Journal of Science and Technology
ISSN: 2456-5660 Volume 7, Issue 02 (MAR-APR 2022)

www.jst.org.in *DOI: https://doi.org/10.46243/jst.2022.v7.i02.pp121-129*

Optimal Placement and Sizing of DGs in Electrical Distribution System using Optimization Techniques

Dr.G.Nageswara Reddy[1]
[1]*Department of Electrical and Electronics Engineering,*
YSR Engineering College of Yogi Vemana University, Proddatur, A.P India
Email: gnageswarareddy@gmail.com

To Cite this Article
*Dr.G.Nageswara Reddy, "**Optimal Placement and Sizing of DGs in Electrical Distribution System using Optimization Techniques**", Journal of Science and Technology, Vol. 07, Issue 02, March-April 2022, pp.:261-267.*

Article Info
Received: 25-02-2022 Revised: 05-03-2022 Accepted: 12-03-2022 Published: 21-03-2022

Abstract:*The Electrical energy is produced at the generating station is conveyed to the consumers through a network of transmission and distribution systems That part of power system which distributes electrical power for local use in (DG's) placement is carried out sufficient smaller than central power plants and can be connected at nearly any point in power system. It has some benefits they are Voltage control power quality, Loss reduction, System reliability. Distribution generation (DG) is a modular technology that can be sited throughout a utility service to lower the cost of service. The optimization is based on the Constriction-factor Particle Swarm optimization (Cf-PSO) technique and Butterfly Optimization Algorithm (BOA) with efficient mathematical function and global search capability. Shunt capacitor bank plays an important role in Electrical Distribution System (EDS). It improves the voltage stability, power factor, reduce network losses. To allocate the DG and SC banks optimally in Radial Distribution System to reduce the Power losses, Enhances the voltage profile, to diminish the total voltage deviation (TVD), to expand the voltage stability index (VSI)To finding the optimal site and size of DG's and SC bank, Butterfly Optimization Algorithm and constriction –factor Particle swarm optimization (Cf-PSO) is applied in IEEE 33-bus system and IEEE 69 bus RDS.*
Key Word*: Constriction factor particle swarm optimization (CF-PSO),Butterfly Optimization Algorithm (BOA), Distribution generation , Improvement of voltage stability index and power loss reduction.*

I. Introduction

Small-scale electrical generating is frequently referred to as "DG." The use of electrical energy is increasing with demand hence DG is becoming more popular. Reduces greenhouse gas emissions, enhances energy security, and improves power quality and dependability if the DG system is technically efficient and priced reasonably. The placement and sizing of DG determine the distribution system's loss. Improved voltage regulation and voltage stability in EDS can help reduce power losses. However, the primary function of DG is to provide active electric power rather than reactive power. Reactive power is also responsible for a share of the total losses. On primary distribution feeders, reactive power loss can be reduced by connecting shunt capacitors in parallel. As a result, the best capacitor is placed in a radial distribution system. The optimal allotment of capacitors is concerned with determining the position, sizing, category, and number of capacitors in order to achieve the most profit without breaching the limits. Many recent literatures have addressed the similar function of decreasing the both power loss and capacitor cost by properly allocating capacitors.

One of the Evolutionary Computation (EC) methodologies is the Particle Swarm Optimization (PSO) algorithm. Kennedy and Eberhart first presented PSO in 1995 as a population-based, self-adaptive approach. This stochastic-based method works in parallel with a population of individuals to probe capable portions of a multidimensional space in pursuit of the best solution. The particles are known as particles, and the population is known as a swarm. With adaptive velocity, each particle in the swarm advances towards the optimal place. Each particle in the population is considered as a point in space with no mass and no volume. Premature convergence is a problem that plagues the particle swarm optimization (PSO) algorithm. Clerc included the constriction factor into the PSO algorithm and termed it Constriction factor PSO to solve this problem (Cf-PSO). This factor regulates the particle's speed in response to a sudden change in position. For transmission system challenges such as reactive power dispatch, congestion management, and economic load.

II. FORMULATION OF THE PROBLEM

Figure 1 depicts a single diagram of the radial distribution system. The sending end I and receiving end (j) are shown in this diagram. The leakage current between the conductance of the I and i^{th} nodes is included in the shunt conductance. Because of its extremely low value, the capacitance of the distribution system is calculated with zero shunt conductance. Because it takes minimal memory, robustness, superior convergence speed, and enhances efficiency, the backward – forward sweep method was used in this radial distribution system (RDS).

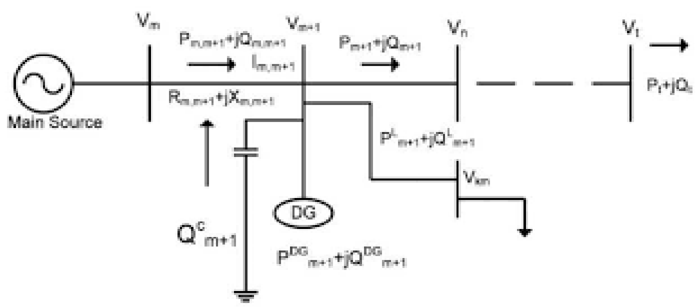

Fig 1. Single line diagram of RDS with placement of DGs and SCs at any bus

2.1 Objective function

The following are the assumptions that will be used to formulate the problem:

a. The location of the source bus's distributed generation (DG) and shunt capacitor (SC) banks is not taken into account.

b. PQ loads are frequently described as constants at loads.

There are different objective functions (OF) are carried out:

- Minimizing the active and reactive power loss (f_1, f_2)
- Minimizing the Total Voltage Deviation (f_3)
- Improving the Voltage Stability Index (f_4)
- Objective function formulation.

2.1.1. Minimizing the active and reactive power loss (f_1, f_2) : To reduce the actual power loss(P_A) is:

$$f_1 = \text{Minimise}(P_A) \quad (1)$$

Where $P_A = \sum_{A=1}^{n-1} P_{loss}(A)$

The value of P_{loss}(AB) for a radial distribution system is given by (2).

$$P_{loss}(AB) = R_{AB} \times \frac{P_A^2+Q_A^2}{|V_A^2|} \quad (2)$$

The term f_2 will be minimizing the reactive power loss (Q_A) is :

f_2 = Minimise(Q_A) (3)

Where $Q_A = \sum_{A=1}^{n-1} Q_{loss}$(A)

The value of P_{loss}(AB) for a radial distribution system is given by (4).

$$Q_{loss}(AB) = X_{AB} \times \frac{P_A^2+Q_A^2}{|V_A^2|} \quad (4)$$

2.1.2. Minimizing the Total Voltage Deviation *(f_3)*:

Any change in bus system voltage has an impact on distribution system operation, which may be calculated using eq (5). The ideal capacitor and DG allocation reduces the total voltage deviation (TVD) of the system, making it more stable.

The term *(f_3)* be used for minimizing the TVD it is shown in eq.5

$$f_3 = \text{Minimize} \left(\sum_{A=1}^{K} |V_A - V_O|^2 \right) \quad (5)$$

Where K is number of buses, V_O represents the reference voltage

2.1.3. Improving Voltage Stability Index (f_4): By using eq. to determine the stability of any bus system, the voltage stability index (VSI) is used (7). The system is stable as long as each bus's VSI value is high. The ideal distribution network allocation of DGs and capacitors raises the value of VSI for each bus in the system.

The term (f_4) will be indicates the VSI is stated in (6)

$$f_4 = \text{Maximise}(VSI_A) = Minimise\left(\frac{1}{VSI_A}\right) \quad (6)$$

Where A = 2,3,4 ……N.

The value of VSI is calculated by (7).

$$VSI_A = |V_B|^4 - 4[P_A X_{AB} - Q_A R_{AB}]^2 - 4[P_A R_{AB} + Q_A V_B]|V_B|^2 \quad (7)$$

2.1.4. Formulation of an objective function: The weighted sum approach is used to optimize a multi-objective function. By multiplying a single objective function by a weighted factor, a single objective function is transformed into a multi objective function in this manner. $F = \sum_{n=1}^{K} P_{Loss}(n)$ (8)

$$OF = w_1 \times f_1 + w_2 \times f_2 + w_3 \times f_3 + w_4 \times f_4 \quad (9)$$

2.2. Constraints

2.2.1. *Equality constraints.* The equality constraints are associated with real and reactive power flow constraints that can be formulated as follows:

$$P_{ref} + \sum_{j=1}^{Z} P_{DG} = \sum_{A=1}^{G} P_{L,A} + \sum_{n=1}^{K} P_{loss}(n) \quad (10)$$

$$Q_{ref} + \sum_{j=1}^{Z} Q_{DG} = \sum_{A=1}^{G} Q_{L,A} + \sum_{n=1}^{K} Q_{loss}(n) \quad (11)$$

Where, P_{ref} and Q_{ref} represents the active and reactive power injection from the slack bus. $P_{L,A}$ and $Q_{L,A}$ represents the active and reactive load demand, Z is the total number of DG units, and G is the total number of buses.

2.2.2. *Inequality constraints*. The inequality constraints are based on the operating system constraints that can be formulated as:

Bus voltage constraints: The bus voltage must be kept within the minimum voltage V_{min} and V_{max} is maximum voltage

$$V_{min} \le V_A \le V_{max} \quad (12)$$

DG sizing limits: The output power of DG must be kept within the maximum and minimum value of the power generation

$$\sum_{n=1}^{nDG} P_{DG}(n) \le \left(\sum_{n=1}^{g} P_r(n) + \sum_{n=1}^{nb} P_{loss}(n) \right) \quad (13)$$

$$\sum_{n=1}^{nDG} Q_{DG}(n) \le \left(\sum_{n=1}^{g} Q_r(n) + \sum_{n=1}^{nb} Q_{loss}(n) \right) \quad (14)$$

$$P_{DG,min} \le P_{DG,n} \le P_{DG,max} \quad (15)$$

$Q_{SC,min} \leq Q_{SC,n} \leq Q_{SC,max}$ (16)

III. TO SOLVE OPTIMAL SITING AND SIZING OF DG IN RDS BY USING CF-PSO:

3.1. Constriction Factor based Particle swarm optimization and Butterfly optimization algorithm (BOA):

After Kennedy and Eberhart proposed the original particle swarm, a lot of improved particle swarms were introduced. Because PSO originated from efforts to model social systems, a thorough mathematical foundation for the methodology was not developed at the same time as the algorithm. Within the last few years, a few attempts have been made to begin to build this foundation. The particle swarm with constriction factor is very typical. Clerc (Clerc 1999) in his study on stability and convergence of PSO have introduced a constriction factor K. Clerc suggests that a constriction factor might be required to ensure particle swarm method convergence. He'd built a mathematical foundation to explain the behavior of a simplified PSO model as it sought the best solution. The PSO's basic system equations (6-8) can be thought of as a type of difference equation. As a result, the system dynamics, specifically the search operation, can be evaluated and regulated using Eigen value analysis, resulting in the system having the following characteristics. a) The system converges; b) By preventing premature convergence, the system may efficiently search different regions. In order to insure the convergence of the PSO algorithm, the velocity of the constriction factor based approach can be expressed as follows:

V_i^{k+1} = k $[V_i^k + c_1 r_1 \times (Pbest_i^k - X_i^k) + c_2 r_2 \times (Gbest_i^k - X_i^k)]$ (17)

$$K = \frac{2}{|2-\phi-\sqrt{\phi^2-4\phi}\,|} \quad (18)$$

Where $\varphi = c_1 + c_2$ and $\phi > 4$

$$w^{t+1} = w_{max} - \frac{w_{max} - w_{min}}{t_{max}} \times t \quad (19)$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad (20)$$

The system's convergence characteristic can be controlled through. To ensure stability in the constriction factor approach, the must be bigger than 4.0. As, however, the constriction factor drops, K decreases, and diversification reduces, resulting in a slower reaction. Typically, when the constriction factor is used, ϕ is set to 4.1(i.e. c_1, c_2 = 2.05) and the constant multiplier K is thus 0.729. This results in the previous velocity being multiplied by 0.729 and the terms $(Pbest_i^k - X_i^k)$ and $(Gbest_i^k - X_i^k)$ being multiplied by 0.729× 2.05=1.49445 (times a random number between 0 and 1).

Individuals that use the restriction factor approach tend to converge over time. The constriction factor approach, unlike other evolutionary computation approaches, guarantees the convergence of the search procedure based on mathematical theory. As a result, the restriction factor approach can produce better answers than the conventional PSO strategy. However, the constriction factor approach only considers dynamic behavior of one individual and the effect of the interaction among individuals. Namely, the equations were developed with a fixed set of best positions (P_{best} and G_{best}), although P_{best} and G_{best} change during the search procedure in the basic PSO equation.

The BOA is one of the newly meta heuristic optimization algorithms proposed. This algorithm mimics the food foraging and the finding of mating partner behaviors of butterflies. Butterflies are chemo receptors that scattered on their bodies and work as sense receptors. The butterflies use these chemo receptors for sensing/smelling the fragrance of the flowers/food. Also, the chemoreceptor helps the butterfly to find the optimal mating partner. Butterflies generate a fragrance with an intensity level while it is changing its places. This fragrance guides the search-agents (butterflies) movement in the BOA algorithm. Based on the fragrance intensity, if a given butterfly fails to sense the fragrance of any butterfly within the search space, this butterfly will do exploitation (local search) by moving to a new random selected position. In case the butterfly senses the fragrance of the best butterfly, then it will move toward that butterfly, and this is called exploration (global search

3.2. Computational Analysis:

1. Read the system data of load and line data, number of iterations, population size, real power DGs (N dg), and Shunt capacitor banks (N sc) in the Radial distribution system first.
2. Get the actual and reactive power losses at each node using the backward forward sweep method in the basic scenario to determine the Radial Distribution System's Total Voltage Deviation (TVD) and Voltage Stability Index (VSI).
3. For each function, determine the weight coefficients..
4. Set the iteration value iter = 1.
5.By using equation (18) to find out the Constriction Factor.
6. The Upper and Lower limits of the size of DGs and SCs banks are randomly generated by the following equations:

$$P_{dg(i)} = P_{dg(i)}^{min} + r \times (P_{dg(i)}^{max} - P_{dg(i)}^{min}) \quad (21)$$

$$Q_{sc(i)} = Q_{sc(i)}^{min} + r \times (Q_{sc(i)}^{max} - Q_{sc(i)}^{min}) \quad (22)$$

Where (r) indicates the random values, $P_{dg(i)}$ and $Q_{sc(i)}$ are indicates the size of i^{th} DGs and Shunt capacitors banks.
7. To form a vector X it contains the corresponding locations and size of the DGs and SC banks is shown in below equation.

$$X = [loc_{dg(1)}, \ldots, loc_{dg(N_{dg})}, P_{dg(1)}, \ldots P_{dg(N_{dg})}, [loc_{sc(1)}, \ldots, loc_{sc(N_{sc})}, Q_{sc(1)}, \ldots Q_{sc(N_{sc})}] \quad (23)$$

8.To Generate the velocity and random position for each particle.
9. To calculate the total power losses, Total Voltage Deviation and VSI by using the (1), (3), (5) and (7).
10. To update the position and velocity of each particle by using the (14) and (19) equations.
11. If Maximum iteration value reaches and minimum objective function value (p.u.) is acquired, go to step 12 or else increase the iteration value one by one and go to step 8.
12. Display the results.

IV. Cost analysis

The Cost of energy losses, total operating cost, price component of Distributed Generator (DGs) and Shunt Capacitor banks (SCs) will be shown in following equations.[8]

Cost of energy losses (CEL): The Annual price of the Energy loss is written in below equation (24)

$$CEL = (P_A) * (K_d + K_a \times L_f \times 8760) \, \$ \quad (24)$$

Where P_A is the active power loss, K_p is the yearly demand cost of P_A (K_p = 57.6923 \$/KW), K_e is the annual price of energy loss (K_e = 0.00961538 \$/kWh) and L_f is the loss factor.

$$L_f = k \times LF + (1-k)\times((LF)^2 \quad (25)$$

The values of k and LF is 0.2,0.47.

Total cost of real power DG

The total cost of the real power DG is shown in below equation

$$C(P_{DG}) = a \times P_{DG}^2 + b \times P_{DG} + c \ \$ \quad (26)$$

Here a, b and c are the constant values a=0, b=20 and c=0.25

Total cost of reactive power SC banks

The total cost of the reactive power SC banks is shown in below equation

$$C(Q_{SC}) = \sum_{I=1}^{NSC}(k_c \times Q_{SC}) + k_f \times NSC \ \$ \quad (27)$$

k_c and k_f are the cost coefficients, k_c = 3 (\$/kVAr),

$k_f = 1000(\$/\text{capacitor})$.

The total operating cost can be calculated by using the below formulae

$$TOC = K_i \times P_A + \sum_{i=1}^{NDG} K_d \times P_{DG} + \sum_{i=1}^{NSC} K_d \times Q_{SC} \ \$ \quad (28)$$

Where K_i= 0.07(\$/kWh), K_d = 5(\$/kW) and K_c = 3(\$/kVAr).

V. Result Analysis

The algorithm was written in MATLAB (R2020a) and then run on a personal computer (i3,1.70 GHz and 8GB RAM). For each scenario, the algorithms are run for 30 times with 200 iterations and 50 population sizes. The parameters of the Cf-PSO algorithm are shown in Table 1. The performance of the DGs and SC banks installation is seen in table 3. Radial Distribution System simulation results are developed for IEEE IEEE 69 bus system. For each test system, the following scenarios are examined.

Test System	f_1	f_2	f_3	f_4
IEEE 69 bus	0.22498	0.1021	0.09937	0.68331

TABLE 1. Objective function value before allocation of SC and DG.

Case-1: In first case 2 DGs are operating at unity power factor (UPF) and 2 SCs banks are installed at their optimal location simultaneously.

Case-2: In this case 3 DGs are operating at unity power factor (UPF) and 3 SC banks are installed at their optimal location simultaneously.

5.1. Test System 2: IEEE 69 bus RDS

There are 69 nodes and 68 branches in the 69 bus system. The IEEE 69 bus Radial Distribution System has a base voltage of 12.66kV and a current of 1 MVA. Figure 6 shows a single line diagram of the IEEE 69 bus Radial Distribution System. Cf-PSO was used to do a performance analysis of the network's total active and reactive power losses. The total load of the network is (3.72 + j 2.3). Table 5 shows the basic case, Case-1, and Case-2 of the Cf-PSO and BOA. The Active power loss (P loss), Reactive power loss (Q loss), Total Voltage Deviation, and Voltage Stability Index (VSI) will be improved in this suggested algorithm, as shown in Table 2. Table 2 shows that the Cf-PSO has the least active power loss (P loss) and improves the voltage profile when compared to BFO. Figure 2 depicts the voltage levels of each bus,. In the IEEE 69 bus RDS, Figure 3 depicts the Voltage Stability Index of each bus after the installation of DGs and SC banks in the base case 1 and case-2. From figure 2, the proposed approach produces a better voltage profile augmentation. Figure 3 shows the voltage magnitude of the IEEE 69 bus system after the installation of DGs and SC banks. Figure 3 shows how the Cf-PSO algorithm improves the voltage stability profile in the IEEE 69 bus system in the Radial Distribution System.

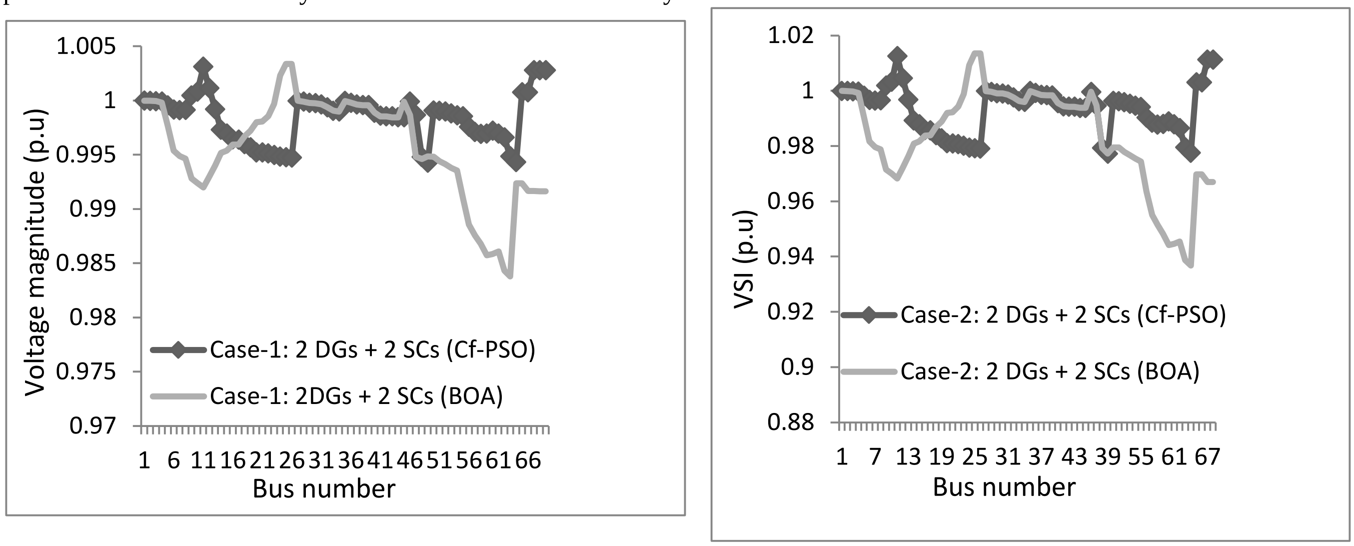

Fig 2. Comparative Voltage plot of IEEE 69 Bus System RDS: Case-1 and Case-2

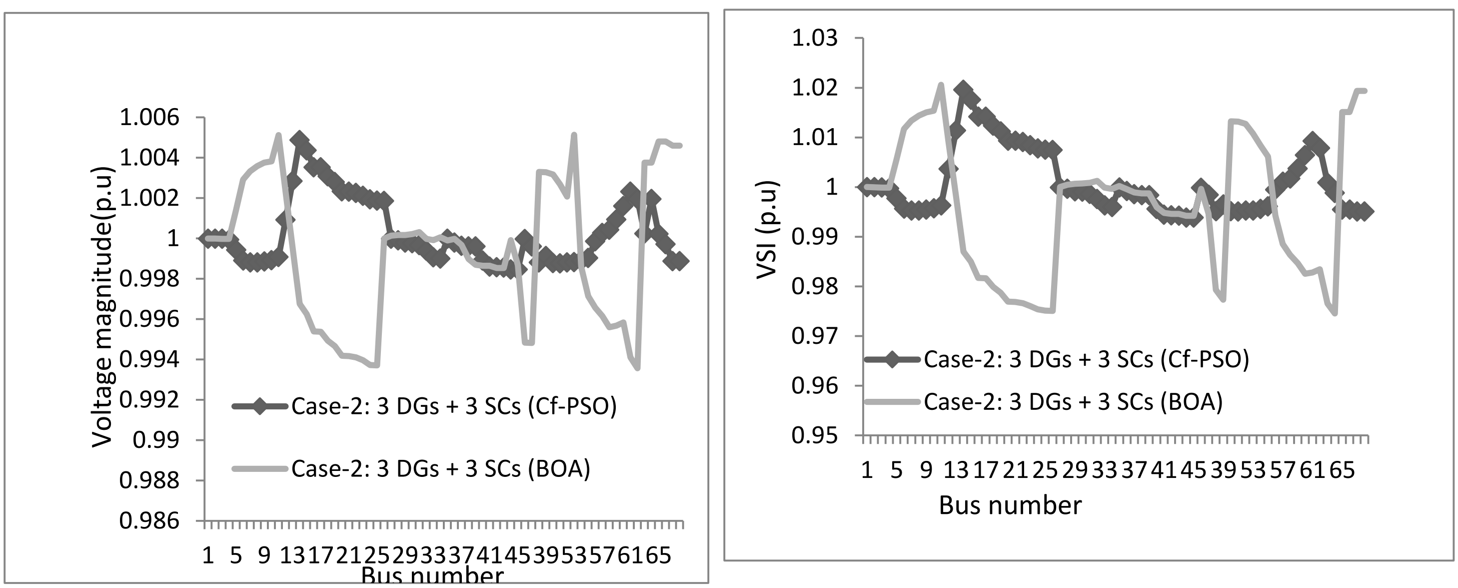

Fig 3. Comparative VSI plot of IEEE 69 Bus System RDS: Case-1 and Case-2

Table 2. The results for IEEE 69 bus RDS

System Parameters	Base Case	BOA[Proposed]		Cf-PSO [Proposed]	
		Case-1	Case-2	Case-1	Case-2
Optimal site and size of DGs (kW)	-	26(595.02) 61(1171.51)	9(1348.78) 12(984.56) 61(1394.33)	12(1079.92) 61(1500.0)	15(725.97) 61(734.03) 62(1031.10)
Optimal site and size of SCs (KVAR)	-	57(648.36) 63(1245.45)	33(200.00) 36(1123.83) 63(1109.55)	18(396.35) 61(1389.4)	11(703.34) 50(683.23) 62(1136.40)
P_{loss} (f_1) (p.u.)	0.22498	0.03394	0.02435	0.01109	0.01109
Q_{loss} (f_2) (p.u.)	0.10219	0.01885	0.01567	0.00912	0.00721
TVD (f_3) (p.u.)	0.09937	0.00265	0.00083	0.00051	0.00018
VSI (f_4) (p.u.)	0.68331	0.93672	0.97454	0.97727	0.99386
V_{min} (p.u) / Bus Number	0.90917/65	0.98379/65	0.99357/65	0.99427/51	0.99846/46
% Reduction in P_{loss}	-	80.31	85.185	81.856	86.28
% Reduction in Q_{loss}	-	79.285	80.51	82.42	85.0909
Cost of energy losses ($)	215962.496	2732.03	1959.73	2846.25	18109.44
Cost of P_{dg} ($)	-	35331.10	74554.19	51538.94	49822.68
Cost of SC banks ($)	-	7681.44	10300.16	7357.69	10586.91
Total operating cost($/year)	146385.56	35326.24	40867.43	25059.16	25909.26
% Savings	-	69.562	67.75	71.003	72.21

VI. CONCLUSION

The Active power loss (P loss), Reactive power loss (Q loss), Total voltage deviation (TVD), and Voltage Stability Index have been used to optimize the siting and sizing of DGs and SC banks (VSI). The multi objective optimization method was used in this work to determine the combining factors. The Cf-PSO algorithm, such as IEEE 69 bus system Radial Distribution System, was solved utilizing the Optimization process. The suggested Cf-PSO algorithm avoids premature convergence by achieving stable and consistent convergence. The estimation algorithm can determine the best position and size for DGs and SC banks while lowering Active and Reactive power losses, lowering Total Voltage Deviation (TVD), and improving the Voltage Stability Index (VSI) of the test network. The Butterfly Optimization Algorithm (BOA) is a population based natural inspired algorithm. The Butterfly Optimization Algorithm are mimics the foraging and the social behavior of butterflies, the movement of butterflies are based on the 3 phases: 1. Global search phase 2. Local search phase and 3. Solution evaluation it represents the intensity of the butterfly objective function. The BOA has the parameter setting, Iteration initialization and initial population. The Cf-PSO and BOA has two cases as follows: Case-1 shows the voltage magnitude of the Cf-PSO and BOA, Case-2 shows the Voltage Stability Index (VSI) of the Cf-PSO and BOA optimization technique. As with other recently emerging state-of-the-art algorithms, the suggested Cf-PSO algorithm considers Total voltage deviation (TVD), Voltage profile, and voltage stability index of the network to improve the outcomes of Active power loss. It's possible to think about the best way to allocate DG by considering the various types of DG integration at different load models and load levels.

VII. REFERENCES

[1] T. Ackermann, G. Anderson, and L. S€oder, "Distributed generation: definition," Electric Power Syst. Res., vol. 57, no. 3, pp. 195–204, 2001. DOI: 10.1016/S0378- 7796(01)00101-8.

[2] S. Ghosh, S. P. Ghoshal, and S. Ghosh, "Optimal sizing and placement of distributed generation in a network system," Elect. Power Energy Syst., vol. 32, no. 8, pp. 849–856, 2010. DOI: 10.1016/j.ijepes.2010.01.029.

[3] B. Singh, V. Mukherjee, and P. Tiwari, "A survey on impact assessment of DG and FACTS controllers in power systems," Renew. Sustain. Energy Rev., vol. 42, pp. 846–882, 2015. DOI: 10.1016/j.rser.2014.10.057.

[4] S. Raha, T. Som, and N. Chakraborty, "Constriction factor based particle swarm optimization applied to reactive power dispatch in transmission system," presented at the International Conference on Sustainable Energy and Intelligent Systems (SEISCON), Chennai, India, pp. 335–339, 2011. DOI: 10.1049/cp.2011.0385.

[5] S. Biswas, K. K. Mandal, and N. Chakraborty, "Constriction factor based particle swarm optimization for analyzing tuned reactive power dispatch," Front. Energy, vol. 7, no. 2, pp. 174–181, 2013. DOI: 10.1007/s11708-013-0246-x.

[6] N. B. Baddu, C. Padmanabha Raju, and R. R. Srinivasa, "A constriction factor based particle swarm optimization for congestion management in transmission systems," Int. J. Electr. Eng. Inform., vol. 10, no. 2, pp. 232–241, 2018. DOI: 10.15676/ijeei.2018.10.2.3.

[7] G. Pranava and P. V. Prasad, "Constriction coefficient particle swarm optimization for economic load dispatch with valve point loading effects," presented at the International Conference on Power, Energy and Control (ICPEC), Sri Rangalatchum, Dindigul, India, pp. 350–354, 2013. DOI: 10.1109/ICPEC.2013.6527680.

[8] V. V. S. N. Murthy and A. Kumar, "Comparison of optimal DG allocation methods in radial distribution systems based on sensitivity approaches," Elect. Power Energy Syst., vol. 53, pp. 450–467, 2013