2023 IEEE International Conference on Energy Technologies for Future Grids
Wollongong, Australia, December 3-6, 2023

Reactive power compensator placement using flower pollination algorithm

Ardiaty Arief[1], Hasniaty A.[1], Muhammad Bachtiar Nappu[1], Tajuddin Waris[1], Andi Nur Aulia Azhar Mangkona[1], Arjun[1], Ayu Indryani[1], and Erwin[2]
[1]Power and Energy Systems Research Group, Department of Electrical Engineering, Faculty of Engineering, Hasanuddin University, Gowa 92119, Indonesia
[2]PT. PLN. (Persero) Education and Training Center (Indonesian State Electricity Company), South Jakarta 12550, Indonesia
ardiaty@eng.unhas.ac.id, hasniaty@unhas.ac.id, bachtiar@eng.unhas.ac.id, tajuddin@unhas.ac.id, auliazhar.911@gmail.com, arjunahafizar21@gmail.com, indryanipanne@gmail.com, erwin.7704010@pln.co.id

2023 IEEE International Conference on Energy Technologies for Future Grids (ETFG) | 978-1-6654-7164-0/23/$31.00 ©2023 IEEE | DOI: 10.1109/ETFG55873.2023.10408338

***Abstract*—Reactive power compensator placement is challenging in distribution systems due to several complex factors and considerations, specifically the complex topology of the distribution network and it involves non-convex optimization problems. Therefore, in this study, the allocation of reactive power compensation devices is proposed by using a flower pollination algorithm (FPA) for decreasing active power losses in a distribution network. The objective of this work is to minimalize the total network power losses by optimally defining the position and capacity of the reactive power compensators, in addition to improving the voltage profile. The proposed approach was applied at the IEEE 33 bus radial distribution network (RDN) for single and multi-units compensation. The results attained are compared with several recent optimization approaches. The results show that FPA is an effectual optimization method for finding solutions for reactive compensator placement issues.**

Keywords— distribution network, flower pollination algorithm, power losses, power system optimization, reactive power compensator.

I. Introduction

Reactive power compensator optimal placement holds a crucial task in the planning and operation of the modern power system, contributing to the efficient and reliable transmission and distribution of electrical energy. It aligns with the broader goal of enhancing the performance and sustainability of power systems while meeting the ever-growing energy demand. Reactive power compensator placement in power distribution systems is a challenging optimization problem that aims to find the optimal locations and capacity for installing reactive power compensators to enhance voltage profile, enhance system efficiency, and lessen power losses [1-3].

In an electrical power system, both active power and reactive power are essential for an efficient operation. Reactive power compensators, like capacitors and reactors, are used to manage and regulate the reactive power flow within the system. This control is crucial for maintaining voltage levels, enhancing power transfer capabilities, and minimizing losses.

Various approaches for placing these devices have been developed, which can be categorized into analytical approaches, numerical methods, meta-heuristic techniques, and artificial intelligence (AI) [4, 5]. However, nowadays, meta-heuristic methods have gained popularity due to several reasons that make them well-suited for solving complex optimization problems. Meta-heuristics are versatile and can be utilized for a wide range of optimization problems, they are more general and do not require detailed knowledge about the problem's mathematical properties. In addition, meta-heuristic algorithms are relatively easy to implement and do not require complex mathematical derivations.

Several meta-heuristic methods have been applied to solve reactive power compensator placement effectively. An artificial bee colony (ABC) was developed in [6] for optimal allocation of FACTS. ABC is capable of exploring the solution space extensively, which makes it effective for finding global optima or near-optimal solutions in complex optimization problems, however, it does not exploit problem-specific information and it can converge prematurely. In [7], the firefly algorithm (FA) was implemented for FACTS placement. FA is simple and has good global exploration but some of its main drawbacks are premature convergence, parameter sensitivity, and computational complexity. Genetic Algorithm (GA) was developed for capacitor placement in [8]. GA is capable of performing a global search in a large solution space. Nonetheless, GA can be computationally intensive, especially for complex problems and large solution spaces, and if not properly tuned or if the parameters are set poorly, it can suffer from premature convergence. Whale optimization algorithm (WOA) was developed to determine the optimal place and size of capacitors in [9]. The effectiveness of WOA is influenced by the properties of the problem being solved and the approach taken to address its limitations, but WOA can suffer from premature convergence to local optima, particularly if the population converges too quickly. Particle swarm optimization was hybridized with a genetic algorithm in [10] and called the hybrid PSO-GA. It combines the global exploration abilities of PSO with the genetic operators of GA for local exploitation to create a more robust optimization algorithm. An improved harmony search algorithm (IHSA) is employed in [11] to find the placement and size of the capacitor.

One of the popular meta-heuristic approaches is the flower pollination algorithm (FPA). FPA is one of the most competent nature-enthused meta-heuristic optimization methods, which was introduced by Xin-She Yang in 2012 [12]. FPA is able to balance between exploration and exploitation, which helps it avoid getting stuck in local optima and enhances the chances of finding global optimal solutions. Furthermore, FPA is conceptually straightforward and can be implemented relatively easily without requiring complex mathematical formulations. Hence in this paper, we propose optimal allocation and size of reactive power compensators using a flower pollination algorithm. The proposed technique was implemented on the IEEE 33 bus RDN for placement of 1, 2, and 3 units of reactive compensator.

The following is how this paper is structured. Section 2 goes over the problem formulation in further detail. Section 3 then describes the proposed method, the flower pollination algorithm. Section 4 presents the results and analysis, and Section 5 summarizes the key conclusions of this work.

II. Problem Formulations

Optimal reactive power compensator placement is an optimization problem commonly encountered in electrical power systems, especially in distribution networks. The primary objective is to define the optimal locations and sizes of reactive power compensators to increase the overall system performance by decreasing power losses, enhancing voltage profile, and enhancing energy efficiency. By strategically locating compensators, voltage deviations, and power losses can be minimized, leading to improved overall system performance. The optimal placement of compensators is influenced by the network's topology, load patterns, and generation characteristics. Certain locations may experience higher voltage drops or increased reactive power demand, making them more suitable candidates for compensator installation.

Optimal reactive power compensator placement is a crucial task for enhancing the operational efficiency and reliability of electrical distribution networks. The solution approach chosen should be tailored to the explicit features of the network and the objectives of the optimization problem.

A. *Objective function*

The main objective function in optimal reactive power compensators placement problem is mainly related to the power loss minimization in the distribution network as:

$$f = \min\left(\sum_{j=1}^{n_{br}} \mathrm{P}_{loss(j)}\right) \tag{1}$$

where, n_{br} is the number of line (branch), $\mathrm{P}_{loss(j)}$ is the active power losses at branch j, f is the total active power losses of the distribution network.

B. *System constraints*

1) Equality Constraints

Equality constraints are the equilibrium between the active power and reactive power generated and the active power and reactive power used, as expressed in (2) and (3) as follows [13]:

$$\mathrm{P}_{slack} = \sum_{i=1}^{n_b} \mathrm{P}_{load(i)} + \sum_{j=1}^{n_{br}} \mathrm{P}_{loss(j)} \tag{2}$$

$$\mathrm{Q}_{slack} + \sum_{i=1}^{N_Q} \mathrm{Q}_{SC(i)} = \sum_{i=1}^{n_b} \mathrm{Q}_{load(i)} + \sum_{j=1}^{n_{br}} \mathrm{Q}_{loss(j)} \tag{3}$$

where, P_{slack} is the active power at the slack bus, Q_{slack} is the reactive powers at the slack bus, $\mathrm{P}_{load(i)}$ is the active load at bus i $\mathrm{Q}_{load(i)}$ is the reactive demands at bus i $\mathrm{P}_{loss(j)}$ is the active losses at section j, $\mathrm{Q}_{loss(j)}$ is the reactive losses at section j, n_b is the number of buses, n_{br} is the branches number, N_Q is the total number of buses where the reactive power compensators are placed, and $\mathrm{Q}_{SC(i)}$ is the reactive power injected at bus *i.*

2) Inequality Constraints

Inequality Constraints are expressed in the form of operating constraints as follows:

a) Voltage Limit Function

$$\mathrm{V}_{min} \le \mathrm{V}_i \le \mathrm{V}_{max} \tag{4}$$

where, V_{min} is the lower limit of voltage profile, and V_{max} is the upper limit of voltage profile. The voltage at each bus should be between 0.95 pu to 1.05 pu.

b) Reactive power injection capacity

$$\mathrm{Q}_{SC-min} \le \mathrm{Q}_{SC(i)} \le \mathrm{Q}_{SC-max} \tag{5}$$

where, Q_{SC-min} is the lower bound of the reactive power injection allowed, and Q_{SC-max} is the allowable upper bound of the reactive power injection.

c) Total injection limit

$$\sum_{i=1}^{N_Q} \mathrm{Q}_{SC(i)} \le \sum_{i=1}^{n_b} \mathrm{Q}_{load(i)} \tag{6}$$

III. Flower Pollination Algorithm (FPA)

The FPA is a nature-motivated optimization method that is enthused by the plant pollination process. It is a meta-heuristic optimization technique for problem-solving in optimization and search. The FPA, which was created based on the natural behavior of flowers and their interactions with pollinators such as bees and butterflies, tries to find optimal solutions through iterative phases.

Two types of pollination in FPA are self-pollination and cross-pollination [14]. Self-pollination occurs when pollen from one flower fertilizes another of the same type of flower. Cross-pollination is the transmission of pollen by insects such as birds, bees, and bats over long distances between plants. It's worth mentioning that certain insects favor one flower over another, a phenomenon known as flower constancy.

The formulation of global pollination and floral constancy is based on incorporating the most appropriate bug through long-distance travelers, as detailed below:

$$\mathfrak{x}_i^{t+1} = \mathfrak{x}_i^t + \gamma \mathcal{L}(\lambda)(g_* - \mathfrak{x}_i^t) \tag{7}$$

where, $\mathfrak{x}_i^{t+1}$ is the updated value of the i^{th} solution at iteration $t+1$, t shows the current iteration, $\mathfrak{x}_i^t$ is the existing position of the i^{th} solution, g_* is the global best solution in the ongoing iteration, $\mathcal{L}(\lambda)$ is a stage produced according to the Levy distribution, and γ is the step size scaling parameter.

While the formulation of local pollination is written as follows:

$$\mathfrak{x}_i^{t+1} = \mathfrak{x}_i^t + \beta(\mathfrak{x}_j^t - \mathfrak{x}_k^t) \tag{8}$$

where β is a random number created between 0 and 1 following the uniform distribution, x_j^t and x_k^t are two solutions from different plants designated randomly from the recent population.

Fig. 1 shows the FPA's flowchart and the detailed computational procedure is summarized in pseudo-code as provided in Fig. 2.

IV. Results and Analysis

The proposed FPA approach was implemented on the IEEE 33 bus RDN for optimal placement of 1, 2, and 3 units of reactive compensators. Fig. 3 shows the single-line diagram of the tested system.

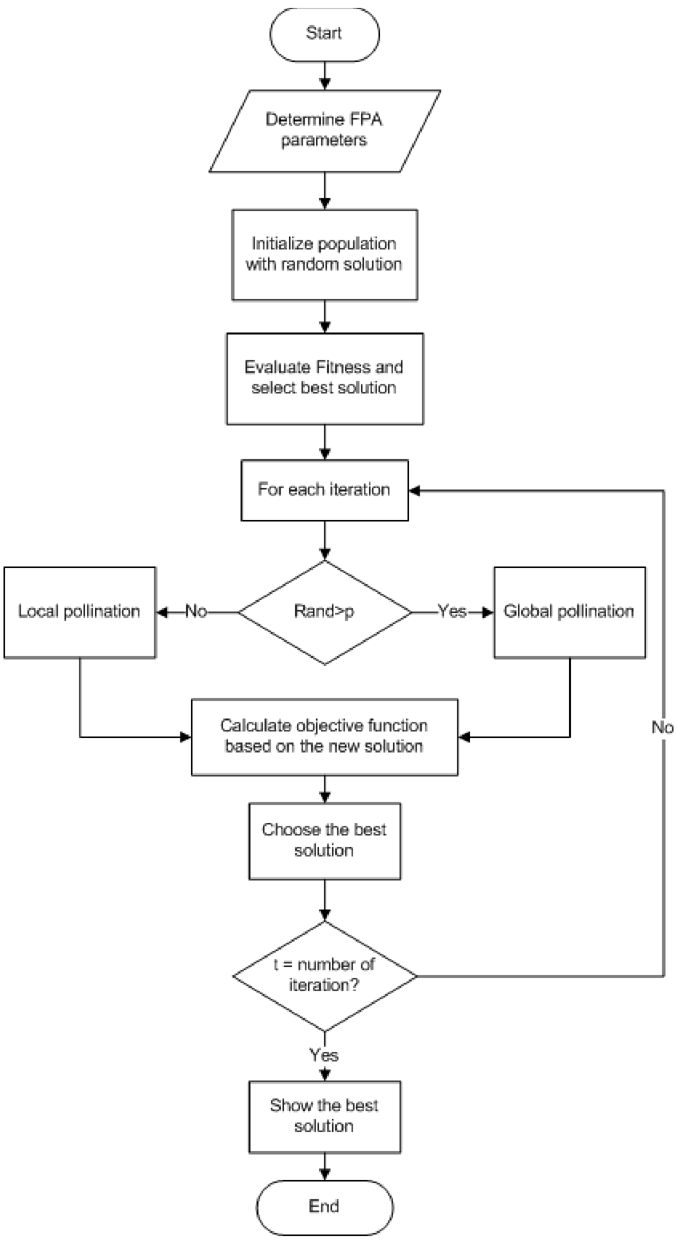

Fig. 1. The FPA flowchart

Objective function min f(x), $f = \min\left(\sum_{j=1}^{n_{br}} P_{loss(j)}\right)$
Initialize a population of candidate solutions (reactive power compensator placements and sizes)
Assess the fitness of each solution in the population
Set the global best solution as the one with the highest fitness
Set the maximum number of iterations (generations)
Set the probability parameter for flower pollination (p)
While *(t<maximum iteration)*
    For *i=1 : n (all n solutions in the population)*
If *rand<p,*
    Get a (d-dimensional) step vector $\mathcal{L}(\lambda)$
    Perform Global pollination through $x_i^{t+1} = x_i^t + \gamma\mathcal{L}(\lambda)(g_* - x_i^t)$
Else
    Obtain from a uniform distribution in [0,1]
    Perform Local pollination through $x_i^{t+1} = x_i^t + \beta(x_j^t - x_k^t)$
Calculate objective function based on new solution
End If
    Assess new solutions
    If new solutions are better, than update them in the population
End While
    Obtain current best solution g_*
End for
Results for the best solution $\min\left(\sum_{j=1}^{n_{br}} P_{loss(j)}\right)$

Fig. 2. The pseudo-code of the proposed method

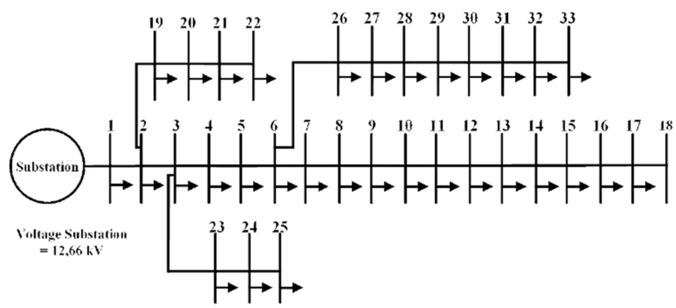

Fig. 3. The test system [15]

A. 1 unit of reactive compensator optimal placement and size

Table I shows the optimal results of a single unit of reactive compensator placement and capacity, where the best location based on FPA is in bus 7 with a capacity of 3200 kVAr. The system losses obtained for this optimization is 184.1230 kW.

TABLE I. FPA Results for 1 unit reactive compensator optimal placement and size

Optimal reactive compensator location (bus)	7
Reactive compensator capacity (kVAr)	3200
Active power losses (kW)	184.1230
Reactive power losses (kVAr)	137.1194

B. 2 units of reactive compensator optimal placement and size

Table II informs the location and size of the reactive compensators for the optimal location of 2 units. The best locations obtained by FPA are buses 15 and 30 with the capacity of 450 kVAr and 1050 kVAr, respectively. The power loss for optimal 2-units placement is 134.2472 kW (active power) and 89.8483 kVAr (reactive power).

TABLE II. FPA RESULTS FOR 2 UNITS REACTIVE COMPENSATOR OPTIMAL PLACEMENT AND SIZE

Optimal reactive compensator location (bus)	15	30
Reactive compensator capacity (kVAr)	450	1050
Active power losses (kW)	134.2472	
Reactive power losses (kVAr)	89.8483	

C. 3 Units of reactive compensator optimal placement and size

The results for 3 units of reactive compensators' optimal placement by using FPA are presented in Table III, where the optimal locations for 3 units of reactive compensators are at buses 11, 30, and 24 with the capacity of 850 kVAr each. The active and reactive power losses after optimization are 137.1654 kW and 91.7496 kVAr.

TABLE III. FPA RESULTS FOR 3 UNITS REACTIVE COMPENSATOR OPTIMAL PLACEMENT AND SIZE

Optimal reactive compensator location (bus)	11	30	24
Reactive compensator capacity (kVAr)	850	850	850
Active power losses (kW)	137.1654		
Reactive power losses (kVAr)	91.7496		

Fig. 4 demonstrates the voltage profile improvement of the tested system after optimal placement and capacity of the reactive compensators. As can be seen from Fig. 4, the voltage profile improves after the injection of reactive compensating devices, but the voltage profile of 1 unit with a capacity of 3200 kVAr at bus 7 informs the best voltage profile compared to 2 and 3 units placement. However, the smallest power loss is obtained for the optimal placement of 3 units.

D. Comparison with other methods

Table IV shows the summary of the optimal placement and size of reactive compensating equipment with some comparative methods. From the literature, we have not found any works for 1 unit optimal placement, hence there is no comparison for the proposed method. For the optimal placement of 2 units, we compare it with the artificial bee colony (ABC) [16]. When placing two units using the ABC method, the power losses can be reduced to 154.0708 kW and 106.4203 kVAr. Meanwhile, by using the FPA method, the power losses can be reduced to 134.2819 kW and 89.8817 kVAr. In placing two units on the IEEE 33 bus RDN, the FPA method is better than the ABC in reducing power losses. Based on the reactive power capacity injected, FPA provides a smaller total capacity of reactive injection than the ABC method. The FPA injects a total reactive power of about 1500 kVAr, while the ABC method injects reactive power with a total of 2250 kVAr.

In placing the three reactive power units, there are two other optimization methods used as comparisons in this study, that are Genetic Algorithm (GA) [17], and Novel Analytical (NA) [18], In the GA method, three reactive power compensator units are placed at buses 32, 15, and 30, with each with a capacity of 360 kVAr, 660 kVAr, and 780 kVAr, respectively. The existence of reactive power injection based on GA can reduce the active power losses to 141.8137 kW. Using the NA method, the reactive power compensator units are placed at bus 14 for 550 kVAr, bus 30 for 480 kVAr, and bus 32 for 330 kVAr, with total power losses become 138.720 kW. With our proposed method, FPA, the optimal locations for 3 units of reactive compensator are at buses 11, 30, and 24 with the capacity of 850 kVAr each, and the active power losses can be reduced to 137.1654 kW, which are smaller than the power losses obtained by GA and NA.

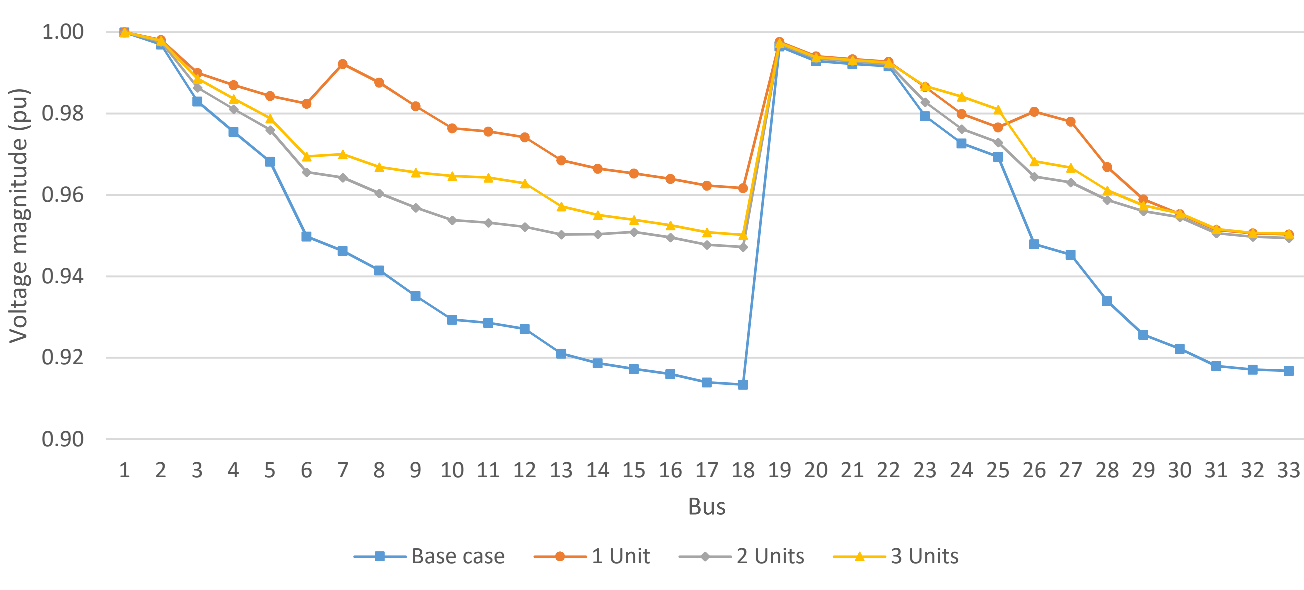

Fig. 4. Voltage profile for the base case and after optimization of 1 unit, 2 units, and 3 units of the reactive power compensator placement

TABLE IV. SUMMARY AND COMPARISON

No	Methods	Optimal location (bus)	Size (kVAr)	Active power losses (kW)	Reactive power losses (kVAr)	Computational time (s)
Single unit						
1	FPA	7	3200	184.1230	137.1194	52.206736
2 units						
2	ABC [16]	30	1750	154.0708	106.4203	-
		14	500			
3	FPA	15	450	134.2472	89.8483	52.954947
		30	1050			
3 units						
4	GA [17]	32	360	141.8137	-	-
		15	660			
		30	780			
5	NA [18]	14	550	138.72	-	-
		30	480			
		32	330			
6	FPA	11	850	137.1654	91.7496	51.008683
		30	850			
		24	850			

V. CONCLUSIONS

This paper presents the optimal placement of reactive power compensation devices with a flower pollination algorithm (FPA) for reducing power losses in a distribution network. The objective of this problem is to decrease the total network power losses by optimally defining the location and size of the reactive power compensators. The FPA method was applied for determining single and multi-units of reactive power compensator. The results obtained are compared with several recent optimization algorithms, such as ABC, GA, and NA. The results show that FPA is more effective than the compared method in determining the optimal location of reactive compensator placement problems to obtain the minimum power losses.

REFERENCES

[1] M. Aryanezhad, "Management and coordination of LTC, SVR, shunt capacitor and energy storage with high PV penetration in power distribution system for voltage regulation and power loss minimization," *International Journal of Electrical Power & Energy Systems,* vol. 100, pp. 178-192, 2018.

[2] A. Selim, S. Kamel, and F. Jurado, "Capacitors Allocation in Distribution Systems Using a Hybrid Formulation Based on Analytical and Two Metaheuristic Optimization Techniques," *Computers & Electrical Engineering,* vol. 85, p. 106675, 2020.

[3] M. Addisu, A. O. Salau, and H. Takele, "Fuzzy logic based optimal placement of voltage regulators and capacitors for distribution systems efficiency improvement," *Heliyon,* vol. 7, p. e07848, 2021.

[4] A. Arief, M. B. Nappu, and Antamil, "Analytical Method for Reactive Power Compensators Allocation," *International Journal of Technology,* vol. 9, pp. 291-319, 2018.

[5] M. M. Aman, G. B. Jasmon, A. H. A. Bakar, H. Mokhlis, and M. Karimi, "Optimum shunt capacitor placement in distribution system—A review and comparative study," *Renewable and Sustainable Energy Reviews,* vol. 30, pp. 429-439, 2014.

[6] M. A. Kamarposhti, H. Shokouhandeh, I. Colak, S. S. Band, and K. Eguchi, "Optimal Location of FACTS Devices in Order to Simultaneously Improving Transmission Losses and Stability Margin Using Artificial Bee Colony Algorithm," *IEEE Access,* vol. 9, pp. 125920-125929, 2021.

[7] A. El-Sherif, G. Elkobrosy, Y. Abouelseoud, and Y. Helmy, "Optimal Placement and Settings of FACTS Devices for Reactive Power Compensation Using a Firefly Algorithm," in *2019 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe)*, 2019, pp. 1-5.

[8] A. Arief, M. B. Nappu, S. Mustafa, Erwin, and S. Thaha, "Optimal capacitor placement in a dominant induction motor loads power system," *Energy Reports,* vol. 8, pp. 592-597, 2022.

[9] A. Osama, H. H. Zeineldin, E. F. T. H.M, and E. F. El-Saadany, "Optimal Placement and Sizing of Capacitor Banks in Radial Distribution Systems Using the Whale Optimization Algorithm," in *2023 IEEE PES Conference on Innovative Smart Grid Technologies - Middle East (ISGT Middle East)*, 2023, pp. 1-5.

[10] G. Upadhyay, R. Saxena, and G. Joshi, "Optimal capacitor placement and sizing in distribution system using hybrid approach of PSO-GA," in *2017 International Conference on Advances in Electrical Technology for Green Energy (ICAETGT)*, 2017, pp. 1-6.

[11] D. Karthikaikannan, R. Gayathri, R. Niranjana, and S. M. Priyadharshni, "Optimal sizing of capacitors in radial distribution system using improved harmony search algorithm," in *2018 IEEE International Conference on System, Computation, Automation and Networking (ICSCA)*, 2018, pp. 1-5.

[12] X.-S. Yang, "Flower Pollination Algorithm for Global Optimization," in *Unconventional Computation and Natural Computation*, Berlin, Heidelberg, 2012, pp. 240-249.

[13] M. A. E.-s. Mohamed El-Saeed, A. F. Abdel-Gwaad, and M. A.-f. Farahat, "Solving the capacitor placement problem in radial distribution networks," *Results in Engineering,* vol. 17, p. 100870, 2023.

[14] M. Abdel-Basset, R. Mohamed, S. Saber, S. S. Askar, and M. Abouhawwash, "Modified Flower Pollination Algorithm for Global Optimization," *Mathematics,* vol. 9, p. 1661, 2021.

[15] J. A. Sa'ed, M. Amer, A. Bodair, A. Baransi, S. Favuzza, and G. Zizzo, "A Simplified Analytical Approach for Optimal Planning of Distributed Generation in Electrical Distribution Networks," *Applied Sciences,* vol. 9, p. 5446, 2019.

[16] S. K. Bilgundi and D. L. Kumar, "Optimal Capacitor Placement in Radial Distribution System Using Artificial Bee Colony Algorithm for Voltage Profile Improvement and Loss Reduction," *International Journal of Science and Research (IJSR),* vol. 6, pp. 2204-2208, 2017.

[17] D. Setianto, O. Penangsang, and R. S. Wibowo, "Minimisasi Rugi Daya Pada Jaringan Distribusi Radial 3 Fasa Menggunakan Genetika Algoritma Untuk Mendapatkan Lokasi Kapasitor Dan DG Yang Optimal," *Jurnal ITS,* 2019.

[18] S. Nawaz, A. K. Bansal, and M. P. Sharma, "A Novel Analytical Technique for Optimal Allocation of Capacitors in Radial Distribution Systems," *Journal of Engineering and Technological Sciences,* vol. 49, 2017.