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Bacterial Foraging Optimization Technique for Optimal Reorganization of Radial Distribution Network with Inclusion of DG and DSTATCOM

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Abstract: Existing transmission infrastructure is unable to handle such a high load demand due to the exponentially expanding demand for electrical power. As a result, either there is a need to make investments to increase the transmission system's capacity or use distributed generation to locally meet consumer demand. Many experts are now focusing on the effect that the growing installation and integration of various small-scale power production technologies into the electrical grid may have on the performance of the grid. The voltage profile is improved and network losses are decreased when the placement and size are ideal. The objective is to choose bus stops where there will be little loss and acceptable potential. Methodology is currently very helpful to the system-planning engineer in dealing with the increase in Distributed Generation (DG) penetration because it can examine the influence on particular system features of DG allocation. In order to improve power quality and optimize DG allocation, a metaheuristic algorithm namely Bacterial Foraging Optimization Technique (BFOT) is developed in this study. A DSTATCOM is added to the system for reactive power compensation in order to increase performance. This aids in loss minimization and voltage quality enhancement. The proposed method is tested on a typical 14-bus & 33-bus radial distribution network (RDN). The simulation is run using Matlab code, and the suggested method's output is compared with Artificial Fish Swarm Optimization Technique (AFSOT) and Ant Colony Optimization Technique (ACOT) and validated against their outputs.

Keywords: DG, BFOT, DSTATCOM, RDN, AFSOT, ACOT

I. INTRODUCTION

Existing transmission infrastructure cannot handle such a high load demand due to the exponentially expanding demand for electrical power. As a result, there is a need to either make investments to increase the transmission system's capacity or use distributed generation to locally meet consumer demand. DG refers to the distribution of small-scale power plants around the grid to produce electrical power. Research on distributed generation has increased dramatically as a result of the development of numerous small-scale power production technologies. Contrary to typical large-scale production facilities, distributed sources have less of an environmental impact, require less capital investment, and have lower maintenance and operating expenses [1]-[2]. This is especially true if the sources are renewable. Reduced network loss and on-peak operating costs, greater system security and dependability, peak load savings, improved voltage stability are some of the benefits of installing DG units in the grid. Other advantages include the availability of modular generating plants, faster building times, the reduction of transmission and distribution congestion, and lower transmission costs as a result of the power plants presence close to hefty loads [3].

The power losses, voltage profile, and voltage stability of the distribution network are impacted by the ideal locations and sizes for distributed generation (DG) sources. The position of the DG units is the most important consideration in ensuring minimal loss, and inefficient DG unit distribution can lead to under or overvoltage in the system. It results in a poor voltage profile, potential increases in power loss, and ultimately a decline in network security [4]-[5]. It is recommended to include the compensation device in the distribution system to prevent such occurrences. The DG & DSTATCOM are employed as a distribution system compensation device in this paper.

The introduction of DG in the radial distribution system was caused by a number of variables. The need for more adaptable electric systems is suggested by environmental concerns like reducing the greenhouse effect, using fossil fuels less and less, and the current deregulation of the power market [6]. While many researchers examined the ideal location and sizing with many DGs, the researchers in [7] examined the optimal location and sizing of a single DG. It is simple to perform linear programming, which is first introduced in [8], but it is quite challenging to boil down models to a set of linear equations. The ideal size of the DG could not be determined by the analytical method used by the authors in [9] to establish its best location and size.

The best position and size were found by the authors in [10] using an analytical approach and an approximate loss calculation. In order to resolve the problem of allocating compensating devices, meta-heuristic techniques had been developed and were now frequently deployed. A fuzzy and PSO technique for DG installation in two stages was put forth in [11]. In the initial stage, a fuzzy technique is employed to choose the ideal place for the installation of DG. Utilizing PSO, the second stage of DG sizing

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results in the greatest loss reduction possible. In order to reduce power loss, the Bee Colony Algorithm was used in [12] to determine the position and size of the DG. [13] put forth an Ant Colony Optimization technique that only required two tuning variables.

In order to cut power losses while enhancing the voltage profile, GA was used in [14] for simultaneous renewable-based DG allocation and reconfiguration in distribution networks. The ideal location for DGs was determined using sensitivity analysis in [15] and the best DG settings and reconfiguration to reduce power losses were then determined using GA. The effective operation of power systems has made reactive power optimization a crucial topic. Reactive power flow must be dispatched to guarantee proper voltages and minimal active power losses. Traditional reactive optimization problems frequently overlook the system's voltage stability resulting in voltage instability at the critical point. Distributed generation can help improve voltage profile and lower feeder current in RDNs by contributing some real or reactive power. Studies on the power system indicate that the DG's poor positioning and small size will lead to greater losses [11]-[16].

The real & reactive power loss in the network and voltage profile for various optimal locations of DG & D-STATCOM and its dimensions determined by the three different optimization algorithms have been studied in this article. An extensive examination of an IEEE 14-bus & an IEEE 33-bus Radial Distribution System is conducted to show the value of the provided method. A variety of circumstances are taken into consideration, and the results are provided, in order to demonstrate the algorithms' usefulness. The remaining part of the article is arranged as below. Section 2 deals the elucidation of the proposed algorithms of this paper. Section 3 describes the system under consideration and its modelling equations. The simulation results are presented in the section 4 and the conclusion is proposed in the section 5.

II. OPTIMIZATION PROCEDURES UTILIZED

a. Ant Colony Optimization Technique (ACOT)

ANN and genetic algorithms have been more well liked recently. In order to determine its use in power system optimization, the study replicates ant foraging behavior and applies ant colony search methodologies to challenges connected to power systems. The collaborating agents (ants) of the algorithm cooperate to solve the optimization problem successfully. The foraging behavior of several ant species served as inspiration for ACO. To mark a clear trail for the rest of the colony to follow, these ants scatter pheromone over the ground. The majority of ants will eventually travel in tandem along a nearly optimal path.

ACO is a metaheuristic that uses a swarm of artificial ants to cooperatively tackle difficult discrete optimization issues. As an alternative, it is possible to distribute processing power across a number of relatively small organisms, such as fictitious ants that communicate with one another through stigmergy, an attribute of ACO algorithms. The agent's cooperative collaboration offers useful solutions as an emergent characteristic.

b. Artificial Fish Swarm Optimization Technique (AFSOT)

The AFSOT introduced by Li Xiaolei et al. in 2002 is a novel population-based evolutionary computation technique [10].The location with the most fish is frequently the one with the greatest nutrients since fish in a water area can often find locations with lots of nutrients on their own or by following other fish. The feature claims that in order to achieve optimization, AFSA creates fake fish to mimic the foraging, clustering, rear-end, and random behavior of a fish swarm [12–15].

c. Bacterial Foraging Optimization Technique (BFOT)

The new nature-inspired optimization method known as the "bacteria foraging algorithm" (BFOT) is based on how a swarm of Escherichia coli forages together. Chemotaxis, swarming, reproduction, and elimination-dispersal are the four fundamental processes that make up the optimization process. Both the theoretical derivations and the specifics of this process are addressed.

Natural selection eliminates animals with inadequate foraging techniques. As a result, this approach favors the genetic transmission of the animals' effective foraging methods. Better food-seeking species can experience successful reproduction, while others with poorer abilities are either destroyed or transformed. The E. coli bacterium that lives in our intestines is mimicked by the BFOT in its feeding habits. The effectiveness of this method as an optimization tool for power system issues has been effectively demonstrated. The four steps of the foraging process—chemotaxis, swarming, reproduction, and elimination are briefly discussed below.

(i) Chemotaxis: The chemotherapy taxis imitate E. coli's swimming and tumbling movements as depicted in figure 1. The bacteria will alternate between the two states throughout its lifetime. Equation (1) describes the E. coli bacteria movement over a nutrient search area.

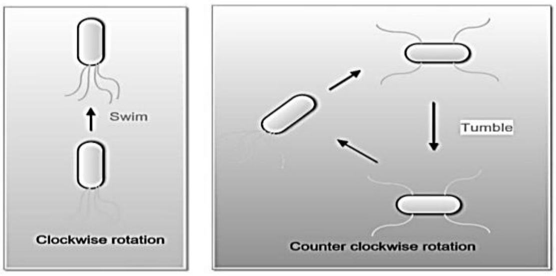

Figure 1 Chemotaxis Process of BFOT

$$\theta^{n}(i+1,j,k) = \theta(i,j,k) + C(n) \cdot \varphi(i) \qquad (1)$$

(ii) Swarming: The mechanism known as swarming is what causes germs to form concentric circles and move forward. With the aid of succinate, it will divide into little groups due to the nutritional effect. When under stress, bacteria generate attractants that tell other bacteria to gather in a swarm. However, it also emits a repellent to warn other people to keep a minimal distance from it. As a result, they are all attracted to one another via the attractant and repelled from one another via the repellent.

(iii) (iii) Reproduction: This is how bacteria replenish their population, according to the most basic idea of natural selection. Which the healthiest bacteria will reproduce in. They will take the place of any unhealthy or dead microorganisms. Therefore, the total population is unchanged. Placed in the same location as the original, the replications of the healthiest, the weaker, healthier germs will perish. Then, regardless of sex, the healthiest bacteria will eventually develop its generation with the same copy.

(iv) (iv) Elimination: The routine life survival of the bacteria will be impacted by the unfavorable environmental conditions or will finally move to the healthiest region of the eco system. This is a natural process whereby an abrupt shift in the environment causes the majority of the germs to be dispersed at random in all directions. The bacteria can now locate the global optimum in this new site. The flow diagram of the proposed BFOT algorithm is shown in the figure 2.

III. SYSTEM DESCRIPTION AND OBJECTIVE FUNCTION

Based on the use of solar, wind, micro/mini hydro turbines, gas turbines, and fuel cells, Type I, Type II, Type III, and Type IV systems are present and among these Type IV is applied for 14 and 33 bus systems. In contrast to the IEEE 33 bus test system, which has 33 buses and six generators, the IEEE 14 bus test system has 14 buses, two generators, and three synchronous compensators. Configuration optimization is carried out in 4 different ways on the selected radial distribution network: without DG integration, with DG integration, without compensation, and with compensation. The load flow modelling of the suggested system makes use of a single line diagram of a straightforward RDN. Basic RDN is shown in figure number 3 as a single line diagram.

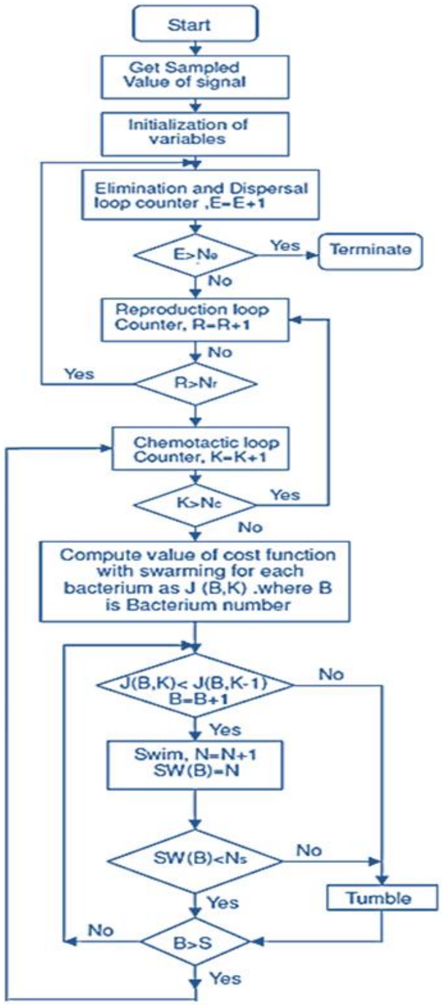

Figure 2 Flow Diagram of BFOT

The appropriate active power, reactive power, and voltages at the (k+1)th bus are calculated using equations (2), (3), and (4), correspondingly.

$$P_{k+1} = P_k - P_{L,k+1} - R_{k,k+1}\left(\frac{P_k^2 + j\,Q_k^2}{|V_k|^2}\right) \tag{2}$$

$$Q_{k+1} = Q_k - Q_{L,k+1} - X_{k,k+1}\left(\frac{P_k^2 + j\,Q_k^2}{|V_k|^2}\right) \tag{3}$$

$$V_{k+1}^2 = V_k^2 - 2\left(R_{k,k+1}\,P_k + X_{k,k+1}\,Q_k\right) + \left(R_{k,k+1}^2 + X_{k,k+1}^2\right)\left(\frac{P_k^2 + j\,Q_k^2}{|V_k|^2}\right) \tag{4}$$

Here,

P_k, P_{k+1} –real power of the buses k and (k+1) respectively.
Q_k, Q_{k+1} –reactive power of the buses k and (k+1) respectively.
$R_{k,k+1}$ –resistance of line between the buses k and (k+1).
$X_{k,k+1}$ –reactance of line between the buses k and (k+1).
V_k, V_{k+1} –voltages of the buses k and (k+1) respectively.
$P_{L,k+1}$ –real power demand of the bus (k+1).
$Q_{L,k+1}$ –reactive power demand of the bus (k+1).

Following the inclusion of a DG with real power P_1 and reactive power Q_1 at bus number (k+1), the aforementioned equations (2) & (3) are modified as follows.

$$P_{k+1} = P_k - P_{L,k+1} - R_{k,k+1}\left(\frac{P_k^2 + j\,Q_k^2}{|V_k|^2}\right) + P_1 \tag{5}$$

$$Q_{k+1} = Q_k - Q_{L,k+1} - X_{k,k+1}\left(\frac{P_k^2 + j\,Q_k^2}{|V_k|^2}\right) + Q_1 \tag{6}$$

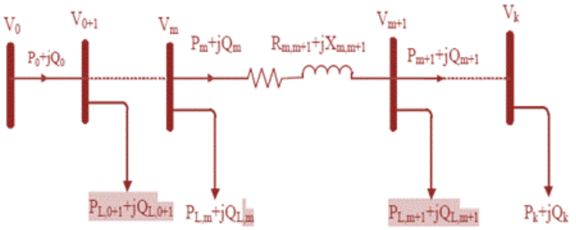

Figure 3 RDN's Line Diagram

Equations (7) and (8), correspondingly, are used to determine the related real and reactive power losses.

$$P_{loss} = R_{k,k+1}\left(\frac{P_k^2 + j\,Q_k^2}{|V_k|^2}\right) \tag{7}$$

$$Q_{loss} = X_{k,k+1}\left(\frac{P_k^2 + j\,Q_k^2}{|V_k|^2}\right) \tag{8}$$

Our primary goal of lowering the total real power losses for all of the N_b branches is done by the equation number (9).

$$P_{Tot} = \sum_{k=1}^{N_b} P_{loss,k} \tag{9}$$

In this work, the optimal location for DG is determined using the loss sensitivity factor (LSF) method, and the best location for D-STATCOM is determined using the voltage stability index (VSI). In terms of active power, the bus with the highest LSF has a better chance of receiving the DG. By partially differentiating equation (7), LSF can be calculated and represented as follows:

$$LSF = \frac{\partial P_{loss}}{\partial P_k} = \frac{2\,P_k\,R_{k,k+1}}{|V_k|^2} \tag{10}$$

All buses' LSFs are computed, and they are arranged in decreasing LSF order. The likelihood of selecting the bus with the highest LSF value as a candidate bus for DG placement is higher. Which bus is most likely to experience a voltage breakdown is determined using VSI. A bus has a better chance of being selected as a candidate bus for DSTATCOM installation if it has the lowest VSI value.It's crucial to remember that lowering voltage deviations as shown by the equation number (11) is necessary to improve the voltage profile.

$$V_D = \sum_{k=1}^{N_b}(V_k - V_{ref})^2 \tag{11}$$

where V_{ref} is the reference voltage, usually 1 p.u., and N_b is the quantity of buses. To decrease total loss and enhance the voltage profile and voltage stability index, renewable DG sources are incorporated into the RDN.

The reduction of total real power losses while satisfying a number of equality and inequality criteria is the aim of optimal DG & DSTATCOM deployment and sizing in RDN. The mathematical formula for the objective function (Z) is

$$\text{Min (Z)} = \text{Min }(P_{Tot}) \tag{12}$$

The aforementioned objective function is subject to the following equality and inequity restrictions.

(i) $\sum_{k=1}^{N_b} P_{Lk} + P_{Tot} = P_1 + P_{Comp} + P_{LS}$

(ii) $V_k^{min} \leq |V_k| \leq V_k^{max}$

(iii) $Q_{Comp,k}^{min} \leq Q_{Comp,k} \leq Q_{Comp,k}^{max}$

(iv) $P_{1,k}^{min} \leq P_{1,k} \leq P_{1,k}^{max}$

whereas P_{Comp} & Q_{Comp} are the DSTATCOM's real & reactive powers.

IV. RESULTS AND DISCUSSON

On the IEEE-14 and IEEE-33 bus systems, two IEEE test bus systems, the proposed ACOT, AFSOT and BFOT algorithms have been evaluated. The simulation in Matlab is implemented using M-file coding. The outcomes are plotted and confirmed. The best location and size for DG and DSTATCOM are chosen using the above-mentioned three techniques. Figures 4 to 12 show the IEEE-14 bus system using the above algorithms. As illustrated in Figure 4, proposed methods are utilized to observe the voltage before and after DG. Figure 5 shows the voltage for suggested techniques with and without DSTATCOM only. Figure 6 displays the voltage for suggested techniques along with DG and DSTATCOM.

Case (i) Results of 14-bus system

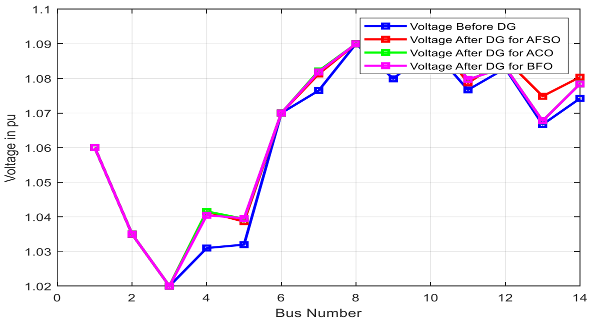

Figure 4 Voltage in p.u. before & after DG for all the three techniques

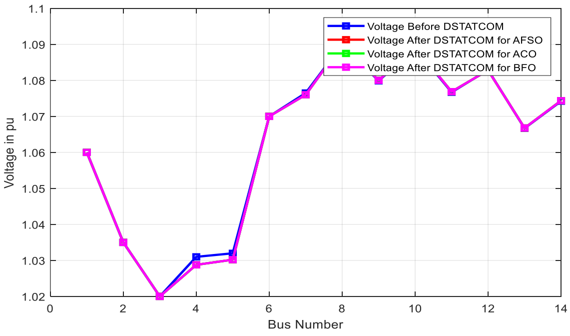

Figure 5 Voltage in p.u. with & without DSTATCOM for all the three techniques

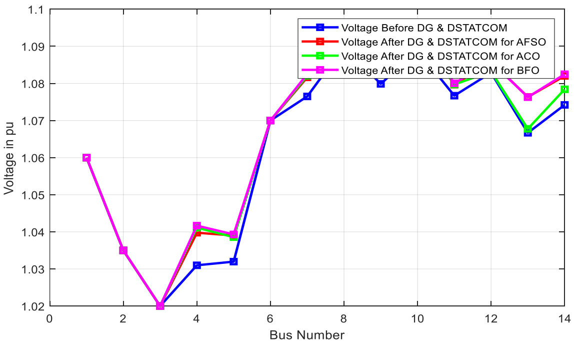

Figure 6 Voltage in p.u. with both DG & DSTATCOM for all the three techniques

Figures 7 and 8 depicts the real and reactive power losses using all the 3 proposed techniques for each branch of the system. Numerous iterations are used to discover the best price, as seen in figure 9 with DG and DSTATCOM. The position of the DGs and DSTATCOMs in their ideal state is shown in figures 10 through 12 for ACOT, AFSOT and BFOT methods respectively.

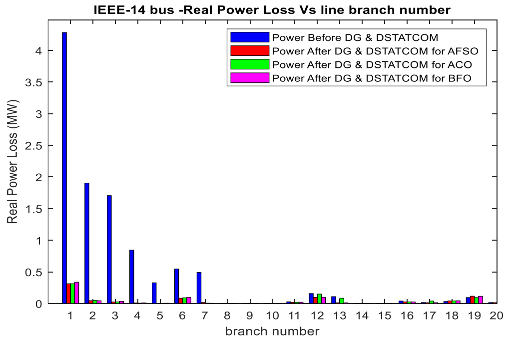

Figure 7 Real Power losses for all the three methods

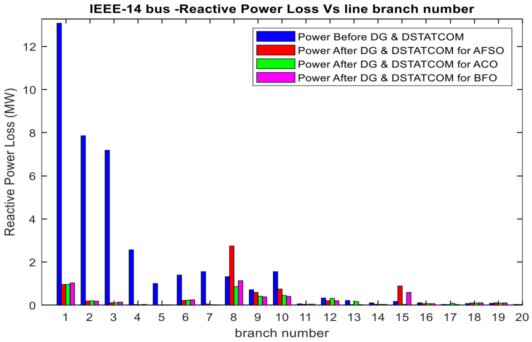

Figure 8 Reactive Power losses for all the three methods

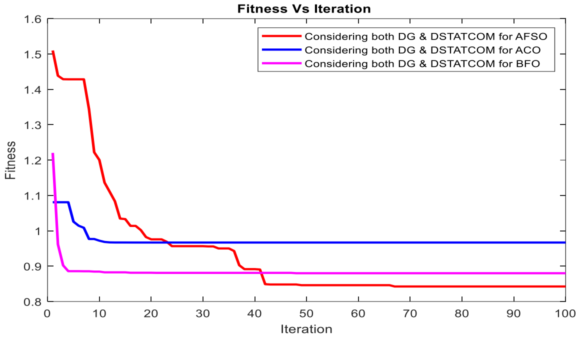

Figure 9 Cost Function for all the three techniques

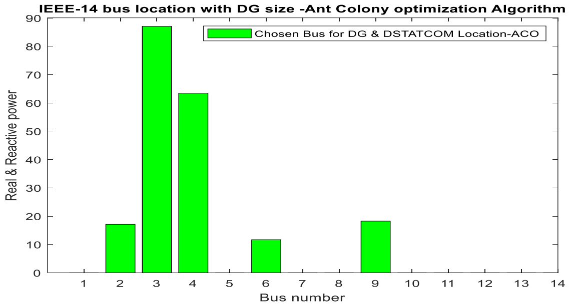

Figure 10 Optimal allocation of DG & DSTATCOM ACOT Method

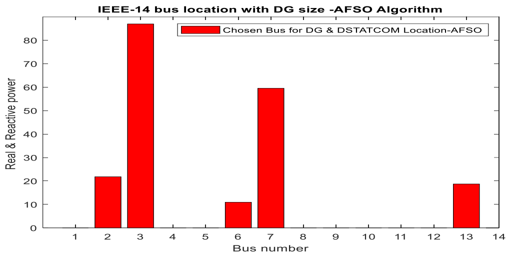

Figure 11 Optimal allocation of DG & DSTATCOM using AFSOT Method

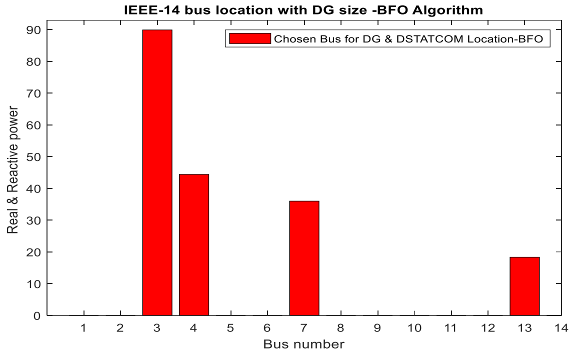

Figure 12 Optimal allocation of DG & DSTATCOM using BFOT Method

Case (ii) Results of 33-bus system

The method is duplicated for the IEEE-33 test bus systems using all the three algorithms. Figures 13 through 21 show the results of the simulation.

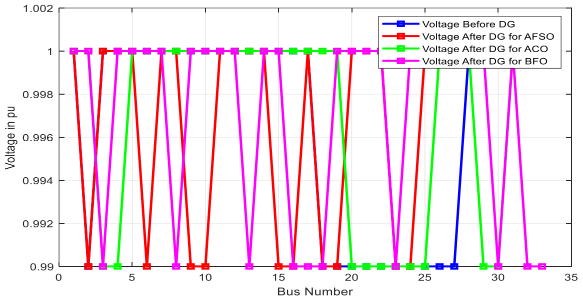

Figure 13 Voltage in p.u. before & after DG for all the three techniques

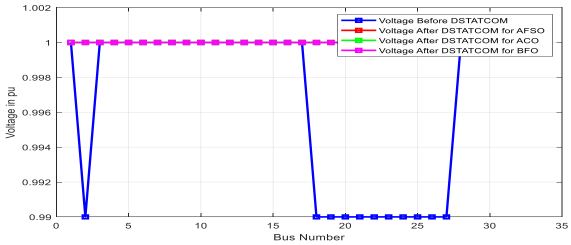

Figure 14 Voltage in p.u. with & without DSTATCOM for all the three techniques

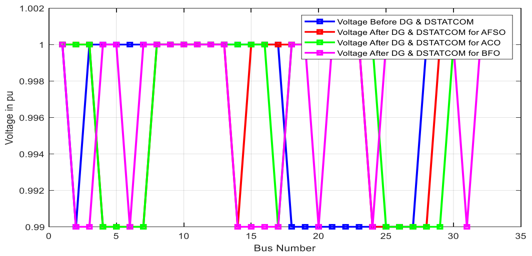

Figure 15 Voltage in p.u. with both DG & DSTATCOM for all the three techniques

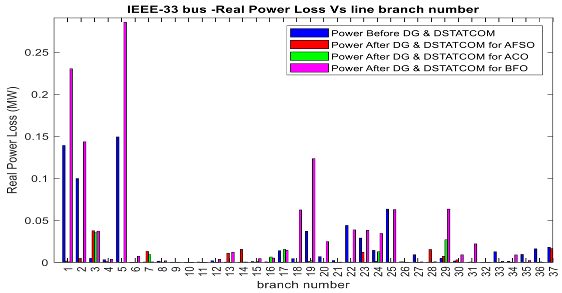

Figure 16 Real Power losses for all the three methods

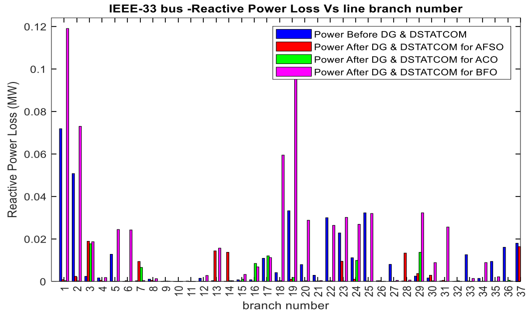

Figure 17 Reactive Power losses for all the three methods

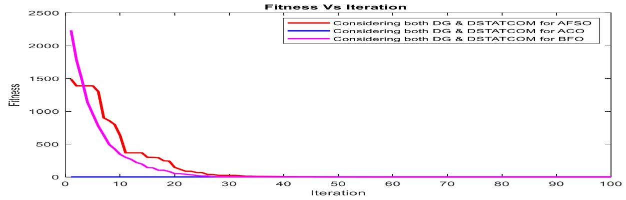

Figure 18 Cost Function for all the three techniques

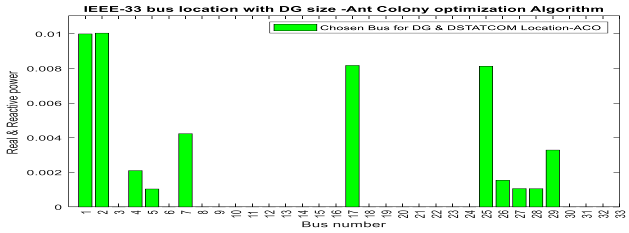

Figure 19 Optimal allocation of DG & DSTATCOM ACO Method

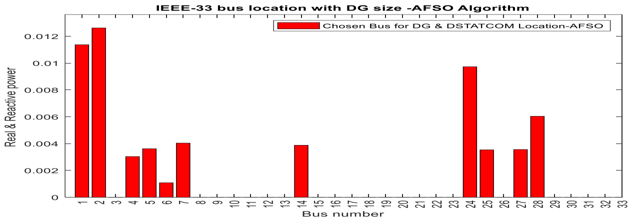

Figure 20 Optimal allocation of DG & DSTATCOM using AFSOT Method

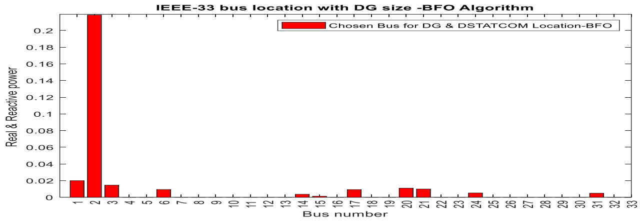

Figure 21 Optimal allocation of DG & DSTATCOM using BFOT Method

	14-Bus System			**33-Bus System**		
	ACOT	**AFSOT**	**BFOT**	**ACOT**	**AFSOT**	**BFOT**
Optimum power losses in MW	0.96684	0.88251	0.84005	0.14275	0.11363	0.10279
Average bus voltages in p.u.	1.0662	1.0671	1.0675	0.99697	0.99697	0.99697

Power inserted with DG in MW	110.5375	186.9423	188.5483	0.03063	0.03853	0.27794
Power inserted with DSTATCOM in MVar	87.087	10.9297	14.8964	0.020048	0.02399	0.030097
% Reduction in real power loss	90.878	91.501	92.6969	83.6323	85.1502	88.6038
% Increase in average bus voltages	100.2884	100.3775	100.4142	100.0304	100.183	100.241

Table 1 Result comparison of all the three methods

The different parameters for the proposed BFOT approach for both 14-bus and 33-bus networks are presented and compared with that of ACOT & AFSOT methods in Table 1. It unequivocally demonstrates the proposed BFOT method's superiority in every regard.

IV. CONCLUSION

This study resolves the problem of properly sizing and placing DGs and DSTATCOM in electrical distribution networks for radial networks. By utilising three different optimization approaches, these adjustments seek to reduce annual operating costs in terms of energy loss by DG and DSTATCOM installation. The suggested BFOT algorithm is a global, simple, fast, and traceable random searching optimal algorithm that can solve nonlinear and discrete optimal problems. In order to determine the appropriate DG's sizing and siting as well as the placement of compensators for loss minimization, the suggested algorithms are successfully constructed in Matlab using m-fie coding. All the three procedures are used to validate the IEEE-14 & IEEE-33 bus test systems. Analysis, examination, and comparison of the output are performed on the results. The results are provided together with the conclusions that were drawn. The suggested method's output outperformed the other two methods in terms of solution quality and computation effectiveness.

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