria" or "limit" is the control parameter responsible for artificial scout classification. If a solution for a source of food, does not improve within pre-specified trials, then the corresponding employed bees discard the result and become a scout. The value of the limit is thus the amount of trials performed to release a solution.
The exploitation process is performed in search space by the onlooker and employed bees. The scout bees control the process of exploration. The control parameters of the ABC algorithm are the number of sources of food which is the same as the number of onlooker bees or employed bees, the limit value, and the maximum cycle number (MCN).
The procedure for solving the minimization problem using the ABC algorithm to optimally locate and size the DGs and CBs are as follows:

Step 1: Setting the artificial bee algorithm parameters including the number of bees, iterations, and selected site.

Step 2: Random initialization of bees. Each bee indicates a different location and size for two and DGs and CBs.

Step 3: Performing unbalanced three-phase load flow and calculating the base power losses.

Step 4: Calculating the ENS reliability index for the studied network.

Step 5: Calculating the objective function using the values obtained in steps 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.

The Flowchart of the ABC algorithm for optimal placement and sizing of DGs and CBs is illustrated in Figure 2.

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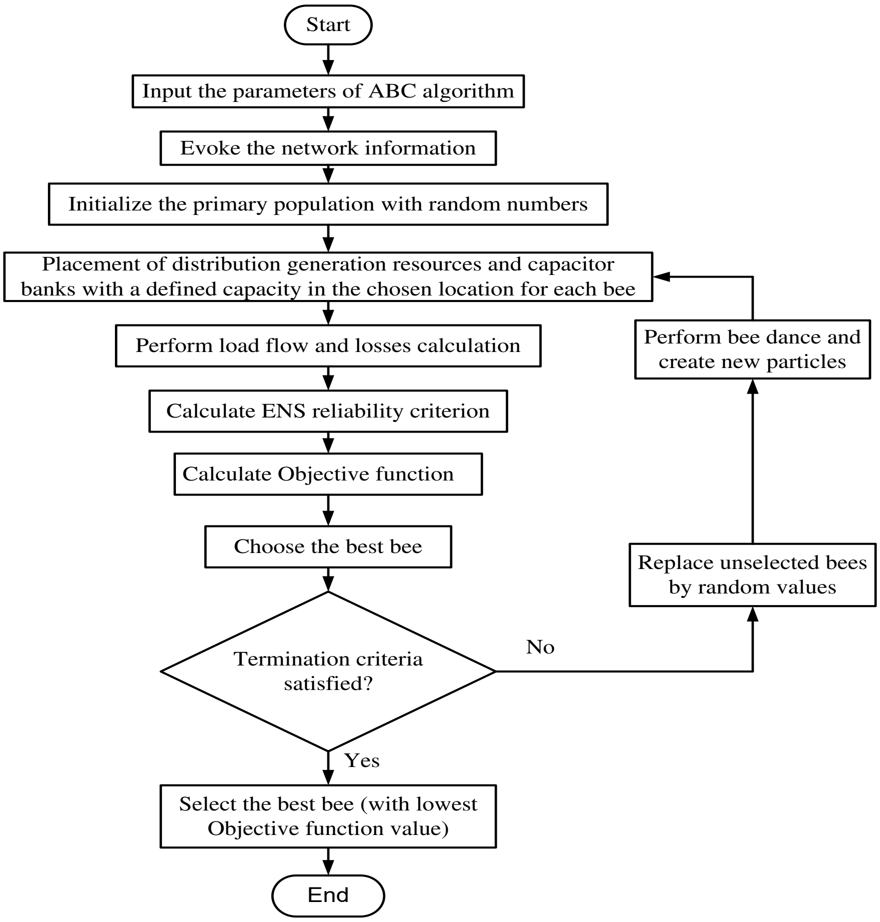

Figure2. Flowchart of ABC algorithm for optimal placement and sizing of DGs and CBs

IV. SIMULATION AND NUMERAL RESULTS

37-bus unbalanced network

In most previous studies in the optimal placement and sizing of DGs and CBs, distribution networks have been considered balanced and studies were limited to the balanced networks, whereas in distribution networks due to the stochastic and non-simultaneous behavior of consumers, the loads are not distributed uniformly on phases, and the distribution networks are inherently unbalanced. Thus, it is better to employ unbalanced distribution networks to conduct studies, so that the results of studies are closer to reality. As most distribution networks are unbalanced, it is appropriate to use an unbalanced load model in studies to examine more accurately and analyze the performance of such networks to obtain more accurate and appropriate results. In this section, the studies of placement and sizing of DGs and CBs have been applied to the IEEE 37-bus unbalanced network shown in Figure 3 [25]. The network is unbalanced due to phases unequal loads and mutual impedances between line phases. The network nominal voltage is 4.8 KV and the bus with index 799 is the slack bus. The line between buses 2 and 3 is the longest line of this network with a distance of 1320 meters and the shortest line between buses 8 and 9 is with a distance of 80 meters. In the simulations, it is assumed that it is only possible to install two distributed generation units with the ability to produce only active capacity with limited capacity and two fixed capacitor banks in the network.

ABC algorithm has been used for optimal placement and sizing of DGs and CBs in the studied network, and finally, the results of this algorithm have been compared to two GA and PSO algorithms to confirm the results of the simulation. The parameters of GA, PSO and ABC algorithms are given in Table 2.

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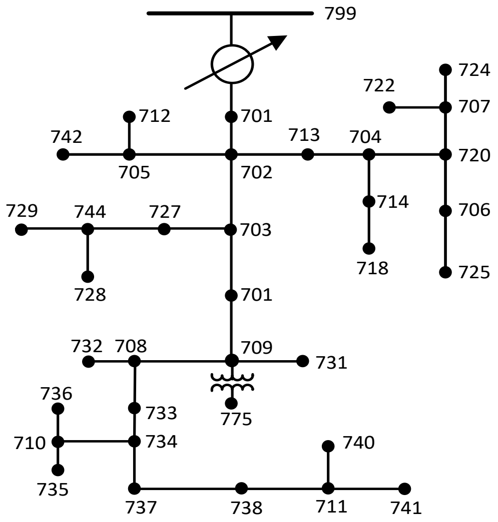

Figure 3. The IEEE 37-bus unbalanced network

Table 2. The algorithms parameters

ABC	**Population**	**Iteration**	**nSelected Site**	**nEliteSite**	**nSelected SiteBee**	**nEliteSite Bee**
	50	30	30	15	30	10
	Population	Iteration	$C_1=C_2$	w	V_{min}	V_{max}
PSO	50	30	2	0.7	0.4	0.9
	Population	Iteration	P_c	P_m		
GA	50	30	0.2	0.8		

The curve of objective function changes for three algorithms in different iterations is shown in Figure 4. According to Figure 4, the ABC algorithm converged after 18 iterations, and GA and PSO algorithms converged to their final values after 20 and 26 iterations, respectively. ABC algorithm performs better than the other two algorithms so that the final value of the objective function for the ABC algorithm is about 0.559, which was obtained after 18 iterations whereas this value is 0.671 and 0.6015 for GA and PSO algorithms respectively.

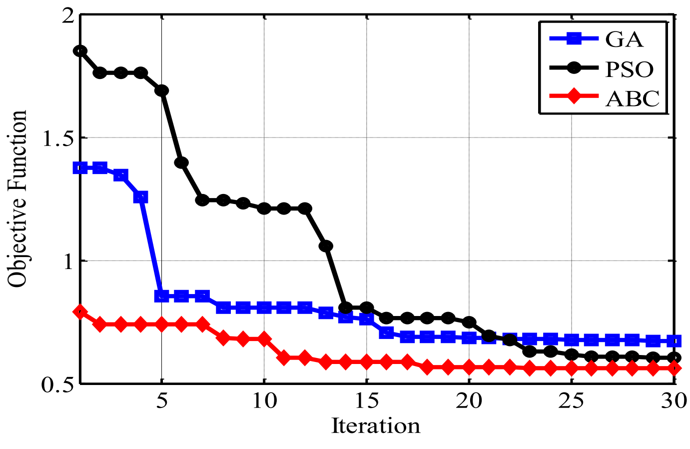

Figure 4. The value of the objective function for 37-bus unbalanced network

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After optimizing and determining the location and capacity of the resources by the three algorithms PSO, ABC and GA, the results obtained in Table 3 were collected. In this table, the value of the objective function, total losses, and ENS for each section are given for a more detailed study of the performance of each algorithm.

Table 3. Optimization results in the 37-bus unbalanced network

Algorithm	DG I		DG II		Capacitor I		Capacitor II		Losses (Mw)	ENS	Objective Function Value
	Bus No.	Capacity (KW)	Bus No.	Capacity (KW)	Bus No.	Capacity (Kvar)	Bus No.	Capacity (Kvar)			
Base	-	-	-	-	-	-	-	-	0.230	78.6	1.592
GA	727	860	732	230	706	340	707	170	0.094	34.2	0.671
PSO	727	680	718	350	728	380	727	279	0.083	31.1	0.6015
ABC	718	740	744	450	728	430	706	245	0.076	29.3	0.559

According to the results obtained in Table 3, after optimization by the ABC algorithm, busses 18 and 10 have been selected for installation of DGs, the capacity of each of which is 740 and 450 kW, respectively. Moreover, CBs with capacities of 430 and 245 kW have been proposed for installation in buses 19 and 12, respectively. The final value of the objective function for the ABC algorithm is 0.558, whereas this value for the PSO algorithm is 0.6015 and 0.671 for GA. The ENS value for the system without compensation is 78.6, and the lowest ENS value is for the ABC algorithm. According to the results, one can claim that after the installation of CBs and distributed generations, ENS value has greatly reduced.
Table 4 shows the values of the customer-based reliability criteria so that the performance of each algorithm can be evaluated from the perspective of network reliability.
According to the results obtained in Table 4, one can deduce that the presence of DGs and CBs has improved the customer-based reliability indices of the network and the cost of the expected energy not supplied has reduced.

Table 4. The values of the reliability indices for 37-bus unbalanced network

	SAIFI	SAIDI	ASAI	ASUI	AENS	SCOC
Base	0.73	5.7	0.99936	0.00064	0.786	5895000
GA	0.58	4.5	0.9995	0.0005	0.342	2565000
PSO	0.53	4.3	0.99952	0.00047	0.312	2332500
ABC	0.47	3.8	0.99958	0.00043	0.294	2197600

The losses of each line in the various phases before the DGs and CBs installation is shown in Figure 5. As shown in Figure 5, the line losses in various phases are different. The reason for this is the imbalance of load in different feeders. If DGs and CBs are not used, the total value of line losses is 230 kW.
The losses of all the lines of the IEEE 37-bus unbalanced network, if the active and reactive power sources are installed, are shown in Figures 6, 7 and 8 for GA, PSO and ABC algorithms, respectively. As Figures 6 to 8 show, the losses of most lines are reduced after installing DGs and capacitors. The total loss of the system is 76 kW if the ABC algorithm is used. However, the losses in the case of using PSO and GA algorithms are 83 and 94 kW, respectively.

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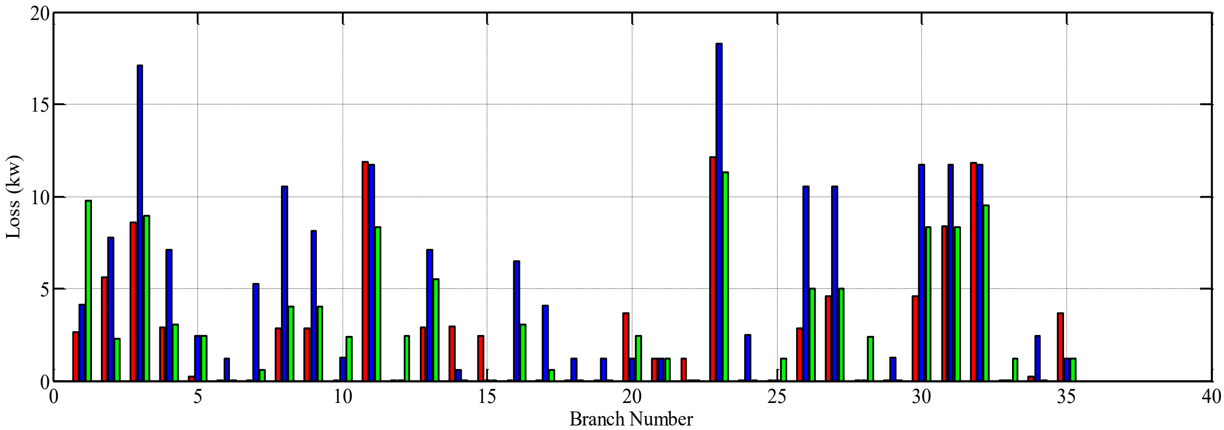

Figure 5. Line losses in the 37-bus unbalanced network before DGs and CBs installation

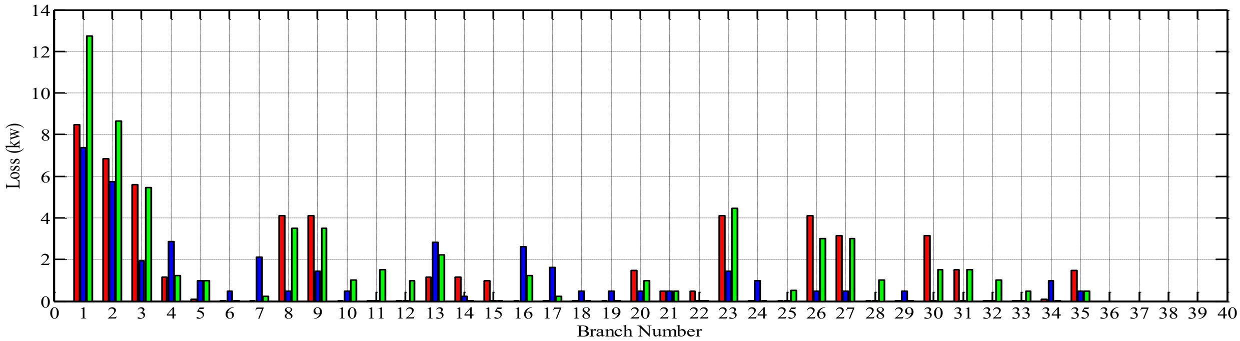

Figure 6. Line losses in the 37-bus unbalanced network:GA algorithm

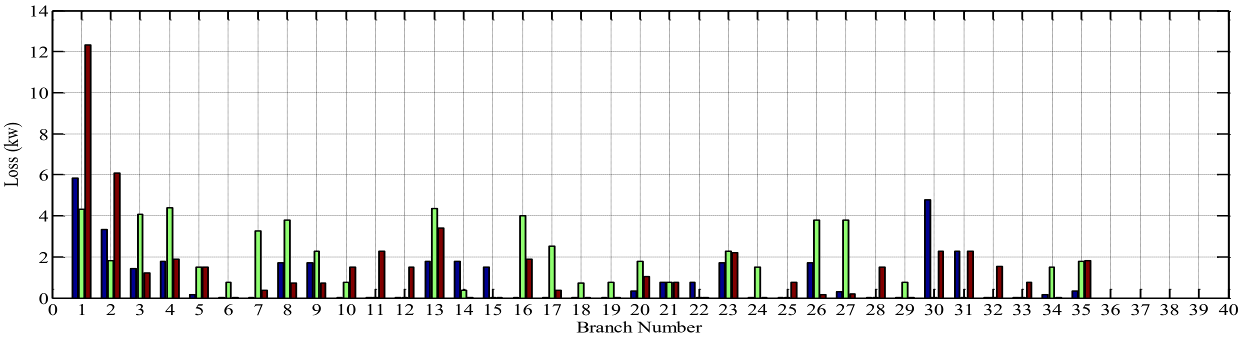

Figure 7. Line losses in the 37-bus unbalanced network:PSO algorithm

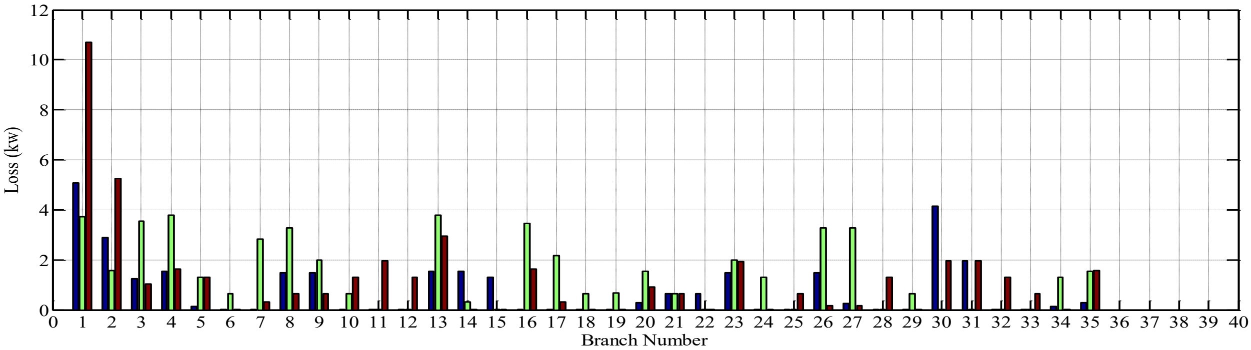

Figure 8. Line losses in the 37-bus unbalanced network: ABC algorithm

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Neyriz's unbalanced distribution network

In this section, the studies of placement and sizing of DGs and CBs have been applied on a 33–bus and 20 kV feeder from Neyriz distribution network by considering the unbalanced loads. The components of this feeder and its related information are as following:

This feeder is connected to the transformer T1 and has a capacity of 20MVA and a maximum allowable current of 300 amps to feed urban and rural residential areas. The feeder current constraint is due to the conductor limitation used in the line, and thus the overcurrent protection relay of this line is set to 300 amps. distribution transformers are installed on each of these buses as a load. Currently, the above feeder is loaded at 60% of its capacity, and according to load prediction studies, the feeder load will reach its nominal value in the near future. The Single-linediagram of the network is shown in Figure 9.

For eachphase ofthe distribution transformers on the feeder, the operator has performed studies during peak load times. It has to be noted that the information collected at the time of load peak was a feeder. The results of the measurements show that the loads have been installed unbalanced on the feeder.

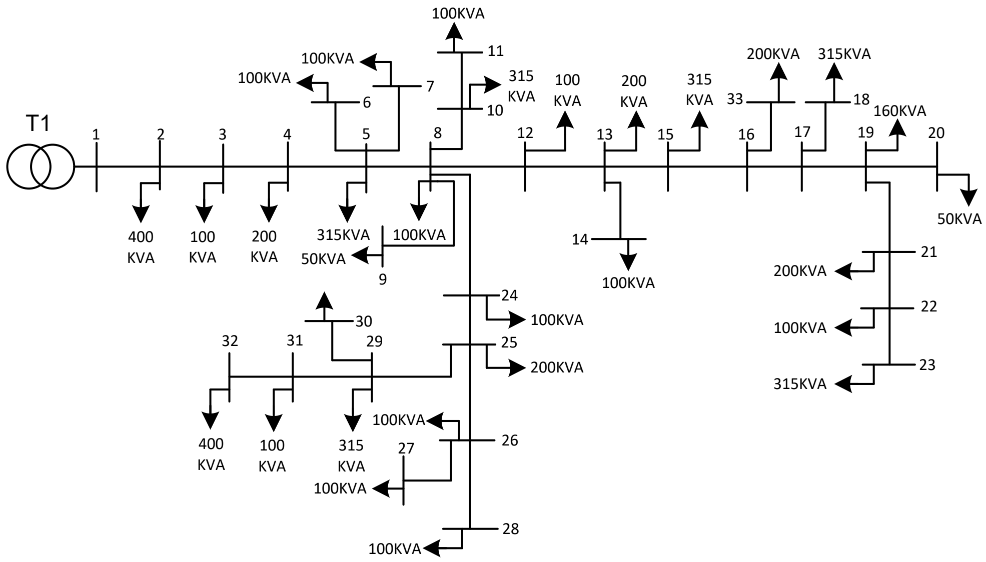

Figure 9. Single-line diagram of the Neyriz unbalanced distribution network

ABC algorithm has been used for optimal placement and sizing of DGs and CBs in the studied network, and finally, the results of this algorithm have been compared to two GA and PSO algorithms to confirm the results of the simulation. The parameters of ABC, GA and PSO algorithms are given in Table 1. After optimization, the convergence of the objective function in successive iterations for these three algorithms is obtained, which is shown in Figure 10.

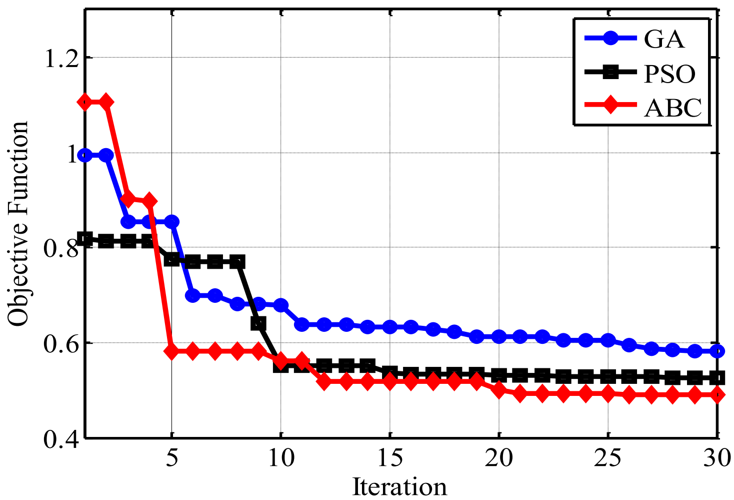

Figure 10. The value of the objective function for the Neyriz unbalanced network

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The value of the objective function for ABC, PSO and GA algorithms is calculated as 0.489, 0.526 and 0.582,respectively. Moreover, ENS values for these three algorithms were 22.3, 23.6 and 25.3, respectively. Table 5 summarizes the results of optimization by algorithms.

If the ABC algorithm is used, bus 17 with an active power capacity of 245 kW and bus 26 with a capacity of 175 kW are recommended for installation of DGs, and buses 28 and 14 are recommended for installation of CBs with capacities of 115 and 130 kVar.The values of the customer-based reliability indices for the unbalanced network are given in Table 6.

According to the results in Table 6, one can see the effect of DGs and CBs on improving reliability indices. This will not only increase customer satisfaction but also reduce the cost of the losses of energy not supplied.

Table 5. The results of optimization in the Neyriz unbalanced network

Algorithm	**DG I**		**DG II**		**Capacitor I**		**Capacitor II**		**Losses (MW)**	**ENS**	**Objective Function Value**
	Bus No.	Capacity (KW)	Bus No.	Capacity (KW)	Bus No.	Capacity (KVAr)	Bus No.	Capacity (KVAr)			
Base	-	-	-	-	-	-	-	-	0.125	67.5	1.1125
GA	15	230	25	180	14	125	17	95	0.094	25.3	0.582
PSO	17	230	24	180	18	105	17	120	0.083	23.6	0.5265
ABC	17	245	26	175	28	115	14	130	0.076	22.3	0.489

Table 6. The values of reliability indices in the Neyriz unbalanced network

Algorithm	**SAIFI**	**SAIDI**	**ASAI**	**ASUI**	**AENS**	**SCOC**
Base	0.83	4.9	0.99944	0.00056	0.675	5062500
GA	0.49	4.1	0.99954	0.00046	0.253	1894500
PSO	0.47	3.8	0.99957	0.00043	0.237	1780000
ABC	0.42	3.3	0.99961	0.00038	0.224	1673500

The Line losses in unbalanced load conditions are calculated as 125 kW. Figure 11, shows the losses of each line. As shown in Figure 11, the line losses in various phases are different. The reason for this is the imbalance of load in different feeders. Figs. 12, 14, and 14 show the line losses for the feeder separately if GA, PSO, and ABC algorithms are used.

As Figures 12 to 14 show, the losses of most lines are reduced after installing DGs and CBs. The total loss of the network is 76 Kw if the ABC algorithm is used. However, the losses in the case of using PSO and GA algorithms are 83 and 94 KW, respectively.

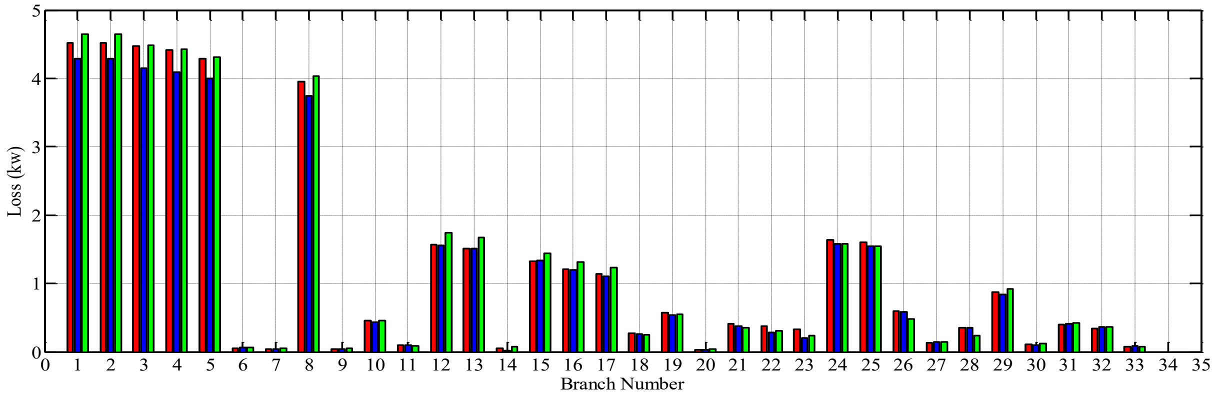

Figure 11. Line losses in the Neyriz unbalanced network before DGs and CBs installation

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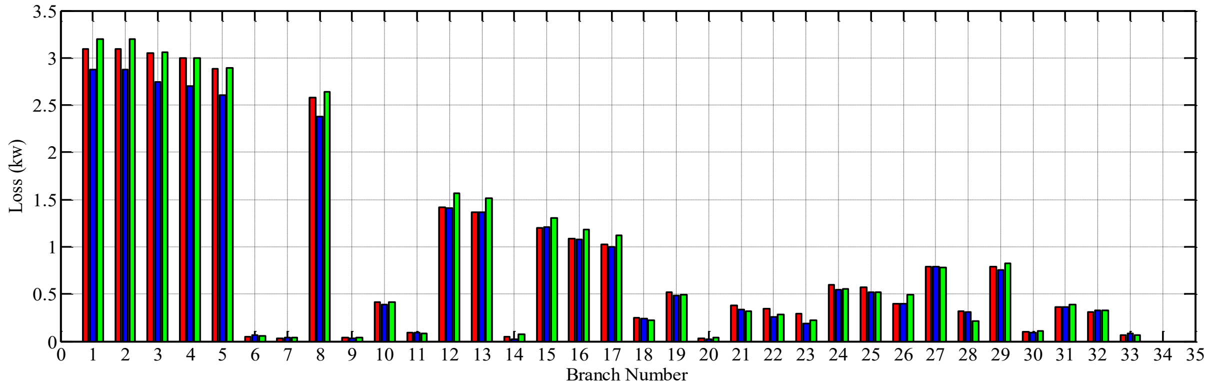

Figure 12. Line losses in the Neyriz unbalanced network: GA algorithm

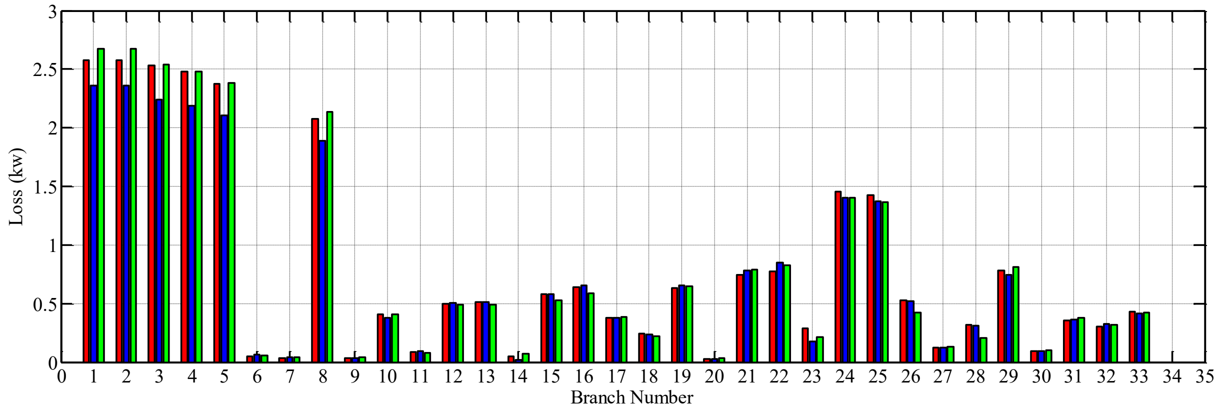

Figure 13. Line losses in the Neyriz unbalanced network: PSO algorithm

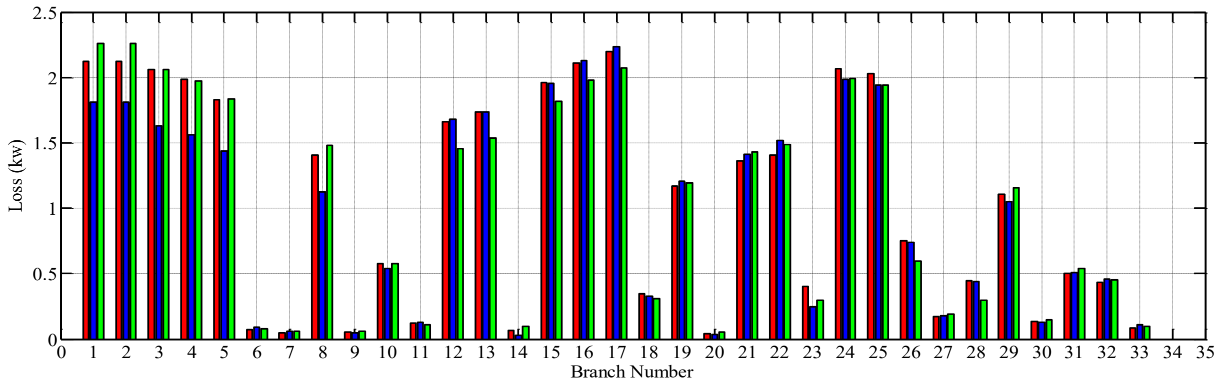

Figure 14. Line losses in the Neyriz unbalanced network: ABC algorithm

V. CONCLUSIONS

Applying DGs and CBs in combination leads to a significant reduction in power losses, increase in reliability and improved distribution network parameters. In this paper, the simultaneous selection of the most suitable location and size of DGs and CBs in the unbalanced distribution networks to reduce losses, and improve the reliability of the network using the ABC algorithm is proposed. The proposed algorithm is applied on the IEEE 37-bus unbalanced network and 33-bus Neyriz distribution network. The results obtained from the ABC algorithm have been compared to the original GA and PSO algorithms that are commonly used in the optimal sitting and sizing problem of DG units and shunt capacitors.The results indicate that compared to the GA and PSO algorithms, the proposed algorithm has yielded better convergence speed and performance and results. The obtained value of the objective function is lower than that of the other two algorithms, so the amount of network losses are reduced to a greater extent, and the lower ENS index has been achieved. Moreover, the values of customer-based reliability indices in the networks have been improved.

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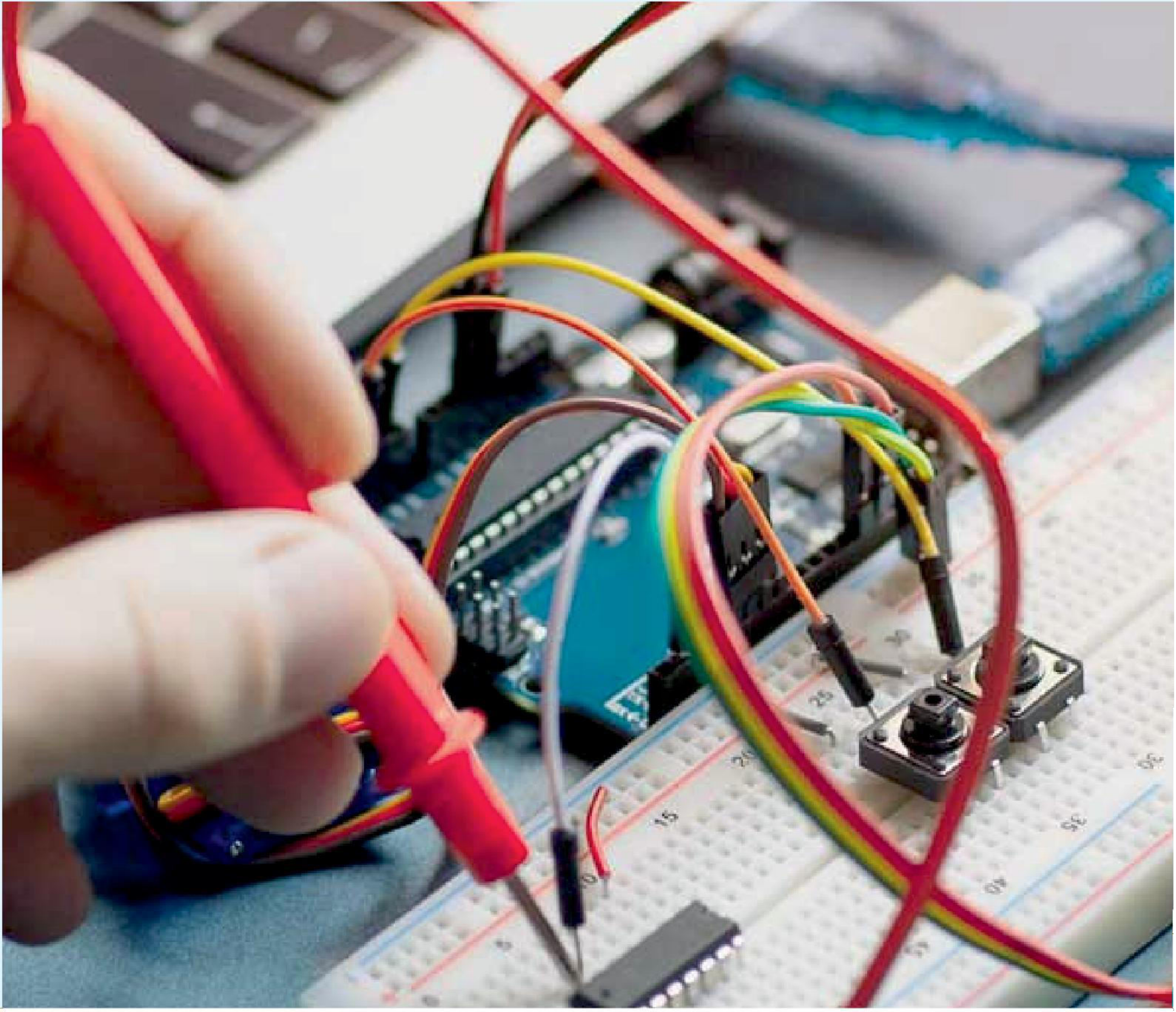

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