Comprehensive Analysis on Optimal Allocation and Sizing of Distributed Generation Units Using Particle Swarm Optimization Technique

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Abstract - *This paper investigated an optimal allocation and sizing of distributed generation (DG) comprehensively using Particle Swarm Optimization (PSO) algorithm. The objective function of this study is to minimize voltage deviation (VD) and total power loss in a radial distribution system. A 33-bus radial network is used to demonstrate the effectiveness of the proposed algorithm. The result shows the weakest voltage level occurs at bus 18 with 0.8981pu. However, with the allocation of 3 DGs, the percentage voltage performance yields a maximum of 20.19% at bus 22, followed by 19.44% and 17.71% at bus 2 and bus 21 respectively. Thus, bus 19 has 0% voltage performance as expected where it has minimum voltage deviation. The PSO results also indicate the optimal allocation of DG units at bus 18, 14 and 17 with corresponding DG sizes of 1.7154MW, 0.1908MW and 1.6159MW. The analysis shows 89.83% reduction of total power loss in the distribution system. Finally, the algorithm has achieved its objectives by using Type I DG and demonstrates that PSO is an effective method for solving problems concerning an optimal sizing and locating of DG for minimizing voltage deviation and total power loss in the distribution system.*

***Key Words*: Distributed Generation, Particle Swarm Optimization algorithm, Total Power Loss, Voltage Deviation, Voltage Profile.**

1. INTRODUCTION

The complexity of power system makes its operation very complicated on considering a high demand for electricity supply and load density. The primary cause of uncertainty in power system planning is the load demand which is originated due to the variety of electricity supply need from a different class of customers [1]. In such circumstances, there is usually voltage profile degradation, and the voltage profile of a distribution system get reduced as it gets away from the sub-station [2]. Thus, this necessitated delivering electrical power over long transmission and distribution line to meet the ever increase of energy demand [3, 4]. Many conventional ways of electricity generation use primary sources of energy that are non-renewable and as such their exhaustiveness in nature. This calls for the use of distributed generation (DG) and the use of DG technology. DG system is a part of smart grid concept which is currently forming the backbone of a modern distribution system. The DG can, however, be renewable energy source (RES) like photovoltaic, wind turbines, small hydro, biomass etc. or fossil fuel based sources such as internal combustion engines (IC), combustion turbines and fuel cells [5].

Several studies provide benefits of DG in terms of their integrating and modular nature in a competitive electricity market environment. These benefits include power loss reduction [1, 6-11], voltage profile improvement [1, 4, 6, 8, 9], reliability [1, 6-8, 11-13], short lead time and low investment risk [14], relieved transmission and distribution congestion [7], peak demand loss reduction [4], energy loss reduction [4], frequency improvement [7], power factor and stability improvement [4], increase the distribution capacity [8], reduced emissions of pollutants [7, 13] in a distribution system. The contributions to achieving solutions for optimization problems of optimal allocation of DG are reviewed in the following item.

1.1 Literature Review

There are several methods proposed in solving an optimization problem in terms of optimal location and sizing of DG, which can either be conventional or stochastic search algorithms. Example of the traditional technique includes analytical way by exact loss formula [15], a study devoid of bus impedance matrix [16], analysis based on load concentration factor [17], Power Voltage Sensitivity Constant method [18], etc. It is evident from the literature [19] that the conventional or classical method of analysis has the disadvantage of finding the optimal solution for the nonlinear optimization problems. DG allocation is a nonlinear optimization problem where traditional optimization techniques are not appropriate for solving. Additional issue is the consideration of a criterion to decide whether a local solution is also a global solution. The advent of stochastic search algorithms has provided alternative approaches for solving optimal DG allocation problems. These population-based techniques exterminate most of the difficulties of classical methods. Many of these stochastic search algorithms have already been developed and successfully implemented to solve optimal DG placement problems [20].

Appropriate sizing and allocating of DG will reduce total loss and increase the overall performance of the distribution system. However, improper DG placement and sizing may affect the DG's benefits negatively such as an increase in system power losses and costs [1, 3, 21-23], which can either be in a steady state or dynamic form [24]. Thus, the allocation of DG unit in a best place and preferable size in distribution systems are categorized as a complex combinatorial optimization problem [25]. Previous studies have reported different optimization techniques to solve optimal allocation and sizing of DG units for different DGs' issues. For instance, an Adaptive Quantum-inspired Evolutionary Algorithm (AQiEA) [21], Feasibility-Preserving Evolutionary Optimization [6], Genetic Algorithm (GA) [4, 26], Dragonfly algorithm [7], Firefly algorithm [27], Chaotic stochastic fractal search algorithm [28], Crow Search Algorithm [29], Nature Inspired Algorithms [30], Particle Swarm Optimization (PSO) Algorithm [31, 32], artificial immune system (AIS) [33], Multi-objective Evolutionary Algorithm with Tables (MEAT) [34], Ant Lion Optimization algorithm (ALOA) [35], Modified Shuffled Frog Leaping optimization Algorithm (MSFLA) [36], bacterial foraging optimization [37], Bat-inspired algorithm [38], Social Learning Particle Swarm Optimization (SLPSO) algorithm [39], Bat-inspired algorithm [40], Chaotic Artificial Bee Colony (CABC) algorithm [41], Cuckoo Search Algorithm (CSA) [42], Differential Evolution (DE) [43], Evolutionary Programming (EP) [44], and Gravitational Search Algorithm (GSA) [23].

However, the algorithms mentioned above have examined different test cases with different types of DG units for the objective function. Type I to type IV DGs are identified by researchers in [3, 8, 11, 14, 45-47] where in type I - the DG inject active power and operates at unity power factor; type II – the DG injects reactive power; type III – the DG injects both kW and kVAr such as synchronous machines, and type IV – the DG consume reactive power but injecting active power like in induction generators, respectively.

This paper utilizes the PSO technique to obtain the optimal size and location of three DGs in a distribution network with objective function of improving voltage profile, minimizing voltage deviation and reducing total power loss of a distribution system.

2. PROBLEM FORMULATION

One of the primary emphasis concerning a DG placement and sizing is to minimize voltage deviation and also reduce the active power loss. However, optimal solutions may face some technical and geographical issues. An alternative solution is to find the optimal DG location and the corresponding minimum size required to achieve a certain planned power loss [48]. The distribution system Power losses have always been an essential issue due to the energy efficiency and the costs for electricity supplies [40].

2.1 Objective function

The objective of the optimal size and location of DG problem using PSO is to increase voltage profile and minimize the total active power loss of the distribution system subject to constraints.

2.1.1 Power loss minimization

$$P_{loss} = min \sum_{i=1}^{n} I_i^2 R_i \qquad (1)$$

Where i is the branch number, n total number of branches and I_i is the ith active current.

2.1.2 Voltage Deviation (VD)

The objective function to improve voltage profile involves computation of voltage deviations as in Equation 2.

$$VD = \sum_{i=1}^{n} |(V_i - 1)| \qquad (2)$$

2.1.3 Percentage voltage performance (PVP)

This is the ratio of the difference between VD at base and VD at DG to VD at base and is given by Equation 3.

$$PVP = \frac{VD_{Base} - VD_{DG}}{VD_{Base}} \times 100 \qquad (3)$$

2.1.4 Constraints

Bus Voltage Limits: This is considered to be ±5% of the nominal voltage value, (V_i) and is given by Equation 4.

$$0.95 \le V_i \le 1.05 \qquad (4)$$

DG constraints: This is a DG size (P_{DG}) limit between the maximum and minimum capacity given by Equation 5. Since type I DG is considered for this study, only active power limit is provided. Thus,

$$1kW \le P_{DG} \le 2MW \qquad (5)$$

3.PARTICLE SWARM OPTIMIZATION (PSO) ALGORITHMS

Particle swarm optimization (PSO) algorithms are nature-inspired population-based metaheuristic algorithms [40, 49-52]. These algorithms mimic the social behavior of birds flocking and fishes schooling. The benefits of Particle Swarm Optimization over other conventional techniques include:

i. PSO is based on the intelligence [46, 52].
ii. PSO requires few particles to be regulated. The search can be carried out by the speed of the particle [46, 50, 52].
iii. PSO gives faster convergence to a solution close to the optimal [46, 49, 50].

The main steps in PSO algorithm implementation [53] is given as

Initialize Population
repeat
Calculate fitness values of particles
Modify the best particles in the swarm
Choose the best particle
Calculate the velocities of particles
Update the particle positions
until requirements are met.

4. Simulation Results and discussion

To appraise the performance of PSO algorithm in the application of DG planning problem, the 33-bus radial distribution system is simulated using MATLAB 2016a software. The PSO is used to find the optimal location and sizing of DG for the minimization of voltage deviation and total loss of the network.

4.1 The 33-bus distribution system

The single line diagram of 33-bus system [54] is shown in Figure 1. The system voltage is 12.66 kV and total system active loads are 3715 kW. This test system consists of 33 buses and 32 branches.

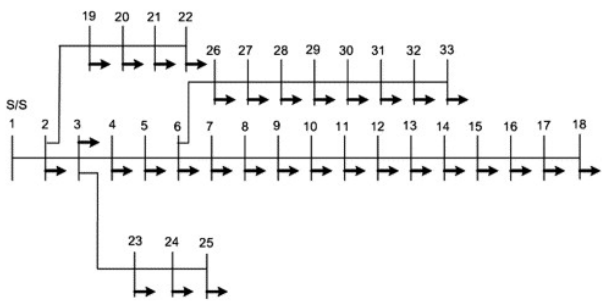

Fig – 1: Single line diagram of 33-bus distribution system

4.2 Established objective function

Like any other metaheuristic algorithm, PSO' s performance is dependent on the values of its parameters. Therefore, the PSO parameters used for this study are used as follows: number of populations is set to 50 and maximum number of iterations is set to 100. The acceleration constant = 0.1, the Initial inertia weight = 0.9 and final inertia weight = 0.4. The minimum global error gradient = 1e-10.

The convergence characteristics for the simulation is plotted on Figure 2. the figure shows the effectiveness of the choice of the proposed PSO technique in avoidance of premature convergence.

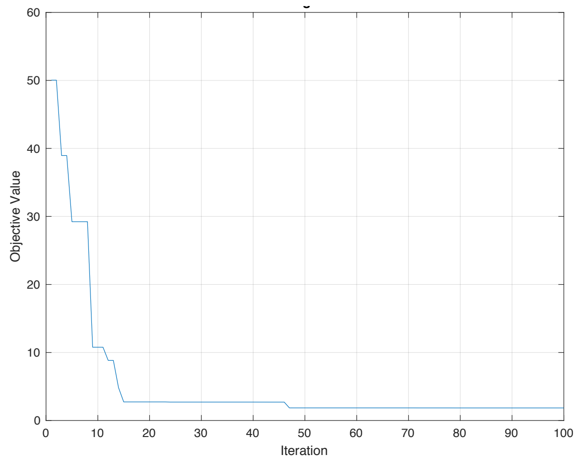

Fig – 2: The PSO convergence characteristics

4.3 Voltage deviation without and without DG allocation.

The values of base voltage and the voltage with the allocation of three DG units using PSO technique are arranged in table 1. The bus 1 has maximum potential of 1pu and seconded with bus 22 that has 0.99pu. The base voltage recorded its weakest voltage level at bus 18 with 0.8981pu. However, with the allocation of 3 DGs at bus locations 18, 14 and 17, the voltage deviation of each bus has changed with an exception of bus 1 and bus 22.

Table -1: Voltage deviation without and with DG of 33-bus system

Bus number	Base voltage (pu)	Volt with DG (pu)	Base voltage deviation	Volt with DG deviation
1	1.000	1.000	0.000	0.000
2	0.996	0.997	0.004	0.003
3	0.980	0.981	0.020	0.019
4	0.971	0.972	0.029	0.028
5	0.962	0.964	0.038	0.036
6	0.941	0.942	0.059	0.058
7	0.937	0.938	0.064	0.062
8	0.931	0.933	0.069	0.067

9	0.924	0.926	0.077	0.075
10	0.917	0.919	0.083	0.081
11	0.916	0.919	0.084	0.082
12	0.914	0.917	0.086	0.083
13	0.907	0.910	0.093	0.090
14	0.904	0.908	0.096	0.092
15	0.903	0.906	0.097	0.094
16	0.901	0.905	0.099	0.095
17	0.899	0.903	0.101	0.097
18	0.898	0.903	0.102	0.097
19	0.996	0.996	0.004	0.004
20	0.991	0.993	0.009	0.007
21	0.990	0.992	0.010	0.008
22	0.990	0.992	0.010	0.008
23	0.975	0.977	0.025	0.023
24	0.967	0.970	0.033	0.030
25	0.963	0.966	0.037	0.034
26	0.938	0.942	0.062	0.058
27	0.935	0.939	0.065	0.061
28	0.922	0.926	0.078	0.074
29	0.913	0.916	0.088	0.084
30	0.908	0.912	0.092	0.088
31	0.904	0.908	0.097	0.092
32	0.903	0.907	0.098	0.093
33	0.902	0.907	0.098	0.093

4.4 Percentage voltage performance (PVP)

The voltage performance improvement for the 33-bus distribution system can be obtained using voltage deviation. The use of PSO has yield a significant voltage performance where it records maximum performance of 20.19% at bus 22 whereas bus 19 record minimum performance with 0% as expected since bus 19 has minimum voltage deviation. The percentage voltage performance of the 33-bus distribution system is shown in Figure 3.

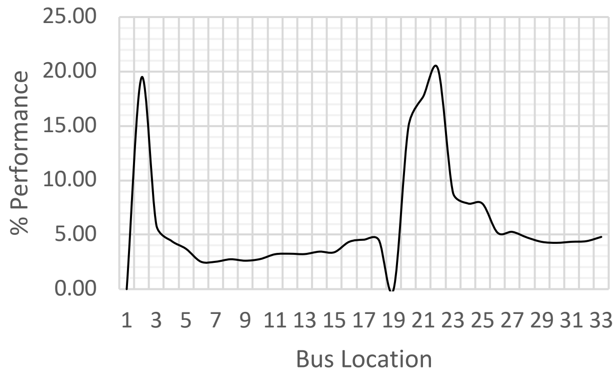

Fig - 3: Percentage voltage performance of 33-bus distribution system

4.5 Optimal locations and DG sizes

Figure 4 shows the optimal locations and sizes of the DGs. DG units of 1.7154MW, 0.1908MW and 1.6159MW are to be installed at bus locations 18, 14 and 17 respectively with total DG capacity of 3.5221MW. The simulation indicated significant reduction of total power loss as a result of allocating of DG from 0.2233MW to 0.0227MW, which is corresponding to 89.83% reduction.

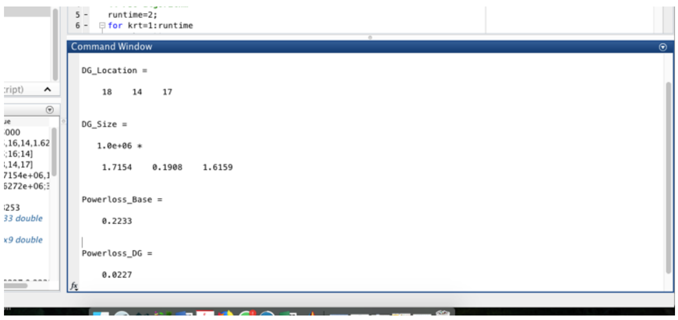

Fig - 4: Extract from MATLAB software environment indicating the DG location, Size and total power loss from the simulation

5. CONCLUSION

This paper presents the allocation and sizing of DG using PSO technique to minimize voltage deviation and total power loss in a radial distributed system. The performance of the algorithm in the application of DG planning is implemented on 33-bus radial distribution network. The results obtained from running of the algorithm shows that the objectives of this investigation have been achieved. Thus, the result demonstrates that PSO is an effective method for solving problems concerning an optimal sizing and locating of DG for minimizing voltage deviation and total power loss in a distribution network.

REFERENCES

[1] N. Kanwar, N. Gupta, K. R. Niazi, and A. Swarnkar, "Optimal distributed generation allocation in radial distribution systems considering customer-wise dedicated feeders and load patterns," *J. Mod. Power Syst. Clean Energy*, vol. 3, no. 4, pp. 475–484, 2015.

[2] M. Kashyap, S. Kansal, and B. P. Singh, "Optimal installation of multiple type DGs considering constant, ZIP load and load growth," *International Journal of Ambient Energy*, 2018.

[3] M. S. Sujatha, V. Roja, and T. N. Prasad, "Multiple DG Placement and Sizing in Radial Distribution System Using Genetic Algorithm and Particle Swarm Optimization," *Ch. Satyanarayana et al., Computational Intelligence and Big Data Analytics, Springer Briefs in Forensic and Medical Bioinformatics*, https://doi.org/10.1007/978-981-13-0544-3_3, 2019.

[4] M. Kashyap, A. Mittal, and S. Kansal, "Optimal Placement of Distributed Generation Using Genetic Algorithm Approach," *In V. Nath and J. K. Mandal (eds.), Proceeding of the Second International Conference on Microelectronics, Computing & Communication Systems (MCCS 2017), Lecture Notes in Electrical Engineering 476*, https://doi.org/10.1007/978-981-10-8234-4_47, 2019.

[5] A. Uniyala and A. Kumar, "Optimal Distributed Generation Placement with Multiple Objectives Considering Probabilistic Load " *Procedia Computer Science* vol. 125, pp. 382–388, 2018.

[6] S. Koziel, A. L. Rojas, M. F. Abdel-Fattah, and S. Moskwa, "Power Loss Reduction Through Network Reconfiguration and Distributed Generation by Means of Feasibility-Preserving Evolutionary Optimization," presented at the EngOpt 2018 Proceedings of the 6th International Conference on Engineering Optimization, 2019.

[7] M. C. V. Suresh and E. J. Belwin, "Optimal DG placement for benefit maximization in distribution networks by using Dragonfly algorithm," *Renewables* vol. 5, no. 4, 2018.

[8] D. P. R. P, V. R. V.C, and G. M. T, "Optimal renewable resources placement in distribution networks by combined power loss index and whale optimization algorithms," *Journal of Electrical Systems and Information Technology*, 2017.

[9] E. Karatepe, F. Ugranlı, and T. Hiyama, "Comparison of single- and multiple-distributed generation concepts in terms of power loss, voltage profile, and line flows under uncertain scenarios," *Renewable and Sustainable Energy Reviews*, vol. 48, pp. 317–327, 2015.

[10] V. V. S. N. Murty and A. Kumar, "Optimal placement of DG in radial distribution systems based on new voltage stability index under load growth," *Electrical Power and Energy Systems*, vol. 69, pp. 246–256, 2015.

[11] B. Patnaik, D. Sattianadan, M. Sudhakaran, and S. S. Dash, "Optimal Placement and Sizing of Solar and Wind Based DGs in Distribution Systems for Power Loss Minimization and Economic Operation," *In C. Kamalakannan et al. (eds.), Power Electronics and Renewable Energy Systems, Lecture Notes in Electrical Engineering 326, DOI 10.1007/978-81-322-2119-7_36*, 2015.

[12] R. Fanish and J. S. Bhadoriya, "Optimal Placement of Multi DG in 33 Bus System Using PSO," *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, vol. 4, no. 4, 2015.

[13] K. Sandhya and D. S. K. Kanth, "Active Power Loss Minimization In Radial Distribution System Using Network Reconfiguration In The Presence Of Distributed Generation," *International Journal of Advances in Electronics and Computer Science*, vol. 2, no. 6, 2015.

[14] B. Singh and D. K. Mishra, "A survey on enhancement of power system performances by optimally placed DG in distribution networks," *Energy Reports*, vol. 4, pp. 129-158, 2018.

[15] M. Mirzaei, J. Jasni, H. Hizam, N. I. A. Wahab, and E. Moazami, "A Combined Analytical Method for Optimal Location and Sizing of Distributed Generation Considering Voltage Stability and Power Loss in a Power Distribution System," *Pertanika J. Sci. & Technol.*, vol. 25, no. 1, pp. 29 - 42, 2017.

[16] A. Tah and D. Das, "Novel analytical method for the placement and sizing of distributed generation unit on distribution networks with and without considering P and PQV buses," *International Journal of Electrical Power & Energy Systems*, vol. 78, pp. 401-413, 2016.

[17] M. Shahzad, I. Ahmad, W. Gawlik, and P. Palensky, "Load Concentration Factor Based Analytical Method for Optimal Placement of Multiple Distribution Generators for Loss Minimization and Voltage Profile Improvement," *Energies*, vol. 9, no. 287, 2016.

[18] S. Nawaz, A. K. Bansal, and M. P. Sharma, "A Novel Approach for Multiple DG Allocation in Real Distribution System," *International Journal of Engineering and Technology (IJET)*, vol. 9, no. 2, 2017.

[19] A. Marimuthu, K. Gnanambal, R. P. Eswari, and T. Pavithra, "Optimal Location and Sizing of DG Units to Improve The Voltage Stability in The Distribution System Using Particle Swarm Optimization Algorithm with Time Varying Acceleration Coefficients," *GRD Journals | Global Research and Development Journal for Engineering | International Conference on Innovations in Engineering and Technology*, 2016.

[20] S. S. P. K. Roy, "Krill Herd Algorithm for Optimal Location of Distributed Generator in Radial Distribution System," *Applied Soft Computing Journal* 2015.

[21] G. Manikanta, A. Mani, H. P. Singh, and D. K. Chaturvedi, "Simultaneous Placement and Sizing of DG and Capacitor to Minimize the Power Losses in Radial Distribution Network," *at K. Ray et al. (eds.), Soft Computing: Theories and Applications, Advances in Intelligent Systems and Computing 742, https://doi.org/10.1007/978-981-13-0589-4_56,* 2019.

[22] M. A. Darfoun and M. E. El-Hawary, "Multi-objective Optimization Approach for Optimal Distributed Generation Sizing and Placement," *Electric Power Components and Systems,* no. 43, p. 8, 2015.

[23] S. a. Daud, A. F. A. Kadir, C. K. Gan, A. R. Abdullah, M. F. Sulaima, and N. H. Shamsudin, "Optimal Placement and Sizing of Renewable Distributed Generation via Gravitational Search Algorithm," *Applied Mechanics and Materials,* vol. 785, pp. 556-560, 2015.

[24] B. Rout and N. M. Pindoriya, "Active Distribution Network Analysis-A Case Study," *2018 IEEE Innovative Smart Grid Technologies - Asia (ISGT Asia),* 2018.

[25] H. HassanzadehFard and A. Jalilian, "Optimal sizing and siting of renewable energy resources in distribution systems considering time varying electrical/heating/cooling loads using PSO algorithm," *International Journal of Green Energy,* vol. 15, no. 2, pp. 113-128, 2018.

[26] A. Hasibuan, S. Masri, and W. A. F. W. B. Othman, "Effect of distributed generation installation on power loss using genetic algorithm method," *IOP Conference Series: Materials Science and Engineering,* vol. 308, no. 012034, 2018.

[27] M. H. Sulaiman, M. W. Mustafa, A. Azmi, Aliman, O., and S. R. Abdul Rahim, "Optimal allocation and sizing of Distributed Generation in distribution system via Firefly Algorithm.," presented at the 2012 IEEE International Power Engineering and Optimization Conference. , 2012.

[28] T. P. Nguyen, T. T. Tran, and D. N. Vo, "Improved stochastic fractal search algorithm with chaos for optimal determination of location, size, and quantity of distributed generators in distribution systems," *Neural Computing and Applications,* 2018.

[29] S. M. Ismael, S. H. E. A. Aleem, and A. Y. Abdelaziz, "Optimal Sizing and Placement of Distributed Generation in Egyptian Radial Distribution Systems Using Crow Search Algorithm," *2018 International Conference on Innovative Trends in Computer Engineering (ITCE), Aswan, Egypt* 2018.

[30] A. Ramamoorthy and R. Ramachandran, "Optimal Siting and Sizing of Multiple DG Units for the Enhancement of Voltage Profile and Loss Minimization in Transmission Systems Using Nature Inspired Algorithms," *The Scientific World Journal,* 2016.

[31] D. B. Prakash and C. Lakshminarayana, "Multiple DG Placements in Distribution System for Power Loss Reduction Using PSO Algorithm," *Procedia Technology,* vol. 25, pp. 785-792, 2016.

[32] S. R. Ramavat, S. P. Jaiswal, N. Goel, and V. Shrivastava, "Optimal Location and Sizing of DG in Distribution System and Its Cost–Benefit Analysis," *in. H. Malik et al. (eds.), Applications of Artificial Intelligence Techniques in Engineering, Advances in Intelligent Systems and Computing 698, https://doi.org/10.1007/978-981-13-1819-1_11,* 2019.

[33] A. Y. Hatata, G. Osman, and M. M. Aladl, "An optimization method for sizing a solar/wind/battery hybrid power system based on the artificial immune system," *Sustainable Energy Technologies and Assessments,* vol. 27, pp. 83-93, 2018.

[34] H. M. G. C. Branco, M. Oleskovicz, D. V. Coury, and A. C. B. Delbem, "Multiobjective optimization for power quality monitoring allocation considering voltage sags in distribution systems," *International Journal of Electrical Power & Energy Systems,* vol. 97, pp. 1-10, 2018.

[35] E. S. Ali, S. M. Abd Elazim, and A. Y. Abdelaziz, "Optimal allocation and sizing of renewable distributed generation using ant lion optimization algorithm," *Electrical Engineering,* vol. 100, no. 1, pp. 99-109, 2016.

[36] L. D. Arya and A. Koshti, "Modified Shuffled Frog Leaping Optimization Algorithm Based Distributed Generation Rescheduling for Loss Minimization," *J. Inst. Eng. India Ser. B,* 2018.

[37] M. I. A and K. M, "Optimal size and siting of multiple distributed generators in distribution system using bacterial foraging optimization," *Swarm and Evolutionary Computation,* vol. 15, pp. 58–65, 2014.

[38] J. E. Candelo and H. H. n. Riaño, "Location and Size of Distributed Generation to Reduce Power Losses using a Bat-inspired Algorithm," *Conference: VII Simposio Internacional sobre la Calidad de la Energía Eléctrica - SICEL, At http://www.revistas.unal.edu.co/index.php/SICEL, Volume: 7. DOI: 10.13140/2.1.1594.9603,* 2013.

[39] R. Arulraj and N. Kumarappan, "Optimal Single and Multiple DG Installations in Radial Distribution Network Using SLPSO Algorithm," *In M.C. Bhuvaneswari and J. Saxena (eds.), Intelligent and Efficient Electrical Systems, Lecture Notes in Electrical Engineering 446, https://doi.org/10.1007/978-981-10-4852-4_8,* 2018.

[40] J. E. Candelo-Becerra and H. E. Hernández-Riaño, "Distributed generation placement in radial

distribution networks using a bat-inspired algorithm," *DYNA,* vol. 82, no. 192, 2015.

[41] M. Natarajan, R. Balamurugan, and L. Lakshminarasimman, "Optimal Placement and Sizing of DGs in the Distribution System for Loss Minimization and Voltage Stability Improvement using CABC," *International Journal on Electrical Engineering and Informatics,* vol. 7, no. 4, pp. 679-690, 2015.

[42] T. Yuvaraj, K. Ravi, and K. R. Devabalaji, "Optimal Allocation of DG and DSTATCOM in Radial Distribution System Using Cuckoo Search Optimization Algorithm," *Modelling and Simulation in Engineering,* 2017.

[43] N. I. A. Wahab, A. S. Hammadi, and M. L. Othman, "Optimal Location and Size of Distributed Generation to Reduce Power Losses based on Differential Evolution Technique," *Pertanika J. Sci. & Technol.,* vol. 25, no. 5, pp. 169-178, 2017.

[44] A. F. A. Kadir, A. Mohamed, H. Shareef, and M. Z. C. Wanik, "Optimal placement and sizing of distributed generations in distribution systems for minimizing losses and THDv using evolutionary programming," *Turkish Journal of Electrical Engineering & Computer Sciences,* vol. 21, pp. 2269 – 2282, 2013.

[45] S. Nawaz, M. Sharma, and A. Tandon, "A New Approach for Power Loss Minimization in Radial Distribution Networks," *In H. Malik et al. (eds.), Applications of Artificial Intelligence Techniques in Engineering, Advances in Intelligent Systems and Computing 697, https://doi.org/10.1007/978-981-13-1822-1_1*, 2019.

[46] A. Apparao and K. Bhashna, "Optimal Allocation of DG Considering Loss Minimization and Voltage Profile Using PSO," *International Journal of Science and Research (IJSR). Paper ID: SUB158085,* vol. 4, no. 9, pp. 659 - 663, 2015.

[47] A. El-Fergany, "Study impact of various load models on DG placement and sizing using backtracking search algorithm," *Applied Soft Computing,* vol. 30, pp. 803-811, 2015.

[48] A. Y. Abdelaziz, Y. G. Hegazy, W. El-Khattam, and M. M. Othman, "Optimal Planning of Distributed Generators in Distribution Networks Using Modified Firefly Method," *Electric Power Components and Systems,* vol. 43, no. 3, pp. 320-333, 2015.

[49] A. Kaveh, "Particle Swarm Optimization," in *Advances in Metaheuristic Algorithms for Optimal Design of Structures*, 2017, pp. 11-43.

[50] O. A. Zongo and A. Oonsivilai, "Optimal placement of distributed generator for power loss minimization and voltage stability improvement " *Energy Procedia* vol. 138, pp. 134–139, 2017.

[51] S. P. Ghanegaonkar and V. N. Pande, "Coordinated optimal placement of distributed generation and voltage regulator by multi-objective efficient PSO algorithm," in *2015 IEEE Workshop on Computational Intelligence: Theories, Applications and Future Directions (WCI)*, 2015, pp. 1-6.

[52] Q. Bai, "Analysis of Particle Swarm Optimization Algorithm," *Computer and Information Science,* vol. 3, no. 1, 2010.

[53] D. Karaboga and B. Akay, "A comparative study of Artificial Bee Colony algorithm," *Applied Mathematics and Computation,* vol. 214, pp. 108–132, 2009.

[54] S. Tamandani, M. Hosseina, M. Rostami, and A. Khanjanzadeh, "Using Clonal Selection Algorithm to Optimal Placement with Varying Number of Distributed Generation Units and Multi Objective Function," *World Journal Control Science and Engineering,* vol. 2, no. 1, 2014.

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