

DISTRIBUTED GENERATION ALLOCATION IN DISTRIBUTION NETWORK FOR ENERGY LOSSES REDUCTION

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Abstract: This paper presents a method for distributed generation (DG) allocation in medium voltage (MV) distribution system based on energy loss minimization. The main objective of the research is to design, implement and test a DG allocation (siting and sizing) method and to investigate how optimal DG allocation influence the operational parameters of the system from the Distribution System Operator (DSO) perspective. The problem is formulated as a single objective optimization problem solved by using both genetic algorithm and particle swarm optimization techniques. Model of a realistic Electric Power Distribution System (EPDS) and IEEE 37-bus EPDS are used as test systems. The results confirm that proposed algorithms can be used for practical DG allocation. The research presented contributes to the field as it provides a DG allocation method for energy loss reduction performed on a EPDS which can be applied in realistic planning and regulatory situations using open-source software.

Keywords: DG integration, distribution network, energy losses, optimization, PSO, PV system

INTRODUCTION

Electrical power distribution systems (EPDS) are currently going through a period of significant transformation. The main traditional components of EPDS include transformers, loads, feeders, capacitors, etc., usually connected in radial topology. Recently, a new energy paradigm based on policies supporting renewable energy sources (RES) and the deregulation of the electricity market has paved the way for the introduction of new standard EPDS components like distributed generation (DG) and energy storages. DG is a term that describes electricity production units that are dispersed at different locations in the network, usually close to consumer sites [1]. It is well documented that appropriately allocated DG units have potential to meet local load requirements, reduce losses, improve network reliability, stability, and power quality [2]. Further, RES are becoming increasingly integrated into the EPDS because they significantly promote the energy transition policies and contribute towards greenhouse gas reduction.

One of the most promising and rapidly developing clean DG technologies are photovoltaic (PV) systems [3]. Additionally, because to the extensive integration of DGs, conventional EPDS are changing from passive, unidirectional systems to active, bidirectional systems [4]. Due to cheaper PV component costs, quick installation, technical advantages, and policies that support prosumers, the PV industry has expanded at a rate of more than 40% per year over the previous ten years [5]. PV systems are emerging as one of the major alternative energy sources, since they are

relatively simple to maintain, use free and inexhaustible energy source and consist of reliable components with a long life-time span. The main source of solar energy – solar irradiation depends mostly on weather and climate conditions, which provides challenges related to reliability, load balancing, voltage and frequency control, especially in weak and isolated network [6]. The implementation of Open Distribution System Simulator (OpenDSS) by the Component Object Model (COM) provides wide range of functionalities which can be used as tool in this task as reported in [7].

Numerous research papers are published related to the optimal allocation of DG into EPDS [8], [9], [10]. The optimal siting and sizing of DG using PSO algorithm is presented in [8] and tested on IEEE 14 bus system. Optimal sizing of DG to reduce power losses and effectively improve voltage profile using Particle Swarm Optimization (PSO) algorithm is described in [11] and [12]. Also, PSO algorithm is used in [13] for optimal allocation of PV. DG allocation is used for improving wide range of non-technical parameters such as reduction of global warming by integrating the roof-top solar PV system into low voltage (LV) distribution network in Australia [14]. In this paper authors also show that DG causes issues such as phase unbalance, current harmonics, and voltage fluctuations and that it also decreases power quality of the network. In [15], authors report the impact of PV system on LV network using load profiles. Impact of changing location of a PV system is presented in [16] on the IEEE 13-bus test system. It was demonstrated that more PV modules specified in certain node tend to recover the

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system. Also, link between OpenDSS and Matlab provides and improved capability of results visualization. Most of the literature consider variable load and DG production by observing daily simulation with averaged hourly values [17], [18] as a significant improvement from constant load and generation model. Improved analytical approach is presented in [19] involving single DG allocation to generate active and reactive power. Multiple DG allocation by improved analytical method is solved in [20]. In [21] two cases are investigated on a realistic distribution network in Bosnia and Herzegovina (BiH) and it was demonstrated that the installation of DG brings new opportunities in traditional distribution system, including DG influence on the network and power losses. Methods for DG allocation based on computational intelligence tools is gaining popularity in recent years. Specifically, Genetic algorithm (GA) is efficient for electrical optimization processes where renewable energy sources are included. The main advantage is the tolerance to discontinuity of functions and the fact that it can be applied to complex nonlinear problems. In [22] authors showed that optimally allocated five PV systems reduces losses up to 50% using GA and PSO techniques. Losses are reduced by 26% in the case of a single PV system connection. In this research a comparison of two algorithms is performed to determine the one with better performance.

The review of the existing work in the area allows us to conclude that DG allocation problem continues to be an important and very vibrant field of research.

This paper presents a method for optimal DG allocation in EPDS. The proposed methods are based on two techniques namely GA and PSO, which are solved separately, and results are compared. All calculations are performed on the model of realistic medium voltage (MV) European network with PV integrated in its topology defined by algorithms. Analysed network is modelled by using OpenDSS and Matlab softwares connected through the COM interface. Main contribution of this paper consists of the following:

- 1) Design, application and testing of a DG allocation method for loss reduction performed on a model realistic distribution network [23] currently operated by the DSO, which can be applied and used in realistic planning and regulatory situations.
- 2) Application of Open-source software, which provides replicability and reduction of uncertainty due to greater precision of load and PV system modelling when compared with traditional power flow simulation tools used by DSO.
- 3) Reduction of uncertainty and improvement of accuracy and confidence in results by using electrical energy values based on 24 hours curves rather than active power.

The organization of the paper is the following. Section 1 describes the mathematical formulation of the problem. Section 2 presents the procedure of the load and generation modelling in the OpenDSS and definition of the

optimization cases. Then, Section 3 specifies the results of the proposed algorithms and optimization cases. Also, IEEE 37 bus test system and comparison with similar methods are presented. Finally, conclusion and future research are outlined in Section 4.

1. PROBLEM FORMULATION

The problem of choosing the optimal DG size and locations in EPDS might be referred to as DG allocation. This is a challenging task because the DSO and investors timing, planning and operational interests do not coincide. Additionally, DG allocation in EPDS is challenging due to intermittent nature and uncertain long-term trends related to load and generation output patterns. The inherent uncertainty of load and generation output load curve, their mutual independence and difficulty to predict times of their coincidence makes the accurate calculation of DG influence on energy losses a non-trivial task. Most practical calculations simplify the problem by reporting only power losses or energy losses using a constant generation model. However, this approach ignores the physicality of the system and artificially reduces results to an interval with high level of uncertainty and imprecision.

1.1. Mathematical formulation of DG

Problem of DG allocation is approached as a single objective constrained optimization problem. The aim is to determine the best locations and sizes of DG units to minimize daily electrical energy losses in EPDS. The key parameters of system energy losses determine system costs leading to technical problems in the EPDS. Connected DG units should reduce energy losses in EPDS without violating the voltage limits [24]. Energy losses should be observed due to time-varying load and behaviour of DG production. 24-hour energy losses can be given by [25]:

$$\min E_{\text{losses}} = \sum_{t=0}^{24} P_{\text{loss}}(t) \cdot \Delta t \quad (1)$$

where E_{losses} are the daily energy losses' objective function for 24 hours, $P_{\text{loss}}(t)$ are the power losses in the network and time step Δt is set as one hour in this research [25]. Numerous constraints are inherent nature of the power system operation and must be taken into consideration when attempting to solve DG allocations problems. The following constraints are proposed:

1. Total electrical energy losses after integration of DGs should be less than before DGs integration

$$E_{\text{loss with DG}} < E_{\text{loss without DG}} \quad (2)$$

where $E_{\text{loss with DG}}$ is the electrical energy loss with DG and $E_{\text{loss without DG}}$ is the electrical energy loss without DG.

2. Voltage constraints i.e. Voltage limits at each node must satisfy conditions as follows:

$$V_{\min} \leq V_i \leq V_{\max} \quad i = \{1, 2, \dots, N\} \quad (3)$$

where $V_{\min}$ and $V_{\max}$ are the minimum and maximum permissible voltage in the network and that is 0.9 p.u. and 1.1 p.u. respectively. V_i is the voltage at node and N is the number of nodes (in this case $N=8$). According to the European norm EN 50160, the voltage must be $\pm 10\%$ of nominal voltage [9]. In case of 35 kV test model, the voltage limits must be as follows:

$$31.5 \text{ kV} \leq V_i \leq 38.5 \text{ kV} \quad (4)$$

3. Constraint of output DG active power which should be less than peak system demand.

$$P_{DG,i} \leq P_{load\ demand,i} \quad i = \{1, 2, \dots, N\} \quad (5)$$

where $P_{DG,i}$ is the power of DG at node i and $P_{load\ demand,i}$ is peak demand at node i . This is to prevent transformer feedback which can cause damage on network [9].

4. Short circuit power [26] or fast voltage variations criteria

Short circuit power constraint must satisfy the relation as follows:

$$\Delta S = k \frac{S_n}{S_{ks}} \quad (6)$$

where S_n is the DG rated power, S_{ks} is the three-phase short circuit power at each node where the DG can be connected. ΔS is the maximum DG rated power and k represents the ratio of DG start and rated current.

The coefficient $k=1$ is used for inverters and synchronous generators while $k=2$ is used for asynchronous generators [26]. In this research, coefficient $k=1$ is used, and the following should be satisfied:

$$\sum S_n \leq \frac{S_{ks}}{25} \quad (7)$$

5. Maximum line thermal rating

Rated current of the line (I_{rated}) must be greater or equal to currents of each line (I_{line}) given by:

$$I_{rated} \geq I_{line} \quad (8)$$

2. METHOD APPLICATION AND PROPOSED ALGORITHMS

2.1. Load and generation modelling using OpenDSS

The proposed DG allocation methods are tested on the realistic network used in [23]. Loads are modelled daily in time-series form in OpenDSS as a power conversion component

[27]. Based on the yearly power consumption of customers, the demand daily profile of each load is calculated using the Matlab code. Generation models are modelled as a vector type meaning that temperature and irradiance are introduced directly as a variable [16]. Power factor has a limit of 1. The typical daily production curve from PV system connected to the EPDS and typical load curve are presented in [23].

2.2. Definition of optimization cases

Two optimization cases (Case I and Case II) are presented with base case in which daily load flow results are used. Considering variable load profile and DG production, Case I and Case II provides GA and PSO results, respectively. These cases do not influence the normal behaviour of EPDS, but it gives very significant insight in optimal DG location and size, which will minimize the daily energy losses. Optimization cases are organized as follows:

- 1) Base scenario
- 2) Case I – DG allocation using GA
- 3) Case II – DG allocation using PSO

The single genes initialized stochastically provide location and size of DG. Optimization cases consider the influence of DG allocation of system energy losses. Population used in proposed algorithms has eight chromosomes i.e., busbars (BB). These BBs are BB1, BB2, BB3, BB4, BB5, BB6, BB7 and BB8, which represents the potential solution of the problem. Therefore, row vector X with eight columns can be represented as follows:

$$X = [x(1); x(2); x(3); x(4); x(5); x(6); x(7); x(8)]$$

X is chromosome with 8 genes. Each of them is crucial for determining the state for the observed BBs. The value of each gene propounded by the algorithm is multiplied with maximum permissible power at each node to obtain DG size. At each deployment, constraints stated in the first section are checked.

Fitness values obtained from both algorithms are multiplied with maximum permissible power i.e., short circuit powers, to get DG size. Short circuit powers are calculated based on the power flow analysis. The values of short circuit powers are given in the Table I.

Table I: 3-phase short circuit powers for test system

No. of bus	S_{k3} [MVA]
BB1	75.8
BB2	119
BB3	120
BB4	118
BB5	114
BB6	100
BB7	119
BB8	134

2.3. GA implementation

The methodology has been implemented in Matlab, which communicates with OpenDSS by the COM interface. In this paper, an algorithm to determine the optimal size and location of DG is performed using Matlab to calculate daily energy losses from OpenDSS. The following steps describe the implementation of algorithm:

START

STEP 1: OpenDSS and COM Interface initialization

STEP 1.1: New script in Matlab is generated with the code calling OpenDSS from Matlab (DSSStartup)

STEP 1.2: Add to Matlab

STEP 1.3: OpenDSS code for running the power flow in OpenDSS

[DSSStartOK, DSSObj, DSSText] = DSSStartup;

if DSSStartOK

DSSText.command='Compile %file location%';

DSSCircuit=DSSObj.ActiveCircuit;

DSSSolution=DSSCircuit.Solution;

else

a='DSS Did Not Start'

disp(a)

end

STEP 2: Linking GA toolbox and Matlab code.

STEP 3: Set GA parameters (fitness function, number of variables, lower/upper bounds, initial range, GA stopping criteria)

STEP 4: Set initial population.

STEP 5: Run GA

If stopping criteria is satisfied, solution converged; otherwise go to STEP 4 again through selection, crossover, and mutation processes.

END

The initial range, P, and population are utilized by default in Matlab and the creation function is depending on constraints. The maximum number of generations is set to $100 \times \text{numberOfVariables}$. A stochastic uniform selection technique is used to choose two parents at random. How much of the outcome is due to the crossover is determined by the crossover fraction, which is 0.8. Constrictions are necessary for the mutation function. The intermediate is the crossover. Forward migration happens at a fraction of 0.2. Additionally, because the migration interval is set at 20, migration occurs every 20 generations.

2.4. PSO implementation

The implementation of PSO algorithm is described in the following steps:

START

STEP 1: Initialize PSO parameters (lower/upper bounds, swarm size, initial velocity)

STEP 2: Set initial velocity and position of each particle.

STEP 3: Obtain fitness for position of each particle.

CONDITION: If position of each particle is better than personal best (P_{best}), then position of each particle = P_{best}

If CONDITION is satisfied, go to STEP 4, otherwise go to STEP 3.

STEP 4: Set best of P_{best} as global best (G_{best})

STEP 5: Update position and velocity

If maximum iteration is not reached, go to STEP 4, if yes, then:

STEP 6: Optimal solution = G_{best}

END

Position and velocity of particles are adjusted for each iteration by setting the best fitness of each particle to be P_{best} . Then, the best of personal bests is set as G_{best} . Swarm size is the number of particles i.e., set of candidate solutions to the optimization problem defined to be 80 based on the number of optimization variables. Initial velocity is set to 2, which specifies starting velocity of moving particles. Initial position and acceleration constants are used as Matlab's default. Velocity and position are then updated.

3. RESULTS AND DISCUSSION

3.1. Daily load flow analysis results – Base scenario

The daily power flow analysis with three iterations is performed without PV system. Total active losses of the network are $P=0.130896$ MW (1.365%) while total reactive losses are $Q=0.44887$ MVar. The basic scenario energy losses are 2045 kWh. The results of the daily load flow of the base scenario are presented to be compared with optimization scenarios. The base case scenario represents an existing network configuration with peak demand load and without DG. Min/max voltage values are 1.008 pu and 1.0235 pu at buses BB6 and BB1, respectively.

3.2. Daily load flow analysis results – Optimization cases

The basic hourly input data for the proposed method are averaged daily load shapes and parameters for DG production such as irradiance and temperature with corresponding power factor. OpenDSS software, which was coupled with Matlab's Optimization Toolbox environment to execute GA and PSO algorithms, is used to calculate the load flow. The computations are carried out in a parallel calculation environment that enables the use of all 5 available processing cores on an Intel(R) Core (TM) i5 CPU 1135G7 2.4 GHz architecture with 16 GB RAM memory, 64-bit OS.

3.2.1. GA results – Case I

The optimal output of the proposed GA i.e., fitness values are 0.014, 0.182, 0.531, 0.301, 0.118, 1, 0.194, 0.014 for buses BB1, BB2, BB3, BB4, BB5, BB6, BB7 and BB8 respectively. It means that DG sizes are 75.04 kW, 551.82 kW, 2527.56 kW, 1432.76 kW, 556.96 kW, 4560 kW, 776 kW, 67.2 kW. The total power of DG is

10547.34 kW. Energy losses are reduced to 1443.3 kWh. Number of required iterations to converge is 94.

3.2.2. PSO results – Case II

The same procedure is applied using PSO algorithm. The output values are 0.014, 0.181, 0.542, 0.011, 0.409, 1, 0.194, 0.004 for buses BB1, BB2, BB3, BB4, BB5, BB6, BB7 and BB8 respectively. Therefore, the DG sizes are the following: 75.04 kW, 548.43 kW, 2579.92 kW, 52.36 kW, 1930.48 kW, 4560 kW, 776 kW and 19.2 kW. Energy losses are reduced to 1443.26 kWh. Total power of DG size is 10541.43 kW. To converge, 65 iterations are required. Min/max voltage profile values after optimization using PSO algorithm are the same as using GA due to very small difference in fitness values.

3.2.3. Comparison of GA and PSO approaches

Energy losses in the base scenario are 2045 kWh and after two optimizations using GA and PSO, energy losses are decreased to 1443.3 kWh as illustrated in Figure 1. This value of energy losses means 29.42% reduction in comparison to the base case without DG.

The total power of DG size for GA is 10547.34 kW while for PSO is 10541.43kW. Reduction of system losses is caused by improving voltage profile. Minimum voltage value before optimization is 1.008 pu at bus BB6 while optimization cases result the same voltage value of 1.0024 pu. Maximum voltage value before optimization is 1.0235 pu at bus BB1 while this value is increased to 1.0275 after two optimization cases.

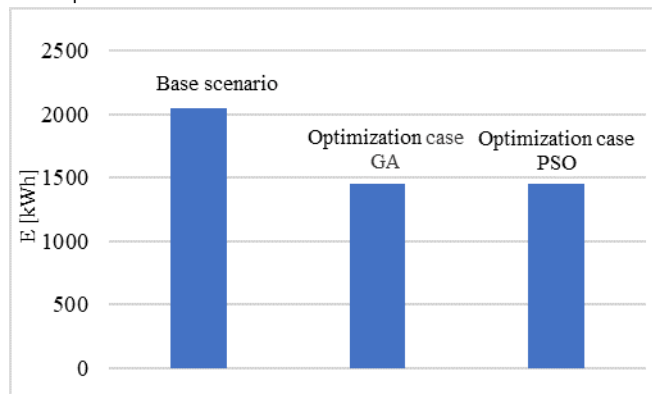


Figure 1: Comparison of energy losses

The only difference between proposed algorithms is the number of required iterations. For the problem to converge, GA is required 94 iterations while PSO is required 65 iterations to solve the same problem. The conclusion is that PSO converges faster in this specific case.

During the optimization cases, reactive component of total losses is neglected. Results are expected due to DG benefit with the minimizing energy losses for satisfying load demand during the day. Voltage profile expressed in pu comparing the base scenario with optimization

cases using GA and PSO are illustrated in Figure 2. After optimization, voltage profiles are increased as expected.

DG allocation as single-objective problem is not enough for energy losses reduction, but losses are decreased as they should be. Important future research direction is usage of multi-objective constrained optimization problem including voltage profile improvement as additional objective function together with existing one.

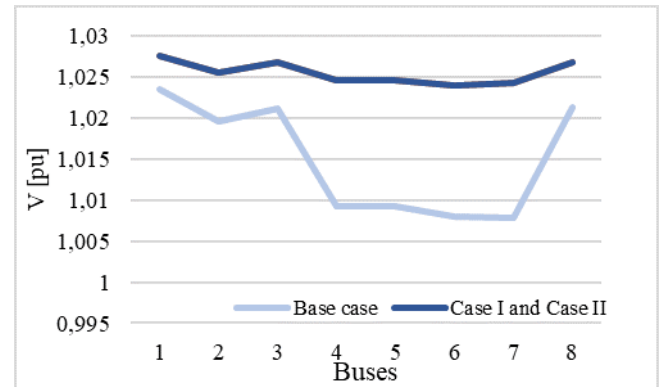


Figure 2: Voltage profile – comparison of GA and PSO with base case

3.3. IEEE 37-bus test system

To increase the research's reproducibility and offer quantifiable findings for comparison with similar methods, the proposed optimization method is applied to the IEEE 37-bus test system. [28]. The test system is delta connected system found in California with operating voltage of 4.8 kV. According to the [29], two scenarios are considered to compare energy loss reduction and demonstrate the effectiveness of the implemented method. Values for corresponding Sk3 are calculated based on the 3-phase fault in the OpenDSS. For the buses 714, 744, 737, 732, 733, 734, 737, 738, 741, 740, the obtained values of Sk3 are the following: 19.9, 19.4, 13.5, 16.1, 16.6, 15.1, 13.5, 12.7, 11.3, 11.5.

As displayed in Table II, energy losses are decreased in all scenarios with respect to the base case. The reduction of energy losses in two scenarios is 25.75% and 28.9%, respectively.

Table II: Results for different DG locations of the IEEE 37-bus test system

Topology	Daily energy losses (kWh) GA/PSO	Total DG size (kW) GA/PSO	Energy losses (%) GA/PSO
Base case	3656	0.0	0.0
Scenario I (DG location at node 714, 744, 737)	2714.74/2714.74	2113/2112.4	25.75
Scenario II (DG location at node 732, 733, 734, 737, 738, 741, 740)	2600.19/2600.19	3055.4/3054.6	28.9

3.4. Comparison with similar methods

To get acquainted with different methods of approaching the same problem, results on the IEEE 37-bus test system are compared with the similar methods in the literature. Authors could find one paper related to energy loss minimization. In [29], authors are using Lagrange multipliers, which relies on the Gauss-Jacobi method for optimal siting of PV system with the aim of reducing daily energy losses. Table III presents the comparison between the research with similar methods and the proposed method. Daily energy losses are more minimized using GA and PSO in the Scenario I, which means that proposed method achieves better results than the methods in [29]. We can see that the results are better in case when we have fewer connected DGs. It can be concluded that GA and PSO are better up to 5 connected DGs. These results show the performance of our proposed methods and gives better results as compared to previous similar results in [29].

Table III: Comparison similar work with proposed method on IEEE-37 bus test system

References	Energy losses [%]
[29] Scenario I	16.03
Scenario II	44.38
Proposed method: Scenario I	25.75
Scenario II	28.9

4. CONCLUSION AND FUTURE WORK

In this research, the optimal sitting and sizing of the DG in real distribution network is proposed to improve network performance in term daily energy loss reduction. Results are achieved by using Matlab, OpenDSS, GA and PSO. DG allocation is presented as single-objective constrained optimization problem. Constraints are voltage profile limits and thermal rating current. Both algorithms are applied on the same realistic EPDS. For time consuming and big iterative problems, PSO algorithm is a great property due to its fast convergence capability. It means that PSO converge faster than GA for the same optimization problem giving almost the same results of fitness values. After the DG installation, it is found that the voltage profile was within the defined voltage limits, therefore improving system reliability, stability and power quality. The energy losses are reduced, and the load demands are satisfied. IEEE 37-bus test system is used for comparison with similar method. The results obtained by our proposed methods on IEEE 37-bus test system give better results compared to the previous published work with similar method for DG allocation. Based on the results taken from this paper, it can be concluded that the proposed method can be potential application for energy loss reduction. Furthermore, this paper can be extended by including costs as new objective function to have multi-objective problem. This paper can be used

for existing EPDS to improve the supply of customers without large energy losses.

REFERENCES

- [1] T. Ackermann, G. Andersson and L. Soder, "Distributed generation: a definition," *Electric Power Systems Research*, vol. 57, pp. 195-204, 2001.
- [2] E. Semic, T. Hubana and M. Saric, "Distributed generation allocation in low voltage distribution network using artificial neural network," *IEEE EUROCON 2019-18th International Conference on Smart Technologie*, no. doi:10.1109/EUROCON.2019.8861816., pp. 1-6, 2019.
- [3] M. Saric, J. Hivziefendic and T. Konjic, "Multi-objective DG allocation in a radial power distribution network for power loss reduction, voltage profile improvement and investment deferral," *Elektrotehniski Vestnik*, vol. 85, no. 5, pp. 253-258, 2019.
- [4] K. S. Sambaiah and T. Jayabarathi, "Loss minimization techniques for optimal operation and planning of distribution systems: A review of different methodologies," *International Transactions on Electrical Energy Systems*, vol. 30(2), no. e12230, 2020.
- [5] D. Nasvall, "Development of a Model for Physical and Economical Optimization of Distributed PV Systems," u Master's thesis, Uppsala, Sweden, Uppsala University, 2013.
- [6] L. Bandic, J. Hivziefendic, M. Saric and M. Tesanovic, "Voltage Regulation of PV System with MPPT and Battery Storage in Microgrid," in *2020 International Conference on Smart Systems and Technologies (SST)*, doi: 10.1109/SST49455.2020.92640 Osijek Croatia, 2020.
- [7] R. A. Balestrin and A. Rossoni, "Using OpenDSS to Reallocate Voltage Regulators and Capacitor Banks in Real Distribution Feeders," in *IEEE PES Conference on Innovative Smart Grid Technologies (ISGT Latin America)*, 2019.
- [8] N. Eltawil, M. Sulaiman, M. Shamshiri and I. Z. Bin, "Optimum allocation of capacitor and DG in MV distribution network using PSO and openDSS," *Journal of Engineering and Applied Sciences*, vol. 14, no. 2, 2019.
- [9] M. Saric, J. Hivziefendic and M. Tesanovic, "Optimal DG Allocation for Power Loss Reduction Considering Load and Generation Uncertainties," in *The 11th International Symposium on Advanced Topics in Electrical Engineering*, Bucharest, Romania, 2019.
- [10] M. Kashyap, A. Mittal and S. Kansal, "Optimal Placement of Distributed Generation Using Genetic Algorithm Approach," in *Proceeding of the Second International Conference on Microelectronics, Computing & Communication Systems*, 2019.
- [11] 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.

- [12] M. N. M. Nasir, N. M. Shahrin, Z. H. Bohari, M. F. Sulaima and M. Y. Hassan, "A Distribution Network Reconfiguration Based on PSO: Considering DGs Sizing and Allocation Evaluation for Voltage Profile Improvement," in 2014 IEEE Student Conference on Research and Development.
- [13] B. Mukhopadhyay and D. Das, "Multi-objective dynamic and static reconfiguration with optimized allocation of PV-DG and battery energy storage system," *Renewable and Sustainable Energy Reviews*, vol. 124, no. 109777, 2020.
- [14] G. M. Shafiullah, M. T. O. Amanullah, A. Stojcevski and A. B. M. Shawkat Ali, "Integration of roof-top solar photovoltaic systems into the low voltage distribution network," *Jornal of Renewable and Sustainable Energy*, vol. 6, no. 3, 2014.
- [15] M. Eisenreich, G. Balzer, J. Backes and B. Maurer, "Integration of PV systems into low voltage networks using standard load profiles," in *International Conference on Renewable Energies and Power Quality*, Granada, Spain, 2010.
- [16] J. A. Ruíz-Garzón and D. J. González-Tr, "Impact of changing location and power of a PV system in electrical distribution networks, integrating MATLAB and OpenDSS," pp. 125-131, 3 June 2018.
- [17] K. Hosseini, S. Araghi, M. B. Ahmadian and V. Asadian, "Multi-objective optimal scheduling of a micro-grid consisted of renewable energies using multi-objective Ant Lion Optimizer," in 2017 Smart Grid Conference (SGC), Tehran, Iran, 2017.
- [18] S. Xuemei, Y. Bin, W. Xuyang, Y. Jin and G. Ciwei, "Study on Optimal Allocation of Distributed Generation in Urban and Rural Distribution Network Considering Demand Side Management," in 2017 International Conference on Smart Grid and Electrical Automation (ICSGEA), Changsha, China, 2017.
- [19] D. Q. Hung, N. Mithulanathan and R. C. Bansal, "Analytical expressions for DG allocation in primary distribution networks," *IEEE Transactions on energy conversion*, vol. 25, no. 3, pp. 814-820, 2010.
- [20] D. Q. Hung and N. Mithulanathan, "Multiple distributed generator placement in primary distribution networks for loss reduction," *IEEE Transactions on industrial electronics*, vol. 60, no. 4, pp. 1700-1708, 2013.
- [21] A. P. Sirat, H. Mehdipourpicha, N. Zendejdel and H. Mozafari, "Sizing and Allocation of Distributed Energy Resources for Loss Reduction using Heuristic Algorithms," in 2020 IEEE power and energy conference at Illinois (PECI), 2020.
- [22] M. Albadi, H. Soliman, M. A. Thani, A. Al-Alawi, S. Al-Ismailli, A. Al-Nabhani and H. Baalawi, "Optimal Allocation of PV Systems to Minimize Losses in Distribution Networks Using GA and PSO: Masirah Island Case Study," *Journal of Electrical Systems*, vol. 13, no. 4, pp. 678-688, 2017.
- [23] M. Hanjalic, E. Melic, M. Saric, and J. Hivzievendic, "Hosting Capacity Assessment in Electrical Power Distribution Systems Using Genetic Algorithm," *Electric Power Components and Systems*, DOI: 10.1080/15325008.2023.2227180, 2023.
- [24] T. D. Castillo and M. Saad, "Optimal Location and Size for Various Renewable Distributed Generators in Distribution Networks," in 2017 IEEE PES Innovative Smart Grid Technologies Conference - Latin America (ISGT Latin America). Quito, Ecuador, 2017.
- [25] P. D. Huy, V. K. Ramachandaramurthy, J. Y. Yong, K. M. Tan and J. B. Ekanayake, "Optimal placement, sizing and power factor of distributed generation: A comprehensive study spanning from the planning stage to the operation stage," *Energy*, Elsevier, vol. 195, no. 117011, 2020.
- [26] M. Saric, J. Hivzievendic and T. Konjic, "Distributed Generation Allocation Using Fuzzy Multi Criteria Decision Making Algorithm," in 2017 International Conference on Smart Systems and Technologies (SST), Osijek, Croatia, 2017.
- [27] L. C. Ribeiro, F. L. Vieira, B. D. Bonatto, A. C. Z. de Souza and P. F. Ribeiro, "Modeling and simulation of active electrical distribution systems using the OpenDSS," in *Decision Making Applications in Modern Power Systems*, Elsevier, 2020, pp. 121-152.
- [28] W. H. Kersting, "Radial distribution test feeders (Published Conference Proceedings style)," in *IEEE Power Engineering Society Winter Meeting. Conference Proceedings*, Columbus, OH, USA, 2001.
- [29] J. A. da Costa, D. A. C. Branco, M. C. P. Filho, M. F. d. M. Junior and N. F. da Silva, "Optimal sizing of photovoltaic generation in radial distribution systems using lagrange multipliers," *Energies*, vol. 12, no. 1728, 2019.

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