

PAPER 124 – OPTIMAL SITING AND SIZING OF D-STATCOM FOR POWER LOSS REDUCTION IN DISTRIBUTION NETWORKS USING BACTERIAL FORAGING ALGORITHM

Alex Aligbe^{1*}, P.E. Orukpe², and Samuel O. Igbiovvia²

¹Department of Electrical and Electronics Engineering, Air Force Institute of Technology, Kaduna, Nigeria.

²Department of Electrical/Electronics Engineering, University of Benin, Benin City, Nigeria.

*Email: a.aligbe@afit.edu.ng and aligbealexprof@gmail.com

ABSTRACT

This paper describes the optimization operation of a distribution network for the purpose of reducing operational expenses and increases the performance of the entire system. The objective of this research is to optimally allocate and size the required kVAr for a Distributed Static Synchronous Compensators (D-STATCom) for a distribution network in order to improve the voltage profile and reduce the total line losses. D-STATCom is a shunt compensating device which is connected to voltage control converter. Bacterial Foraging Algorithm (BFA) was deployed for allocating and sizing of the D-STATCom. BFA is a natural inspired Algorithm that allow bacterial to search for food and avoid harmful substances. The proposed algorithm was demonstrated in IEEE 33 bus and Irrua Distribution Network (IDN). It was observed that the proposed algorithm sited D-STATCom at bus 14 with kVAr value of 3350 and reduces the kW and kVAr losses by 56.61% and 54% respectively for IEEE 33 bus and sited D-STATCom at bus 38 with kVAr value of 5090 and reduces the kW and kVAr losses by 46.7% and 43.4% for IDN. The proposed algorithm was compared with other existing algorithm; the proposed algorithm gave a better result in term of power loss reduction. The optimal siting of D-STATCom devices and proper sizing was able to reduce the total line losses and improve the voltage profile of the networks.

KEYWORDS: D-STATCom, power loss, distribution network, and voltage profile.

23. INTRODUCTION

In recent years, because of the rapid growth in power electronics due to its low cost, fast switching ability and low losses makes the control and operation of power system more flexible and economical [1]. The maximum operating capacity of power system can be exploited by installing Flexible AC Transmission system (FACTS) devices on the network. Installing FACTS devices in distribution network makes the operation more reliable [2]. A distribution system is the network that link the transmission system (high voltage) and the final consumers (low voltage), they have high R/X ratio, which makes the power losses to be high [3]. In a distribution system, there is need to provide the required power to the entire loads and maintain the voltage magnitude at an accepted range which is one of the main constraint of the system [4].

FACTS device technology was design initially for transmission network, due to the advancement in technology; the idea was now gaining ground for distribution network application. There are FACTS devices that are suitable for improving voltage level, minimize power loss, and improve power quality in distribution system; these devices are Solid State Transfer Switch (SSTS), Static VAR Compensator (SVC), Unified Power Quality Conditioner (UPQC), Dynamic Voltage Restorer (DVR) and Distributed Static Synchronous Compensator (D-STATCom). D-STATCom is a shunt compensating device connected to a voltage source DC/AC converter, used to resolve power quality related issues such as voltage sag, unbalance load, power loss, voltage instability, operational cost and harmonics distortion. Installation of D-STATCom on all the buses in a distribution network is not economical and therefore unnecessary, there is need to optimally place this devices on the network.

There are several novel techniques that have been deployed in reaching for the optimal location of D-STATCom devices in a distribution network. In [5], immune Algorithm was used to optimally site and size D-STATCom in IEEE-33 and 69 bus networks for multi-objective function, the performance of the network was examined under different load conditions. The author in article [6], optimally sized and sited shunt FACTS devices in a standard IEEE-14 and 57 bus network using fuzzy-Genetic Algorithm (FGA) for multi-objective function. In [7], the authors optimally sited and sized FACTS devices on IEEE-30 bus network using Success History based Adaptive Differential Evolution (SHADE) and Superiority Feasible solution (SF) to solve optimal power flow problem when wind turbines was integrated into the network. The placement and size of SVC was demonstrated in radial distribution system to influence the performance of the network after installing renewable energy sources on the network in [8]. Particle Swarm Optimization (PSO) Algorithm was deployed in [9] to optimally site and size D-STATCom for power quality improvement on a radial distribution network. The study of various load impact when D-STATCom are optimally allocated in a distribution network was demonstrated in [10-11]. In [12], grey

wolf optimization was proposed to reconfigure and allocate D-STATCom in radial distribution network for multi-task functions. Authors in article [13] reconfigured the network by optimally allocating a D-STATCom in order to save energy. JAYA Algorithm was deployed to optimally allocate D-STATCom in a distribution system to enhance the voltage profile and minimizes the total line losses in [14]. Ant Colony Algorithm (ACA) was used to site and size D-STATCom in a radial IEEE 33 bus network in [15]. A Modified Sine Cosine Algorithm (MSCA) was used to optimally site and size D-STATCOM in a distribution network in [16]. In [17], Multi-objective Genetic Algorithm (MGA) was used to optimally allocate and size D-STATCom for Total Harmonic Distortion (THD) mitigation and cost reduction in operation. In this paper, Bacterial Foraging Algorithm (BFA) is propose for optimal siting and sizing of D-STATCom in IDN and IEEE 33 bus Network with the purpose of improving voltage profile and reducing power losses.

24. OVERVIEW OF D-STATCOM MODEL AND THE RESEARCH OBJECTIVE FUNCTION

2.1 Mathematical Model of D-STATCom

D-STATCom belongs to the family of Distributed Flexible AC Transmission System (DFACTs), which comprises of Voltage Source DC/AC Converter (VSC), power transformer and DC capacitor to store energy. D-STATCom has the capacity to absorb or inject kW and kVAR when sited on a network; the amount of power injected or absorbed will depend on the capacity of the energy storage device. D-STATCom can monitor the line voltage and compare it with the reference AC voltage, and provide the required leading or lagging reactive current in order to improve the network voltage. Figure 1 shows the steady state connection of D-STATCom to bus m in a distribution network.

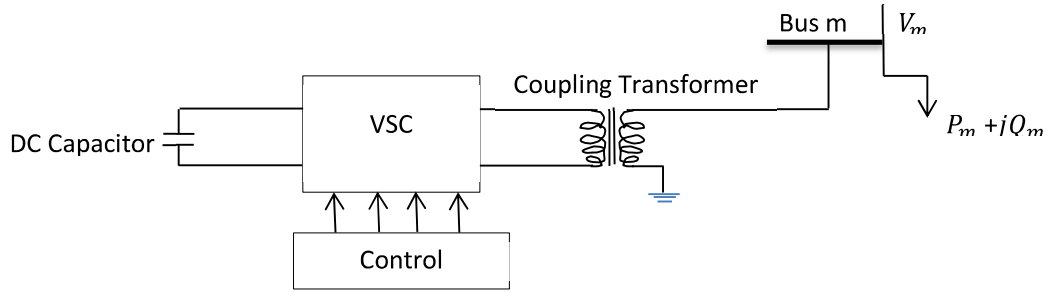


Fig 1: D-STATCom connected to a Distribution Network.

Let consider the schematic diagram shown in figure 1 as a two bus network represented as bus m and m+1, where the line resistance and reactance between the two buses are R_m and X_m respectively. The voltage on bus m and m+1 are V_m and V_{m+1} . After installing D-STATCom on bus m, the voltages on bus m and m+1 changes to V'_m and V'_{m+1} , likewise the injected current by D-STATCom is $I_{DSTATCOM} < (\alpha' + 90^\circ)$ and the line current is $I_L < \phi_L$.

The new voltage on bus m can be calculated after installing D-STATCOM on the network as;

$$V'_m < \theta' = V_m < \delta - (R_m + jX_m) * I_L < \phi_L - (R_m + jX_m) * I_{DSTATCOM} < (\alpha' + 90^\circ) \quad (1)$$

$$\text{where; } V'_m = V'_m < \theta' \quad (2)$$

The injected kVAR at bus m is given as;

$$jQ_{DSTATCOM} = V'_m * I_{DSTATCOM} < (\alpha' + 90^\circ) * \quad (3)$$

Where * denote conjugate of complex variable.

2.2 The Research Problem Formulation

A. Load Flow Analysis

Backward/Forward Sweep Algorithm (BFSA) was used to analyze the load flow in this research work. Kirchhoff's voltage and current law are applied to BFSA method. Let's consider a two-bus one line diagram for a distribution system as shown in figure 2.

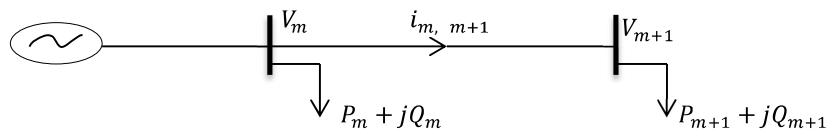


Fig 2: One line diagram for a two-bus distribution System.

The steps required to calculate load flow using BFSa are listed as follows;

Step 1: calculate the bus current.

The current generated at bus m can be calculated as;

$$i_m = \frac{P_m + jQ_m}{V_m^*} \quad (4)$$

where V_m represent the voltage magnitude at bus m, P_m and Q_m are the kW and kVAr at bus m. According to Kirchhoff's current law, the summation of all the current that flow in and out of the bus must be equal to zero.

Step 2: calculate the branch current.

The amount of current that flows between bus m and m+1 is given as;

$$J_{m,m+1} = i_m + i_{m+1} \quad (5)$$

Step 3: representing the bus current injected and the branch current in matrix form;

$$[J] = [BIBC] [I] \quad (6)$$

Where, [BIBC] matrix represents the line data of the network.

Step 4: calculate the bus voltage.

The voltage on bus V_{m+1} can be calculated by applying Kirchhoff' voltage law and is given as;

$$V_{m+1} = V_m - i_{m, m+1}(R_m + jX_m) \quad (7)$$

where; R_m and X_m are the line resistance and reactance.

Step 5: calculate the power losses on the lines.

For kW loss is given as;

$$P_{Loss(m,m+1)} = \left(\frac{P_{m,m+1}^2 + jQ_{m,m+1}^2}{|V_{m,m+1}|^2} \right) * R_m \quad (8)$$

While for kVAr loss is given as;

$$Q_{Loss(m,m+1)} = \left(\frac{P_{m,m+1}^2 + jQ_{m,m+1}^2}{|V_{m,m+1}|^2} \right) * X_m \quad (9)$$

The total kW and kVAr loss on the entire network can be calculated as;

$$P_{TLoss} = \sum_{m=1}^N P_{Loss(m,m+1)} \quad (10)$$

Similarly,

$$Q_{TLoss} = \sum_{m=1}^N Q_{Loss(m,m+1)} \quad (11)$$

B. The Research Objective Function

This research is carried out to solve two major problems in Irrua distribution network which are, voltage profile improvement and reduction in power losses;

i. Total Power Losses

This objective function min(F) can be determine by referring to the two bus single line distribution network diagram shown in figure 2;

$$\min(F) = \min(P_{Loss(m,m+1)} + (V_m - V_{m+1})) \quad (12)$$

ii. Inequality Constraints

▪ Bus Voltage Constraints

The voltages on every bus on the network should be within the accepted range, that is, $\pm 5\%$ of its nominal values as expressed in eq.(13).

$$0.95pu \leq 1pu \leq 1.05pu \quad (13)$$

▪ D-STATCom Size Constraints

The kVAr that will be injected by the installed D-STATCom into the network should not exceed the required kVAr value, as expressed in eq.(14)

$$Q_m^{min} \leq Q_{D-STAT} \leq Q_m^{max} \quad (14)$$

Where, Q_{D-STAT} is the kVAr injected at bus m.

25. PROPOSED METHOD FOR THE RESEARCH

3.1 Description of Bacterial Foraging Optimization Algorithm

Bacterial Foraging Algorithm (BFA) is a biological inspired swarm intelligence algorithm that is driven by stochastic search approach developed by Passino. This algorithm has been used by different researchers in finding solutions to optimization problems in power system. The concept of BFA is based on the foraging behavior of Escherichia coli bacterial that reside in human intestine. A set of tensile flagella helps the bacterium to perform two basic operations which are swimming and tumbling during foraging. Whenever each flagellum pulls out a cell, the flagella will rotate in a clockwise direction making the movement of flagella to be independent and cause bacterium to tumble less but when found in a harmful place, it will tumble several times to get a nutrient gradient.

There are basically four steps for BFA, they are Chemotaxis, Swarming, Reproduction, and Elimination and Dispersion. These four steps are applied in solving objective functions either singular or multiple.

3.2 The proposed Algorithm for optimal placement and sizing of D-STATCom

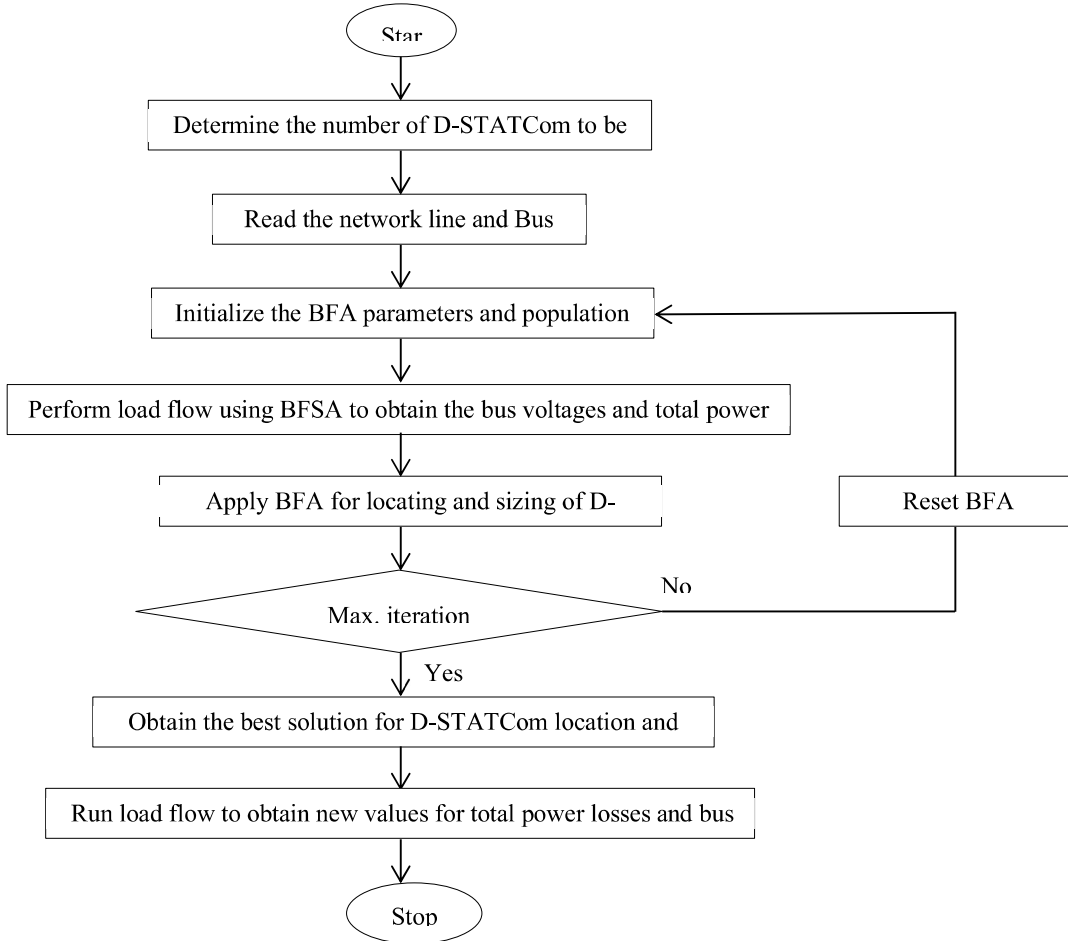


Fig 3: Flow chart for the optimal placement and sizing of D-STATCom using proposed Algorithm.

26. SIMULATION RESULTS AND DISCUSSION.

The proposed Algorithm was demonstrated on IEEE 33 bus network before deployed on Irrua distribution Network. The research work was simulated using MATLAB R2020a environment, the parameter used for both networks are similar.

4.1 Simulation Results for IEEE 33 Bus Network

IEEE 33 bus network consists of 33 buses, 32 lines with a total kW and kVAr load of 3715 and 2295 respectively. The total reactive power flowing through the network is 2487.96kVAr. Backward and forward sweep algorithm (BFSa) was used to analyse the load flow in order to identify weak buses while BFA was used to site and size D-STATCom on the network. The proposed method placed D-STATCom on bus 14 with a kVAr value of 3349.840. Figure 4a shows the improvement in the voltage profile after the installation of D-STATCom. It was observed that kW and kVAr losses were reduced by 56.61% and 54% respectively as shown in figure 4b. The proposed method was compared with other existing methods; it was observed that proposed method gives a better total power loss reduction as shown in table 1

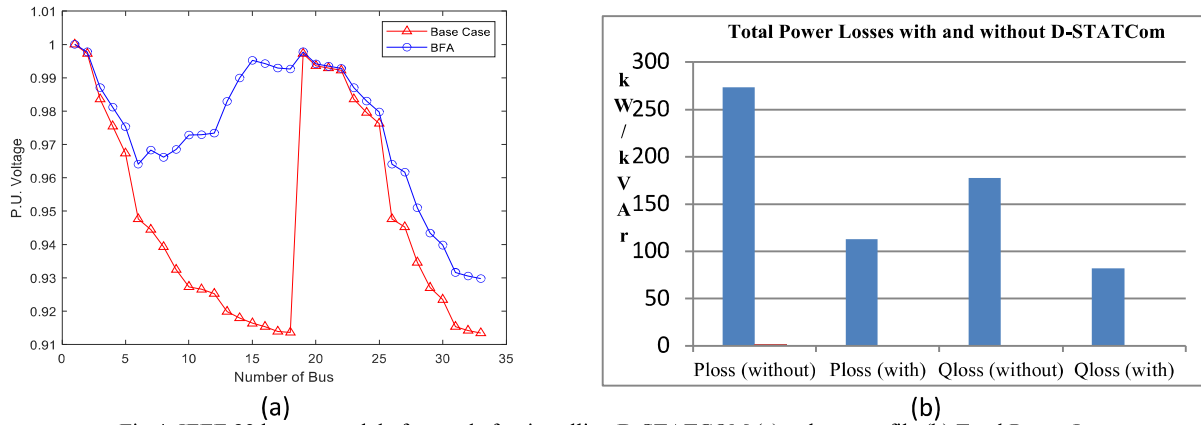


Fig 4: IEEE 33 bus network before and after installing D-STATCom (a) voltage profile (b) Total Power Losses

Table 1: A comparison between the proposed method and existing methods for IEEE 33 bus system.

Parameter	proposed Method	In [18]	In [10]
Without D-STATCom installation (kW)/(kVAr)	273 / 178	211/ 143	210.98
With D-STATCom installation (kW)/(kVAr)	113 / 82	151.5 / 103.4	151.37
Optimum size of D-STATCom (kVAr)	3349.840	1144	1250
Optimum location of D-STATCom	14 th bus	30 th bus	30 th bus
% loss reduction	56.61 / 54	28.19 / 27.7	28.25

4.2 Irrua Distribution Network (45-bus) Simulation Results

IDN consists of 45 buses, 44 lines with a total load of 8817 kW and 5596 kVAr. Backward and forward sweep algorithm (BFSA) was used to analyse the load flow in order to identify weak buses. BFA was used to site and size D-STATCom on the network. The proposed algorithm placed D-STATCom on bus 38 with a kVAr value of 5090. Figure 5a shows the improvement in voltage profile after the installation of D-STATCom. It was observed that kW and kVAr losses were reduced by 46.7% and 43.4% respectively after installing D-STATCom as shown in figure 5b.

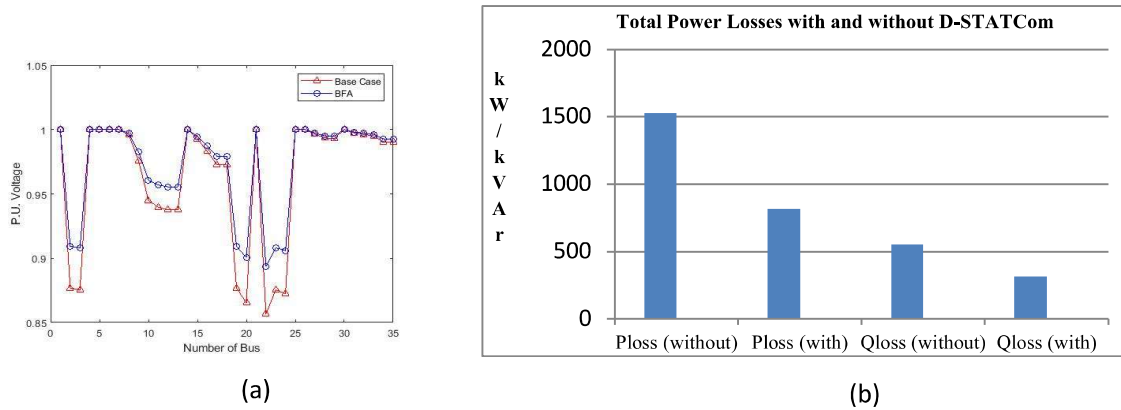


Fig 5: IDN network before and after installing D-STATCom (a) Voltage profile (b) Total power losses

27. CONCLUSION

In the research work, BFA was used to optimally placed and sized D-STATCom on both IEEE 33 bus and IDN. BFSA was used to carry out the load flow analysis while BFA was used to perform the optimal placement and sizing of D-STATCom. The results show that D-STATCom was properly sited and sized on both networks which lead to the significant minimization of total power losses and improvement in the voltage profile when compared to the base case. Some of the benefit of the proposed method is that; it was able to minimize power losses, improve the network voltage profile and the simulation time was short. For future research; D-STATCom should be optimally sited alongside Distributed Generators (DGs) using novel Optimization techniques for multi-objective

function which include costing, voltage stability index, power losses and so on. Artificial Intelligent (AI) should be considered for controlling D-STATCom in a distribution network.

REFERENCES

- [1] A. Aligbe, A. E. Aioboman, A.S. Uyi, and P.E. Orukpe "Microgrid, Its Control and Stability: The State of The Art," *International Journal of Emerging Scientific Research*, vol. 3. January, 2021, doi: 10.37121/ijesr.v3.145.
- [2] A. Samimi, and M. A. Golkar "A Novel Method for Optimal Placement of STATCOM in Distribution Networks Using Sensitivity Analysis by DiGSILENT Software," *IEEE Conference*, 2011.
- [3] P.E. Amaize, A. E. Aioboman, A. Aligbe, K.T. Abayomi and K.O. Okokpujie "An Assessment of Renewable Energy Potentials in Nigeria Using Biogas," *International Journal of Civil Engineering and Technology (IJCIET)*, vol. 9, no. 11, pp. 2938–2948, 2018.
- [4] S. M. S. Hussain and M. Subbaramiah "An Analytical Approach for Optimal Location of DSTATCOM In Radial Distribution System," *IEEE (2013) Conference*, pp. 1365–1369, 2013.
- [5] S. A. Taher and S. A. Afsari, "Optimal location and sizing of DSTATCOM in distribution systems by immune algorithm," *Int. J. Electr. Power Energy Syst. (Elsevier)*, vol. 60, pp. 34–44, 2014, doi: 10.1016/j.ijepes.2014.02.020.
- [6] A. R. Phadke, M. Fozdar, and K. R. Niazi, "A new multi-objective fuzzy-GA formulation for optimal placement and sizing of shunt FACTS controller," *Int. J. Electr. Power Energy Syst. (Elsevier)*, vol. 40, no. 1, pp. 46–53, 2012, doi: 10.1016/j.ijepes.2012.02.004.
- [7] *P. P. Biswas, P. Arora, R. Mallipeddi, P. N. Suganthan, and B. K. Panigrahi, "Optimal placement and sizing of FACTS devices for optimal power flow in a wind power integrated electrical network," pp. 1–27.
- [8] F. Reli, P. Mari, H. Glavaš, and I. Petrović "Influence of FACTS Device Implementation on Integrated Renewable Energy Sources," *mdpi energies*, vol. 13, pp. 1–15, 2020. doi:10.3390/en13205516
- [9] S. Devi and M. Geethanjali, "Optimal location and sizing of Distribution Static Synchronous Series Compensator using Particle Swarm Optimization," *Int. J. Electr. Power Energy Syst. (Elsevier)*, vol. 62, pp. 646–653, 2014, doi: 10.1016/j.ijepes.2014.05.021.
- [10] A. R. Gupta, and A. Kumarb, "Impact of various load models on D-STATCOM allocation in DNO operated distribution network," *6th International Conference on Smart Computing and Communications (Elsevier)*, 2018, doi: 10.1016/j.procs.2017.12.110.
- [11] A. Jain, A. R. Gupta, and A. Kumar, "An Efficient Method for D-STATCOM Placement in Radial Distribution System," *IEEE Conference*, 2014.
- [12] G. Selvaraj, and K. Rajangam "Multi-objective grey wolf optimizer algorithm for combination of network reconfiguration and D - STATCOM allocation in distribution system," *Int Trans Electr Energy Syst (John Wiley)*, pp. 1–21, 2019, doi: 10.1002/2050-7038.12100.
- [13] A. R. Gupta, and A. Kumar, "Energy saving using D-STATCOM placement in radial distribution system under reconfigured network," *5th International Conference on Advances in Energy Research (Elsevier)*, vol. 90, pp. 124–136, 2016, doi: 10.1016/j.egypro.2016.11.177.
- [14] A. A. A. El-ela, M. T. Mouwafi, and A. S. Shammah "Optimal Placement of D-STATCOM in Distribution Systems Using JAYA Algorithm," *IEEE 2018 Twentieth International Middle East Power Systems Conference (MEPCON), Cairo University, Egypt*, pp. 834–838, 2018.
- [15] A. Oloulade, A. M. Imano, A. Viannou, and H. Tamadaho, "Optimization of the number, size and placement of D-STATCOM in radial distribution network using Ant Colony Algorithm," *American Journal of Engineering Research and Reviews (AJOERR)*, pp. 1–13, 2018, doi: 10.28933/AJOERR.
- [16] M. Ebeed, S. Kamel, and A. Youssef, "Optimal Integration of D-STATCOM in RDS by a Novel Optimization Technique," *IEEE 2018 Twentieth International Middle East Power Systems Conference (MEPCON), Cairo University, Egypt*, pp. 638–642, 2018.
- [17] M. H. Nazari, A. Khodadadi, A. Lorestani, S. H. Hosseinian, and G. B. Gharehpetian, "Optimal multi-objective D-STATCOM placement using MOGA for THD mitigation and cost minimization," *Journal of Intelligent & Fuzzy Systems*, vol. 35, pp. 2339–2348, 2018, doi: 10.3233/JIFS-17698.
- [18] M. O. Okelola, S. A. Salimon, O. A. Adegbola, E. I. Ogunwole, S. O. Ayanlade, and B. A. Aderemi, "Optimal Siting and Sizing of D-STATCOM in Distribution System using New Voltage Stability Index and Bat Algorithm," vol. 2, no. 2, pp. 2–6, 2021.