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Optimizing location and size of capacitors for power loss reduction in radial distribution networks

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ABSTRACT

Power radial distribution systems are increasingly more and more important in transmitting the electric energy from power plants to customers. However, total loss in lines are very high. This issue can be solved by allocating capacitor banks. Determining the suitable allocation and optimal sizing of capacitor banks needs an efficient approach. In this study, the diffusion and update techniques-based algorithm (DUTA) is proposed for such reason. The efficiency of DUTA is inspected on two distribution systems consisting of 15-bus and 33-bus systems with different study cases. The solutions attained by DUTA are competed with recently published methods. As a consequence, the method is more effective than the other methods in terms of the quality of solution.

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NOMENCLATURE

$P_{g,g+1}$	Real power of the branch linking buses *g* and *g+1*
$Q_{g,g+1}$	Reactive power of the branch linking buses *g* and *g+1*
V_g	Magnitude of voltage at bus *g*
N	Number of buses
Q_L	Reactive power of load at bus
Q_{CC}	Compensated reactive power
I_c	Current magnitude of the cth branch
I_c^{max}	The maximum current magnitude of each branch
Z_{best}	The global solution
C	Current iteration
δ	Random number
Q_{min}, Q_{max}	The minimum and maximum rated power of capacitor

V_{min}, V_{max}	The minimum and maximum rated voltage of bus
Z_{r1}, Z_{r2}, Z_{r3}, Z_{r4}, Z_{r5}	Randomly selected solutions
K	Penalized factor

1. INTRODUCTION

Radial distribution systems are transit stations of transferring the electric energy from power plants to customers. Such systems account for large spaces; however, they exist some advantages such as voltage drops, low voltage as well as high power loss. Voltage drops, low voltage and low power quality make a reduction of equipment lifetime, increasing of the energy consumption and the maintenance cost whilst the high-power loss has very economically significant impacts on the overall power system. So far, a solution that has been regarded as the best way for solving such issues, is optimally installing and sizing shunt capacitor units at some buses of radial distribution systems. The work brings a great advantage in minimizing real and reactive power losses, enhancing power factor and voltage profile, and releasing overload of feeders and transformers. Therefore, the optimal capacitor placement and sizing determination problem (OCPSD) is being received more attentions of researchers and operation engineers.

A huge number of researchers have proposed and applied deterministic and meta-heuristic methods for standard radial distribution systems such as 15-bus, 33-bus, 69-bus and 118-bus systems to find the best solution for OCPSD problem. In this paper, we have used 15-bus and 33-bus test systems to implementing an applied method with different study cases. For the first test system, a number of methods as highly efficient method (HEM) [1], particle swarm optimization with time varying inertia weighting (PSO-TVIW) [2], ant colony optimization (ACO) algorithm [3], genetic algorithm (GA) [4] and improved harmony algorithm (IHM) [5] have been recommended. In the studies [2-4], the suitable locations of capacitors have been found by loss sensitivity factor (LSF) technique while the optimal sizes of capacitors have been determined by PSO-TVIW, ACO and GA, respectively. In [5], the mission of determining capacitor placements at candidate buses is assigned to a fuzzy technique while the optimal capacitor size determination is in charge of IHM. For the second test system, many algorithms such as analytical method (AM) [6], grid search algorithm (GSA) [6], golden section search algorithm GSSA [6] and minimization of power losses (MLP) [6], grasshopper heuristic optimization algorithm (GOA) [7], plant growth simulation algorithm (PGSA) [8], two-stage method (TSM) [9], interior point (IP] [10], simulated annealing (SA) [10] and gravitational search method (GSM) [10], flower pollination algorithm (FPA) [11] and ant lion optimizer (ALO) [12] have been successfully applied for implementing the OCPSD problem. In previous method group, the work in [11, 12] has the same manner because the authors have employed FPA and ALO methods to discover both the correct locations and the sizing of capacitor. The combination of K-Mean Clustering and Elbow Technique has been applied for a real distribution network in Vietnam [13]. A dolphin algorithm was suggested in [14] for 16 and 33-buses systems but there has been comparison with previous methods. Distributed generators [15] as well as reconfiguration [16-19] are two solutions for reducing power loss of distribution. Both capacitor placement and reconfiguration were combined to reduce total loss [20]. In addition, static synchronous condenser (STATCOM) was also proposed to improve voltage profile of distribution systems [21]. In general, these proposed solutions could reduce loss and improve voltage; however, the cost of other components is much higher than capacitors.

In this paper, the process for determining both the suitable positions and the ratings of capacitor has been resolved by diffusion and update techniques-based algorithm (DUTA). DUTA was formed by three phase including diffusion phase and two other update phases for creating solutions [22]. The first phase's mission is to explore search spaces by using many new solutions whereas two other phases are in charge of exploit the search space. The experienced results of DUTA method are very promising via executing on 15-bus and 33-bus standard distribution systems. Subsequently, this paper offers some contributions as follows:
- Clearly analysis the structure of DUTA
- Solve OCPSD problem with many study cases by using DUTA
- DUTA can offer favorable solutions

2. OCPSD PROBLEM FORMULATION

2.1. Load flow

Power flow calculation in the distribution network is very essential to analyze or assess the operating state of the distribution system. From here, we can determine voltage at buses, calculate the current running on branches and compute active power losses between two nodes. For this work, a single line diagram of the simple distribution system as displayed in Figure 1 is considered, where g is the sending bus and $g + 1$ is the receiving bus. From Figure 1, equations for the power flows can be established as follows:

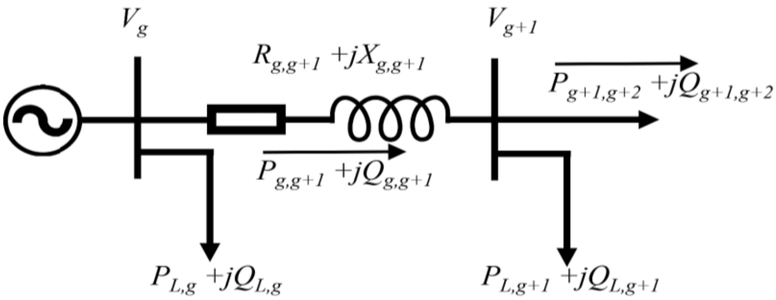

Figure 1. Simple distribution system

$$P_{g,g+1} = P_{g+1} + P_{L,g+1} + R_{g,g+1}\left(P_{g,g+1}^2 + Q_{g,g+1}^2\right)/\left|V_g\right|^2 \quad (1)$$

$$Q_{g,g+1} = Q_{g+1} + Q_{L,g+1} + X_{g,g+1}\left(P_{g,g+1}^2 + Q_{g,g+1}^2\right)/\left|V_g\right|^2 \quad (2)$$

$$V_{g+1}^2 = V_g^2 - 2\left(R_{g,i+1}.P_{g,i+1} + X_{g,i+1}.Q_{g,i+1}\right) + \left(R_{g,i+1}^2 + X_{g,i+1}^2\right).\left(P_{g,g+1}^2 + Q_{g,g+1}^2\right)/\left|V_g\right|^2 \quad (3)$$

From shown in (1) and (2), we can easily deduce the loss of the active and reactive power of the *kth* line between bus *g* and *g+1* as the following equations:

$$P_{\text{Loss(g,g+1)}} = R_{g,g+1}\left(P_{g,g+1}^2 + Q_{g,g+1}^2\right)/\left|V_g\right|^2 \quad (4)$$

$$Q_{\text{Loss}(g,g+1)} = X_{g,g+1}\left(P_{g,g+1}^2 + Q_{g,g+1}^2\right)/\left|V_g\right|^2 \quad (5)$$

The total kW losses of the distribution system (P_Σ) are specified by the following equations:

$$P_\Sigma = \sum_{g=1}^{N} P_{\text{Loss(g,g+1)}} \quad (6)$$

2.2. Objective function

The main target of the capacitor placement in distribution systems is power loss reduction and voltage quality improvement. The objective function (OF) of OCPSD problem can be given by:

$$Minimize P_\Sigma = \sum_{g=1}^{N} P_{\text{Loss(g,g+1)}} \quad (7)$$

2.3. Constraints

- Voltage Constraints: the voltage magnitude at buses is permitted to be between the predetermined limits:

$$Vg\ \mathrm{g}_{max_{min}} \quad (8)$$

- Total Injected reactive power: the sum of the compensated reactive power must be less or equal than that of loads.

$$\sum_{g=1}^{N_c} Q_{cc}(g) \leq \sum_{g=1}^{N} Q_L(g) \quad (9)$$

- Capacitor size and branch current limits: each installed capacitor and current flowing each branch must be constrained by:

$$Qk\ c_{max_{min}} \quad (10)$$

$$|I_c| \leq I_c^{max} \quad (11)$$

3. THE APPLIED DUTA METHOD

DUTA was recommended and developed by adding two update phases to fractal search-based algorithm (FSA) [22, 23]. The author proved that DUTA was capable for solving optimization problems via implementing on some traditional benchmark test functions. In addition, DUTA was also extended to solve complex optimization problems such as economic load dispatch [24], optimal reactive power dispatch problem [25] and optimizing distributed database queries [26]. The searching power of DUTA is based on three phases including diffusion the first update and the second update phases. The mission of such phases is described as follows:

Diffusion mechanism-based search algorithm (DMBSA) is implemented by:

$$Z_d^{new} = \text{Gaussian } (Z_{\text{best}}, \partial) + \delta(Z_{\text{best}} - Z_d);\ \text{d} = 1, \dots, P_s \tag{12}$$

$$Z_d^{new} = \text{Gaussian } (Z_d, \partial) \tag{13}$$

$$\partial = |(Z_{\text{best}} - Z_d).log(c)|/c \tag{14}$$

To use shown in (12) or (13), a comparison between a random number (θ) and a walk factor (ω) is determined. If θ < ω, shown in (12) is assigned and otherwise, shown in (13) is given. Clearly, the value of ω plays a key role in selecting two previous equations. If ω is fixed to 1, new solutions are created by (12). If ω is fixed to 0, new solutions are generated by (12). Otherwise, both as shown in (12) and (13) are used for producing new ones. After performing DMBSA, the first and second updates are implemented by the two following equations:

$$Z_d^{new} = Z_{r1} + \delta(Z_{r2} - Z_d) \tag{15}$$

$$Z_d^{new} = \begin{cases} Z_d^{new} + \delta(Z_{r3} - Z_{r4}) \text{ if } \alpha > 0.5 \\ Z_d^{new} - \delta(Z_{r5} - Z_{\text{best}})\ else \end{cases} \tag{16}$$

4. THE IMPLEMENTATION OF DUTA TO OCPSD PROBLEM

In OCPSD problem, the location and size of capacitors are also controlled by variables corresponding to a solution of DUTA. Such variables are dependent on the number of capacitors added to the system. For calculating the power loss and the voltage at each bus, we run the power flow program using forward–backward sweep technique [27]. The fitness function for assessing solutions is specified by using as shwon in (17);

$$Fitness = \sum \quad Ploss + K(\Delta V + \Delta I) \tag{17}$$

Steps to implement the DUTA for OCPSD problem are presented by the flowchart provided in Figure 2.

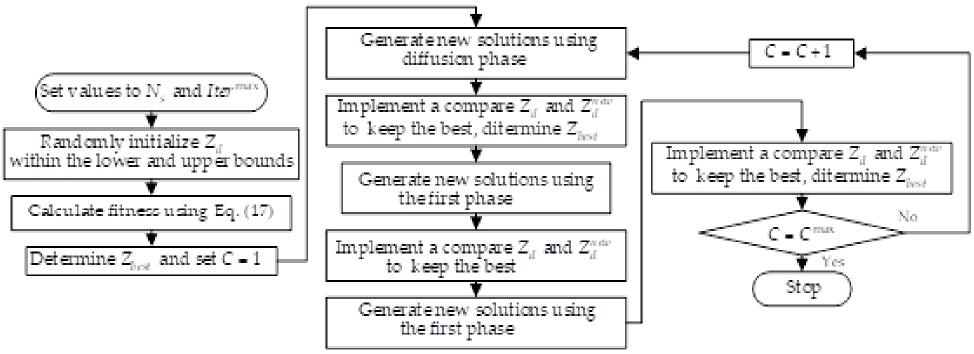

Figure 2. The flowchart of DUTA for implementing OCPSD problem

5. COMPARISON AND DISCUSSION

In this paragraph, an actual performance of DUTA is studied by making the result comparisons of such method to other previous reported methods. Two distribution test systems are employed for solving the optimal capacitor placement problem with two the following intentions:

- Distribution system of 15 buses and 33 buses are used as the basic models for accessing the ability of DUTA.
- Such test systems are regarded as the expediency for surveying different compensated capacitor placements.

5.1. The 15-bus network

The IEEE 15-bus test distribution system has a total load of 1.2264 MW and 1251.2 MVAr. The investigated system is suffered an active power loss of 61.8 kW [1]. Clearly, such power loss is significant that needs to be reduced by adding capacitors. However, a determination of location, the number and size of capacitors has to be selected carefully because it can lead to over compensation. It is for that reason that DUTA is applied for this task with two cases for capacitor placements. Namely, Case 1 install two capacitors while Case 2 adds three capacitors to the system. With each optimization problem, investigating parameters to access the efficacy, sturdiness and stability of the search process of DUTA are extremely important. Wherein population sizes (P_s) and the maximum number of iterations (C^{max}) are two parameters to be investigated.

For case 1, Table 1 shows that the best power loss is 32.306 kW corresponding with P_s = 10 and C^{max}= 30. Clearly, the P_s value is impossible to decrease although C^{max} is increased. However, the standard deviation (STD) value of subcase 1.1D is smaller than that of subcase 1.1C. Figure 3 provides the power loss results of 50 runs from subcase 1.1A to subcase 1.1C whilst Figure 4 shows the best power loss and STD of these subcases.

Table 1. The power loss (kW) obtained from different values of P_s and C^{max} over 50 runs

No	Subcase 1.1A	Subcase 1.1B	Subcase 1.1C	Subcase 1.1D
P_s	5	5	10	10
C^{max}	10	15	30	50
Min loss	32.524	32.312	32.306	32.306
Aver loss	34.668	34.204	32.719	32.515
Max loss	37.563	41.295	37.095	34.678
STD	1.508	1.841	0.898	0.477

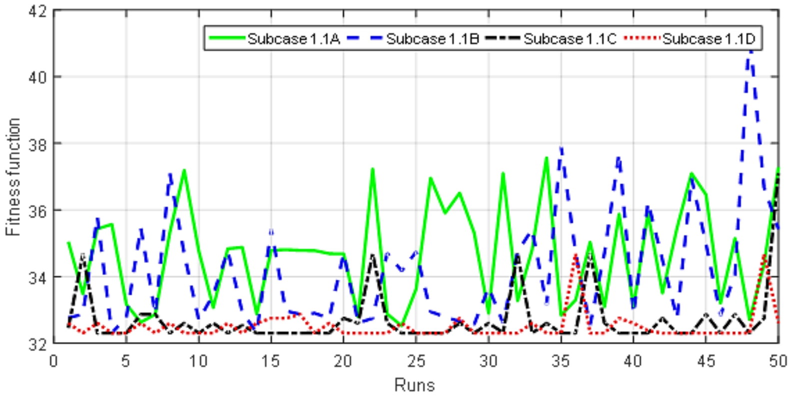

Figure 3. The best power loss of 50 runs from sub-case 1.1A to sub-case 1.1D

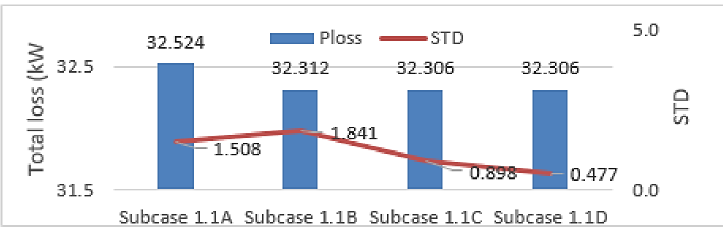

Figure 4. The best power loss and STD for case 1 from sub-case 1.1A to sub-case 1.1D

The results of DUTA are compared to other methods for Case 1 as shown in Table 2. Seeing the table can recognize that DUTA and ACO [3] find the same positions of capacitors but different positions with HEM [1] and PSO-TVIW [2]. However, power loss of DUTA is the smallest while that of ACO [3] is the highest. For Case 2, the process for investigating these mentioned parameters of DUTA is again implemented with the results obtained as displayed in Figure 5. From the figure, the power loss of 31.280 kW is corresponding to P_s = 5 and C^{max}= 10, that of 30.378 kW is corresponding to P_s = 5 and C^{max}= 20. That of 30.338 kW, which is considered as the best power loss, is corresponding to P_s = 10 and C^{max}= 40. If C^{max} is continuously increased to 60, the best power loss does not still change but STD is better. Table 3 shows the optimal results obtained from DUTA and IHA [5] in term of capacitor positions and sizes, total compensation, power loss and minimum voltage. It can be proven that DUTA is superior to IHA. Figure 6 is plotted to illustrate improvement of the first system voltages due to connected capacitors.

Table 2. Result comparison between DUTA and other methods for case 1

Methods	Capacitor node	Size (kVAR)	Total KVAR	Total loss (kW)	Minimum Voltage (p.u)
HEM [1]	3, 6	805, 388	1193	32.6	-
PSO-TVIW [2]	3, 6	871, 321	1192	32.7	-
ACO [3]	4,6	630, 410	1040	36.81	0.95
DUTA	4,6	438.46, 702.64	1141.1	32.306	0.96504

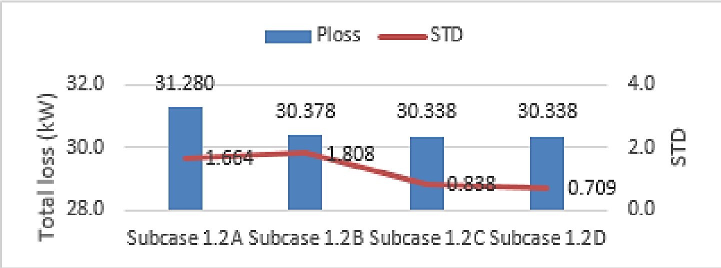

Figure 5. The best power loss and STD for case 1 from sub-case 1.2A to sub-case 1.2D

Table 3. Result comparison between DUTA and other methods for case 2

Methods	Capacitor node	Size (kVAR)	Total KVAR	Total loss (kW)	Minimum Voltage (p.u)
IHA [5]	6, 11, 15	350, 300, 300	950	31.12	0.9658
DUTA	4, 6, 11	488.24, 408.08, 300.1	1197.14	30.34	0.96955

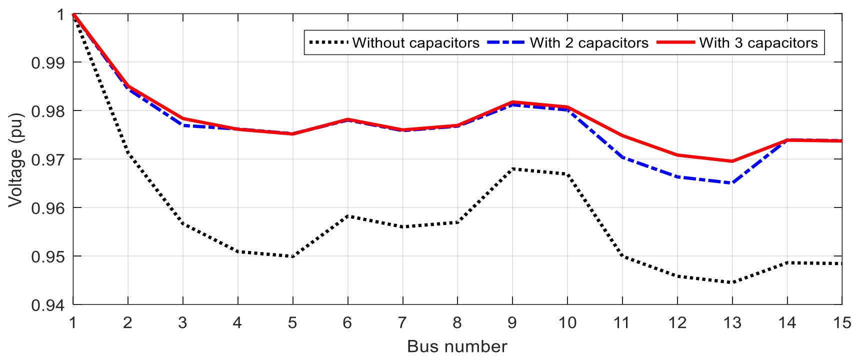

Figure 6. The influence of compensated capacitors on the voltage of 15 bus system

5.2. The 33-node network

This system without compensation has the minimum bus voltage of 0.9038 p.u at bus 18 and total active power loss of 210.97 KW [13]. For purposing loss reduction of such system, DUTA is utilized to seek the correct positions and optimal sizes of capacitors with two survey cases. Single and three capacitors are considered, where two cases are reported in Table 4 and Table 5. For each study case of the system, we also analyze P_s and $C^{max}$to find the best optimal results achieved by DUTA for comparisons. As a result, P_s = 10 and C^{max}= 50 are selected for the case with one capacitor and P_s = 10 and C^{max}= 70 are set for the case with three capacitors. It is seen from Table 4 that DUTA gives capacitor placement, total power loss and minimum voltage like other five methods. This demonstrates that all methods can result in the same as a solution quality.

In case of locating three capacitors, DUTA identifies the optimum positions as bus numbers 13, 24, 30 and optimal sizes as 387.92, 544.21 and 1037.03 kVAR, respectively. Total loss is lessened to 138.372 kW from the base case of 210.97 kW corresponding 34.41% of active power loss rate and the minimum voltage is improved to be 0.9567 pu. As shown in Table 5, total loss from GSA [10] is the smallest but it is easily recognized that GSA uses P_s = 2000 and C^{max}= 400, leading to number of solution generations (P_s x C^{max}) is 800.000. Clearly, this value is very high. From this view, that of DUTA of 138.266 kW is considered as the best result as compared to other methods. This illustrates the performance and effectiveness of DUTA. Furthermore, the voltage profile significantly has been enhanced with installation capacitors as shown Figure 7. The Figure shows the influence of compensated capacitors on the voltage of 33 bus system before and after compensation cases.

Table 4. Result comparison between DUTA and other methods with single capacitor

Methods	Capacitor node	Size (kVAR)	Total loss kW	Minimum Voltage (p.u)
AM [6]	30	1229.8	151.40	0.9162
GSA [6]	30	1265	151.38	0.9165
GSSA [6]	30	1258	151.38	0.9165
MPL [6]	30	1258	151.38	0.9165
GOA [7]	30	1250	151.38	0.916
DUTA	30	1258.01	151.379	0.91648

Table 5. Result comparison between DUTA and other methods with three capacitors

Methods	Capacitor node	Size (kVAR)	Total KVAR	Total loss (kW)	Minimum Voltage (p.u)	P_s	C^{max}
GOA [7]	13, 24, 30	375, 550, 1050	1975	138.27	0.931	40	100
PSGA [8]	6, 28, 29	1200, 760, 200	2160	151.98	0.946	-	-
TSM [9]	7,29,30	850,25,900	1775	144.042	0.9251	-	-
IP [10]	9, 29, 30	450, 800, 900	2150	171.78	0.9501	-	-
SA [10]	10,30,14	450,350,900	1700	151.75	0.9591	-	-
GSA [10]	13, 15, 26	450, 800, 350	1600	134.5	0.9672	2000	400
FPA [11]	13, 24, 30	450, 450, 900	1800	139.08	0.933	20	200
ALO [12]	13, 24, 30	350, 600, 1050	2000	138.372	0.9304	50	100
DUTA	13, 24, 30	387.92, 544.21, 1037.03	1969.16	138.2660	0.94568	10	70

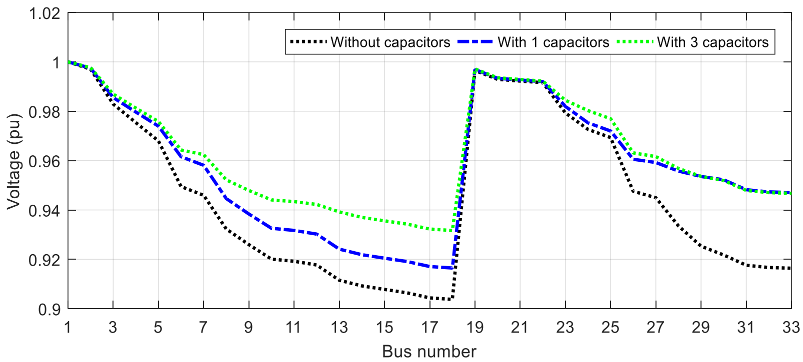

Figure 7. The influence of compensated capacitors on the voltage of the 33bus system

6. CONCLUSION

This work is to use DUTA for the most appropriate location and sizing of fixed capacitor banks in order to reduce total loss as well as improve the voltage profile of the radial distribution network. The applied method is verified on standard 15-bus and 33-bus networks with different study cases. Results achieved from DUTA show that the power losses are decreased while the voltage profile is enhanced. Also, the comparisons of solutions obtained by DUTA with those by recently reported methods indicate that the method can attain approximate or better power loss for all test cases. Therefore, it is possible to imply that the method should be regarded as an effective method for solving OCPSD problem.

REFERENCES

[1] M. H. Haque, “Capacitor placement in radial distribution systems for loss reduction,” *IEE Proceedings-Generation, Transmission and Distribution*, vol. 146, no. 5, pp. 501-505, September 1999.

[2] K. Prakash, M. Sydulu, “Particle swarm optimization-based capacitor placement on radial distribution systems,” *2007 IEEE Power Engineering Society General Meeting*, June 2007.

[3] El-Ela A. A., Kinawy, A. M., Mouwafi, M. T., & El-Sehiemy, R. A., “Optimal sitting and sizing of capacitors for voltage enhancement of distribution systems,” *2015 50th International Universities Power Engineering Conference (UPEC)*, September 2015.

[4] Reddy V. V. K., & Sydulu, M., “2Index and GA based optimal location and sizing of distribution system capacitors,” *2007 IEEE Power Engineering Society General Meeting*, June 2007.

[5] Ali E. S., Elazim, S. A., & Abdelaziz, A. Y., “Improved harmony algorithm and power loss index for optimal locations and sizing of capacitors in radial distribution systems,” *International Journal of Electrical Power & Energy Systems*, vol. 80, pp. 252-263, September 2016.

[6] Aman M. M., *et al*., "Optimum shunt capacitor placement in distribution system—A review and comparative study," *Renewable and Sustainable Energy Reviews*, vol. 30, pp. 429-439, 2014.

[7] Elsayed A. M., *et al*., "Optimal allocation and control of fixed and switched capacitor banks on distribution systems using grasshopper optimisation algorithm with power loss sensitivity and rough set theo," *IET Generation, Transmission & Distribution*, vol. 13, no. 17, pp. 3863-3878, 2019.

[8] Sarma A. K., Rafi K. M., "Optimal selection of capacitors for radial distribution systems using plant growth simulation algorithm," *International Journal of Advanced Science and Technology*, pp. 43-54, January 2011.

[9] Sarma A. K., & Rafi K. M., "Optimal selection of capacitors for radial distribution systems using plant growth simulation algorithm," *International Journal of Advanced Science and Technology*, pp 43-54, January 2011.

[10] Shuaib Y. M., Kalavathi M. S., & Rajan C. C. A., "Optimal capacitor placement in radial distribution system using gravitational search algorithm," *International Journal of Electrical Power & Energy Systems*, vol. 64, pp. 384-397, January 2015.

[11] Tamilselvan V., Jayabarathi T., Raghunathan, T., & Yang X. S., "Optimal capacitor placement in radial distribution systems using flower pollination algorithm," *Alexandria engineering journal*, vol. 57, no. 4, pp. 2775-2786, January 2015.

[12] George T., Youssef A. R., Ebeed M., & Kamel S., "Ant lion optimization technique for optimal capacitor placement based on total cost and power loss minimization," *2018 International Conference on Innovative Trends in Computer Engineering (ITCE)*, pp. 350-358, February 2018.

[13] Duong M. Q., *et al.,* "Combination of K-Mean clustering and elbow technique in mitigating losses of distribution network," *GMSARN International* Journal, vol. 13, pp. 153-158, 2019.

[14] Waleed Khalid Shakir Al-Jubori, Ali Nasser Hussain, "Optimum reactive power compensation for distribution system using dolphin algorithm considering different load models," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 10, no. 5, pp. 5032-5047, October 2020.

[15] Ang S., *et al*., "Sine cosine algorithm for optimal placement and sizing of distributed generation in radial distribution network," *GMSARN International* Journal, vol.12, pp. 202-212, December 2018.

[16] Mohammedi R. D., *et al*., "Optimum network reconfiguration using grey wolf optimizer," *TELKOMNIKA Telecommunication Computing Electronics and Control*, vol. 16, no. 5, pp. 2428-24, September 2018.

[17] Mmary E. R., Marungsri, B., "Integration of multi-renewable energy distributed generation and battery in radial distribution networks," *GMSARN International* Journal, vol. 12, pp. 194-201, 2018.

[18] Mmary E. R., & Marungsri, B., "Multiobjective optimization of renewable distributed generation and shunt capacitor for techno-economic analysis using hybrid invasive weeds optimization," *GMSARN International Journal*, vol. *12*, pp. 24-33, January 2018.

[19] Safitri N., "Non-uniform rooftop PVs distribution effect to improve voltage profile in residential feeder," *TELKOMNIKA Telecommunication Computing Electronics and Control*, vol. 16, no. 4, pp.1388-1395, August 2018.

[20] Kadom H. F., *et al.,* "Dual technique of reconfiguration and capacitor placement for distribution system," *International Journal of Electrical & Computer Engineering*, vol. 10, no. 1, pp.80-90, February 2020.

[21] Alhamrouni M. I., *et al*., "Load flow-based voltage stability indices for voltage stability and contingency analysis for optimal location of statcom in distribution network with integrated distributed generation unit," *TELKOMNIKA Telecommunication Computing Electronics and Control*, vol. 16, no.5, pp. 2302-2315, October 2018.

[22] T. Phan Van Hong, T. Tran The*,* "Economic dispatch in microgrid using stochastic fractal search algorithm," *GMSARN International Journal,* pp. 102-115, September 2017.

[23] Salimi H., "Stochastic fractal search: a powerful metaheuristic algorithm," *Knowledge-Based Systems*, vol. 75, pp. 1-18, February 2015.

[24] Pham L. H., *et al*., "Stochastic fractal search-based method for economic load dispatch," *TELKOMNIKA Telecommunication Computing Electronics and Control*, vol. 17, no. 5, pp. 2535-2546, October 2019.

[25] Van Tran H., *et al.,* "Finding optimal reactive power dispatch solutions by using a novel improved stochastic fractal search optimization algorithm," *TELKOMNIKA Telecommunication Computing Electronics and Control*, vol. 17, no. 5, pp. 2517-2526, October 2019.

[26] Sohal M., *et al*., "A framework for optimizing distributed database queries based on stochastic fractal search," *Int. J. Comp. Sc. and Mob. Computing (JCSMC)*, vol.4, no. 6, pp. 544-55, January 2015.

[27] Augugliaro A., *et al*., "A backward sweep method for power flow solution in distribution networks," *International Journal of Electrical Power & Energy Systems*, vol. 32, no. 4, pp. 271-280, May 2010.