Optimization and analysis of distributed generation units in distributed system for minimizing losses

Bharath Suriyakumar[1], Vasuki Arumugam[2]
[1]Department of Electrical and Electronics Engineering, SNS College of Technology, Coimbatore, India
[2]Department of Electronics and Communication Engineering, Kumaraguru College of Technology, Coimbatore, India

Article Info

Article history:

Received Nov 25, 2023
Revised Jan 1, 2024
Accepted Jan 3, 2024

Keywords:

Design thinking
Distributed network system
Power loss reduction
PV cell
Renewable energy sources
Voltage sensitivity index

ABSTRACT

The proposed study presents a novel methodology aimed at mitigating losses in distributed generation (DG) systems within distributed networks. This methodology involves the integration and implementation of DG units that utilize non-conventional, sustainable resources, potentially enhancing traditional DG systems. When DG units are located near the point of consumption, they create favorable conditions for voltage support, reduction in energy losses, and lower emissions. The strategic placement of DG units, in terms of both size and location within an existing generation network, is critical for the construction, execution, and operational planning of real-time distribution networks. This optimal positioning is key to maximizing voltage stability and minimizing power loss. The study proposes an innovative strategy to decrease real power losses and improve voltage profiles, which includes optimizing substation capacity by introducing DG units.

Corresponding Author:

Bharath Suriyakumar
Department of Electrical and Electronics Engineering, SNS College of Technology
Coimbatore, India
Email: bharathbhadri@gmail.com

1. INTRODUCTION

The growing demand for energy in the near future must be addressed with alternative power generation methods due to the declining supply of fossil fuels which is a primary concern in the realm of energy production and distribution. Furthermore, the development of major power projects is often discouraged in many countries because of environmental constraints and their potential impact on climate change. Problem statement, to overcome these challenges, generating power from renewable energy sources emerges as an optimal solution to replace conventional fossil fuels [1]. Although power stations based on renewable resources tend to be smaller in scale compared to existing power stations, such renewable-based power generation is particularly well-suited for producing low-voltage power in close proximity to load centers. The concept of distributed power generation has fundamentally altered the field of electric power systems, which were originally predicated on a unidirectional power flow [2]. This concept encapsulates the generation of power in proximity to its demand site, rather than relying on remote, centralized power stations, with a preference for renewable energy sources. Distributed systems, also known as on-site generation (OSG), represent a network of small-scale power generation and storage units, collectively referred to as distributed energy resources (DES).

Residential DES systems typically include solar panels, miniature wind turbines, and natural gas setups, while commercial systems may comprise combined heat and power plants, photovoltaic panels, and generation from hydro, wind, and biomass combustion. distributed generation (DG) systems offer a mixed bag of benefits and drawbacks. Advantages include improved voltage support and system reliability, while challenges lie in ensuring safety and maintaining protection stability. To address these challenges and enhance the overall system stability and efficiency, various interconnection strategies for DG systems have been endorsed worldwide. Unstandardized DG systems in the energy market lead to complications in establishing regulatory frameworks for costs, incentives, and management.

Renewable DG is fundamentally categorized into three main components to effectively model and strategize for implementation in public distribution networks: The “DG site” and “connection point” denote the location where the DG is set up, while “electrical connection” pertains to the infrastructure-either overhead lines or underground cables-that links the generation unit to the load point. Survey of literature, among the various methods for the precise placement and optimization of DG systems, Chiradeja and Ramakumar [3] proposed a method to evaluate the benefits and limitations of DG, with a focus on voltage improvement, mitigating social/environmental impacts, and reducing line losses. This methodology was later refined by Khan and Choudhry [4] through an analytical algorithm for positioning single and multiple DG units. The determination of the precise location for multiple DG units with an optimal power factor was further explored by Hung and Mithulananthan [5]. A genetic algorithm was applied to devise a strategy that overlooks the size and total power loss in the system [6]. However, the technique employed by Ghosh *et al.* [7] for sizing and locating the DG units proved highly effective in loss reduction, a finding subsequently corroborated by Ziari *et al.* [8] and Babu and Singh [9] through the use of particle swarm optimization [10].

Tarraq *et al.* [11] developed an innovative method combining a chaotic strategy with a neural network algorithm, termed as CNNA, to address the challenge of finding the best DG allocation in radial distribution systems. This method focuses on pinpointing the ideal locations and capacities of DGs, aiming to optimize certain goals while adhering to specific security constraints. The effectiveness of CNNA was validated through its application to two standard radial distribution systems, the IEEE 33-bus and 69-bus systems. Meanwhile, the previous authors employed particle swarm optimization for sizing and positioning DGs, leveraging its ability to search in parallel. Their research highlighted that a mix of wind and solar DGs enhances the sizing process. These systems also improved the voltage profile, leading to more efficient power systems, and outperformed traditional DG systems in reducing power losses and maintaining voltage stability.

Ansari and Byalihal [12] introduced a hybrid algorithm combining teaching learning-based optimization with particle swarm optimization for optimally placing DG and STATCOM. Their approach, applied to both IEEE 33 and a real-time 52 bus distribution system, aimed to balance cost-benefit and voltage stability while reducing power losses and network security risks. Bujal *et al.* [13] proposed a novel multi-objective approach using the firefly analytical hierarchy algorithm. This method, enhanced by integrating the analytical hierarchy process with the firefly algorithm, was designed to find the optimal allocation and size of DG. The algorithm’s performance was assessed on a 118-bus radial distribution network, with a focus on bus voltage at DG locations.

Belbachir *et al.* [14] explored the optimal placement and sizing of DGs based on solar photovoltaic panels in electrical distribution networks. They employed various hybrid particle swarm optimization algorithms, enhanced with chaotic maps and adaptive acceleration coefficients, to minimize a multi-objective function encompassing total active power loss, voltage deviation, and operation time of overcurrent relays. Wartana *et al.* [15] determined the optimal location and size for wind energy-based DG, incorporating a static var compensator for control. This approach improved voltage profiles and reduced power losses by optimizing load bus system scenarios. They tackled this multi-objective problem, which included constraints like loading and generation limits, using the non-dominated sorting genetic algorithm.

Rosli *et al.* [16] used a particle swarm optimization technique with time-varying acceleration coefficients to find the best locations and sizes for DG units. Their method, initially assessing system power loss through distribution load flow analysis, was applied to the standard IEEE 33-bus radial distribution network, achieving optimal DG placement and sizing while minimizing total active power loss. Considering the above discussed approaches, a simplest method for potential profile improvement with minimum power loss using voltage sensitivity analysis is proposed in this article. This study analyses the power using forward-backward sweep algorithm [17] which is an effective approach for deriving numerical control problems. The analyses of different DG units were conducted using IEEE 33 bus radial distribution system.

2. DIFFERENT TYPES OF DISTRIBUTION SYSTEMS

Ramana *et al*. [18] have provided a taxonomy of DG types, including both prevalent and less common varieties, with a detailed analysis that considers factors such as scale, operational duration, and power in a technological context. As outlined by Acharya *et al.* [19], the output characteristics of DGs, pertaining to both real and reactive power, can be segmented into four principal categories. These categories, which are central to the discussion in this paper, are characterized as follows [20]:

- Type 1: with the aid of converters and inverters, active power sources like fuel cells, microturbines, and photovoltaics can all be incorporated into the main grid. However, the photovoltaic system can also produce reactive power and is occasionally required to do so in accordance with the present circumstances and grid standards.
- Type 2: generation units which can produce both active-reactive power fall in this type. This category includes gas turbines and co generative systems which are synchronous machine-based DG units
- Type 3: DGs that can only supply reactive power come under this type. Synchronous compensators which run at zero power factor like gas turbines, is an exact example of this type.
- Type 4: these type of generation units can deliver active power consuming reactive energy. This category mostly includes induction generators, employed in wind farms. However, dual fed induction generator (DFIG) systems behave similarly to synchronous generators which produce reactive power and consume active power.

Since the major work of the distribution system is to deliver and distribute power to the consumers through the transmission lines, it is classified into two major classes' namely primary distribution system and secondary distribution system. Whereas the primary type deals with very high voltage ranges to the consumers at load centers, the secondary type is used to distribute low voltages to consumers premises. Further, based on connection of distribution units, the system can be further classified into:

(i) Radial distribution system which is less expensive and preferred for low voltage systems.
(ii) Ring main distribution system which is really expensive when compared to the radial distribution system where every buses are connected directly to the source [21].

3. PROPOSED METHOD

As DG penetration evolves, the distribution network's nature shifts from passive to active, and a distribution company market run by distribution system operator (DSO) emerges [22]. In this novel environment, the DSO's responsibility for upkeep of the secure distribution system is analogous to the ISO's responsibility for the transmission system. One of the crucial instruments for DSO to fulfill this responsibility is the power flow calculation. Further, the crucial load factor is to be considered. This is because, in real time analysis, the load will not be the same throughout the year but changes with respect to the season. Numerous researches have been done on the distribution power flow when DGs are present. The advancement in technology and features of distribution networks makes the analysis of the systems more difficult by the usual convention Newton Raphson method and Gauss Seidel approach [23], [24]. The power flow computation and analysis of features like radial structure, un-balanced loads and R/X ratio seems to be difficult when the comparison is done between distribution system and transmission system [25]. The limitations encountered with traditional analysis methods for both balanced and unbalanced radial systems have necessitated the search for alternative, more effective methods for study. These conventional methods often struggle with complexity and computational inefficiency when dealing with the intricate nature of radial distribution systems, thus highlighting the need for a more streamlined and robust approach. The backward and forward sweep-based algorithm was selected as an ideal analytical tool for load flow studies due to its minimal memory requirements and enhanced computational efficiency. This algorithm is recognized for its ability to conduct load flow analysis with improved accuracy and reduced processing time, making it a superior choice in comparison to other more memory-intensive options.

3.1. Forward-backward sweep method

In case of a radial system, forward-backward sweep method for flow computation of load is an iterative method with dual steps at each iteration being conducted: a one source network's load flow can be solved using couple of periodic equations through repeated solving. The initial group of periodic equations used for determining the power flow through the branches, begin with the final branch and proceed backwards. The remaining group of equations is for determining the voltage and angle of each node, beginning with the root node, and progressing ahead to the last node. Schematic of radial distribution system is given in Figure 1 with reference to [26].

3.1.1. Forward sweep

The forward sweep is basically a computation of the voltage loss considering current and power flow throughout the network. Voltages at node points are simultaneously regulated in forward sweep, beginning from the first layer, and progressing to final branches. The aim of the forward propagation is to determine node voltages at each point beginning with the feeder source node. The voltage at the feeder substation is set to its real value. The effective power obtained in each branch is kept constant to the results recorded in the backward walk throughout forward propagation.

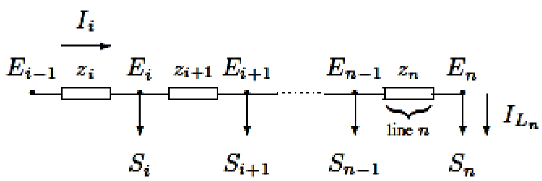

Figure 1. Forward-backward sweep method

3.1.2. Back sweep

Backward sweep constitutes a current and power flow solution with voltage regularities. It begins straight opposite to forward sweep method with branches in final layer and progresses to the branches near the root node. Propagation in reverse mode calculates the updated effective power flows in each branch by taking previous iteration's node voltages into account. Further the voltage in the forward sweep method is maintained unchanged during backward propagation. The revised power flows in each branch are transferred back via the load via the back path. This implies that backward propagation begins at the far end node and proceeds to the source node.

The current magnitude is calculated by two different sweep methods in forward backward sweep method, where corresponding voltage profile will be and recorded. No continuous numbering of nodes or branches is required. The successive nodes are identified to calculate the current in all linked branches and nodes of the system which ensures the analysis of all possible branches and paths in nodes. The following assumptions are made for analysis [27]. They are:

- Initial voltage should be 1.
- Real and reactive power losses are assumed to be insignificant and hence its value will be zero.
- Balanced Radial distribution network can be further simplified using a single line diagram.

Algorithm for finding network matrices,
Step1: Start
Step2: Change the values of resistance, voltages, and power to unit form
Step3: Calculate matrix [A] which is branch node incidence matrix
Step4: Calculate possible number of paths by computing the end nodes
Step5: Identify the node at every possible path. The bus matrix[B]=(1*m)
Step6: To find the connected nodes, frame the node matrix[C].

3.2. IEEE-33 bus system

For power flow analysis the IEEE-33 bus system was adopted to evaluate and compare the different DG units which is located and distributed over an entire IEEE-33 bus system with feeder to the substation. Figure 2 represents the IEEE-33 bus radial distribution system which is built up with 32 lines and 33 buses with voltage of 12 kV along with maximum load of 3.715 MW.

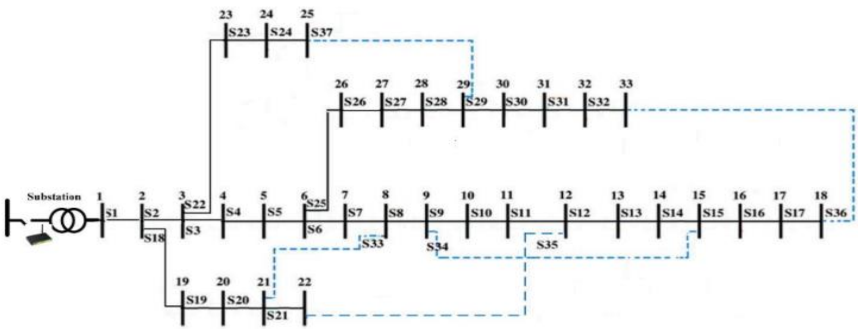

Figure 2. Schematic representation of IEEE 33 bus system

3.3. DG Location optimization using voltage sensitivity index

The voltage sensitivity index (VSI) calculation and analysis can predict the power load shedding at particular positions. These VSI calculations are used to find the sensitivity node of the system. The VSI of the bus "t" is defined [12] as per the given in (1). Here, the Vt represents the voltage of the kth node where 'n' shows the number of nodes.

$$VSI_x = \sqrt{\frac{\sum_{k=1}^{n}(1-V_t)^2}{n}} \quad (1)$$

3.4. Guidelines for DG size allocation

The following steps has to be followed to compute the optimum size of the DG;

- Initially node with minimum VSI is identified and the DG is placed on that particular node.
- Size of the DG unit is varied from minimum feeder load to maximum feeder load capacity considering the power factor as the deciding parameter.
- DG with negligible losses is considered to be the optimum size for DG.

4. FINDINGS AND DISCUSSIONS

Simulation studies were conducted on the IEEE 33 bus network system, characterized by a 12 kV voltage level and a power output of 3.715 MW, using MATLAB and Simulink simulation software. The data obtained from these simulations was meticulously analyzed under two distinct scenarios: firstly, where the DG operates at a unity power factor, and secondly, where the system operates at a 0.9 lagging power factor. These scenarios are critical for understanding the impact of power factor variations on the overall performance and efficiency of the power distribution network.

The initial step involved calculating the bus voltage range and overall power loss in the radial distribution system, using a reference case flow analysis. This was followed by an assessment with 25% of the load capacity, combined with a feeder loading capacity of 1 MVA, as per Table 1. The voltage stability index (VSI) at various bus nodes was computed using this equation. The results are graphically depicted in Figure 3, which illustrates the VSI values across all bus nodes. Notably, bus node 18 registered the lowest VSI value, recorded at 0.0312. This indicator suggests that bus node 18 is the optimal location for placing the DG unit. The graph also highlights a notable increase in the VSI value subsequent to node 18, indicating a shift in voltage stability past this point in the network.

Table 1. VSI data at various bus nodes

Sl. No	Voltage sensitivity index VSI	Bus number (Nodes)
1	0.0651	1
2	0.0611	2
3	0.0582	3
4	0.0553	4
5	0.0534	5
6	0.0472	6
7	0.0453	7
8	0.0434	8
9	0.0393	9
10	0.0364	10
11	0.0353	11
12	0.0354	12
13	0.0355	13
14	0.0355	14
15	0.0355	15
16	0.0313	16
17	0.0313	17
18	0.0312	18
19	0.0623	19
20	0.0623	20
21	0.0624	21
22	0.0625	22
23	0.0583	23
24	0.0581	24
25	0.0581	25
26	0.0467	26
27	0.0455	27
28	0.0432	28
29	0.0423	29
30	0.0412	30
31	0.0411	31
32	0.0400	32
33	0.0399	33

Following the identification of the optimal location for the DG unit at bus node 18, the next phase involved determining the ideal size and capacity of the DG unit. This was achieved by incrementally increasing the power capacity from the initial setting of 0.5 MVA to 4 MVA. The analysis was conducted under two different operating conditions: one with the system functioning at a lagging power factor of 0.9, and the other at a unity power factor. This step was crucial in understanding how varying power capacities of the DG unit impact the system's performance under different power factor conditions. Figure 4 represents power loss at different DG capacity with non- linear increase with increase in capacity. The graphs show there is a reduction of power loss till 2 MVA and then the power loss increases to a greater extent at 4 MVA. DG with unity power factor produces a difference of 1.45 pu loss in power with respect to the 0.9 lag power factor.

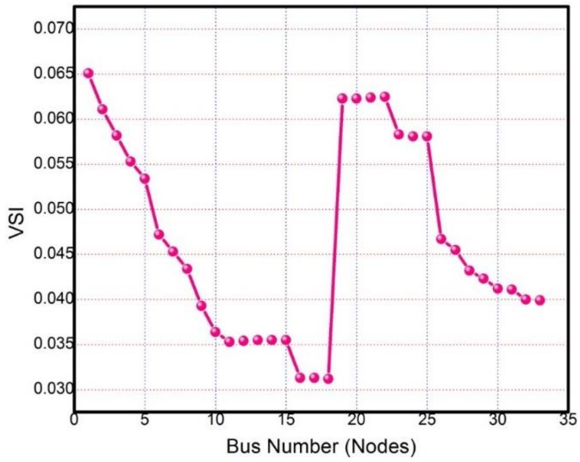

Figure 3. Graphical representation of VSI recorded at different bus nodes

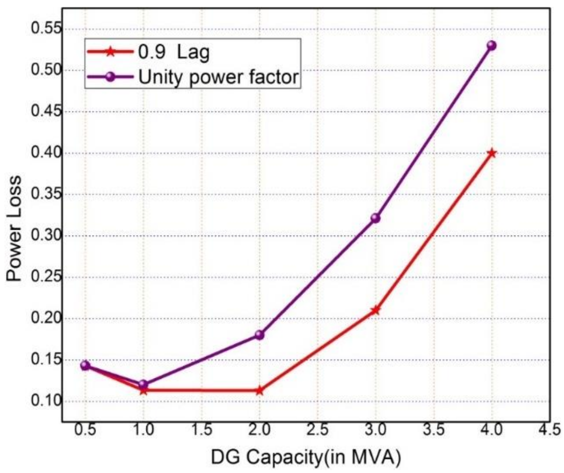

Figure 4. Power losses at different DG capacity

From Figure 4, the optimum size of the DG is found to be 2 MVA for 0.9 power factor lagging and 1.0 MVA for unity power factor. The performances at various cases are given in Table 2 for the base case and optimized values were noted. Table 2 makes it clear that the power loss including both real and reactive losses for base case (without DG) is 0.241 pu and 0.154 pu, respectively, However, these losses for the optimal DG of size 2 MVA unit is much higher than compared to the optimal sizes and power factor of DG of 1.0 MVA at unity power factor. Further, the ideal size, placement, and power factor (DG technology) depend on the highest possible power loss reduction in distribution networks using DG. Table 2 also compares the substation capacity release brought on by the adoption of DG in various scenarios.

Figure 5 provides a graphical representation of the voltage profile across various bus nodes with the DG unit positioned optimally. The integration of the DG unit leads to an enhancement in the system's voltage profile. This improvement is attributed to the DG unit's ability to supply both real and reactive power to the load, which contributes to a reduction in current along parts of the distributed network. Consequently, this lowers the load demand on the network, thereby increasing the voltage magnitude at the consumer end. Moreover, the voltage regulation is particularly noteworthy when the generation unit operates at a capacity of 2 MVA with a 0.9 power factor. This scenario demonstrates superior voltage values compared to other cases, as depicted in Figure 4. This figure contrasts the variations in the voltage profile under three different conditions, illustrating the significant impact of the DG unit's size and operating power factor on voltage regulation within the distribution network.

Table 2. System performance at different cases

Sl. No	Parameters (In pu)	Base case	Power factor	
			0.9 lag	Unity
1	Real power from sub station	3.89	2.43	2.63
2	Reactive power from sub station	2.54	1.67	2.43
3	Active power loss	0.241	0.121	0.123
4	Reactive power loss	0.154	0.073	0.091

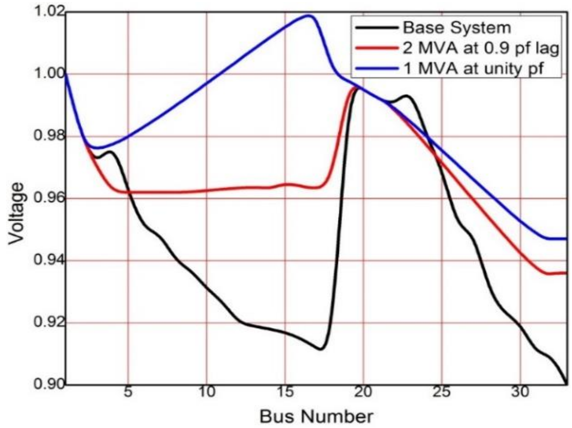

Figure 5. Voltage profile at different cases

5. CONCLUSION AND FUTURE SCOPE

Factors like the location and size of DG units in a distribution network are crucial for the design and implementation of an active distribution system, aiming to enhance system efficiency with optimal voltage and minimized losses. The integration of DG into the distribution system notably improves the voltage profile, as it contributes both real and reactive power to the load, thereby increasing the voltage and reducing losses. This study proposes a novel method for identifying the ideal location for a DG unit and determining its optimal size to achieve an efficient distribution system. One of the key benefits of DG is the reduction in line losses. However, it is important to note that at very high levels of DG penetration, the losses might increase, influenced by the ratings and locations of the DG units. Furthermore, the type of DG plays a crucial role in realizing these benefits. The voltage regulation is efficient when the generation unit operates at a capacity of 2 MVA with a 0.9 power factor. The approach employed in this study was based on investigative methods. However, there are numerous other research and numerical methods that promise greater reliability and effectiveness, which could be explored in future studies. Considering a longer time span and aiming for ideal DG placement from a planning perspective introduces additional complexities. These include the variability in load demand over time, the integration of renewable and conventional power generation, and the need to account for load growth. Looking ahead, incorporating additional system components like PV cells or fuel cells could be considered to enhance the system's transient stability. This future-oriented approach would enable a more comprehensive and adaptive power distribution system, catering to evolving energy demands and technological advancements.

REFERENCES

[1] A. Ipakchi and F. Albuyeh, “Grid of the future,” *IEEE Power and Energy Magazine*, vol. 7, no. 2, pp. 52–62, Mar. 2009, doi: 10.1109/MPE.2008.931384.

[2] T. Ackermann, G. Andersson, and L. Söder, “Distributed generation: a definition,” *Electric Power Systems Research*, vol. 57, no. 3, pp. 195–204, Apr. 2001, doi: 10.1016/S0378-7796(01)00101-8.

[3] P. Chiradeja and R. Ramakumar, “An approach to quantify the technical benefits of distributed generation,” *IEEE Transactions on Energy Conversion*, vol. 19, no. 4, pp. 764–773, Dec. 2004, doi: 10.1109/TEC.2004.827704.

[4] H. Khan and M. A. Choudhry, “Implementation of distributed generation (IDG) algorithm for performance enhancement of distribution feeder under extreme load growth,” *International Journal of Electrical Power and Energy Systems (IJEPES)*, vol. 32, no. 9, pp. 985–997, Nov. 2010, doi: 10.1016/j.ijepes.2010.02.006.

[5] D. Q. Hung and N. Mithulananthan, “Multiple distributed generator placement in primary distribution networks for loss reduction,” *IEEE Transactions on Industrial Electronics*, vol. 60, no. 4, pp. 1700–1708, Apr. 2013, doi: 10.1109/TIE.2011.2112316.

[6] N. Mithulananthan and L. V. Phu, “Distributed gener ator placement in power distribution system using genetic algorithm to reduce losses,” *Thammasat Int. J. Sc. Tech*, vol. 9, no. 3, pp. 55–62, 2004, [Online]. Available: https://ph02.tci-thaijo.org/index.php/SciTechAsia/article/view/41639.

[7] S. Ghosh, S. P. Ghoshal, and S. Ghosh, “Optimal sizing and placement of distributed generation in a network system,” *International Journal of Electrical Power and Energy Systems (IJEPES)*, vol. 32, no. 8, pp. 849–856, Oct. 2010, doi: 10.1016/j.ijepes.2010.01.029.

[8] I. Ziari, G. Ledwich, A. Ghosh, D. Cornforth, and M. Wishart, “Optimal allocation and sizing of DGs in distribution networks,” in *IEEE PES General Meeting, PES 2010*, Jul. 2010, pp. 1–8, doi: 10.1109/PES.2010.5588114.

[9] P. V. Babu and S. P. Singh, “Optimal placement of DG in distribution network for power loss minimization using NLP & PLS Technique,” *Energy Procedia*, vol. 90, pp. 441–454, Dec. 2016, doi: 10.1016/j.egypro.2016.11.211.

[10] D. Singh, D. Singh, and K. S. Verma, “Multiobjective optimization for DG planning with load models,” *IEEE Transactions on Power Systems*, vol. 24, no. 1, pp. 427–436, Feb. 2009, doi: 10.1109/TPWRS.2008.2009483.

[11] A. Tarraq, F. El Mariami, and A. Belfqih, “Multi-objective distributed generation integration in radial distribution system using modified neural network algorithm,” *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 13, no. 5, pp. 4810–4823, Oct. 2023, doi: 10.11591/ijece.v13i5.pp4810-4823.

[12] A. Ansari and S. C. Byalihal, “Application of hybrid TLBO-PSO algorithm for allocation of distributed generation and STATCOM,” *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 29, no. 1, pp. 38–48, Jan. 2023, doi: 10.11591/ijeecs.v29.i1.pp38-48.

[13] N. R. Bujal, A. F. A. Kadir, M. Sulaiman, S. Manap, and M. F. Sulaima, “Firefly analytical hierarchy algorithm for optimal allocation and sizing of DG in distribution network,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 13, no. 3, pp. 1419–1429, Sep. 2022, doi: 10.11591/ijpeds.v13.i3.pp1419-1429.

[14] N. Belbachir, M. Zellagui, A. Lasmari, C. Z. El-Bayeh, and B. Bekkouche, “Optimal integration of photovoltaic distributed generation in electrical distribution network using hybrid modified PSO algorithms,” *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 24, no. 1, pp. 50–60, Oct. 2021, doi: 10.11591/ijeecs.v24.i1.pp50-60.

[15] I. M. Wartana, N. P. Agustini, and S. Sreedharan, “Optimal integration of wind energy with a shunt-FACTS controller for reductions in electrical power loss,” *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 23, no. 1, p. 41, Jul. 2021, doi: 10.11591/ijeecs.v23.i1.pp41-53.

[16] H. M. Rosli, S. A. Halim, L. J. Awalin, and S. M. Mustaza, “A PSO-TVAC for optimal installation of multiple distributed generations in a radial distribution system,” *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 32, no. 2, p. 612, Nov. 2023, doi: 10.11591/ijeecs.v32.i2.pp612-619.

[17] M. H. Haque, “Efficient load flow method for distribution systems with radial or mesh configuration,” *IEE Proceedings: Generation, Transmission and Distribution*, vol. 143, no. 1, pp. 33–38, 1996, doi: 10.1049/ip-gtd:19960045.

[18] T. Ramana, V. Ganesh, and S. Sivanagaraju, “Distributed generator placement and sizing in unbalanced radial distribution system,” *Cogeneration and Distributed Generation Journal*, vol. 25, no. 1, pp. 52–71, 2010, doi: 10.1080/15453661009709862.

[19] N. Acharya, P. Mahat, and N. Mithulananthan, “An analytical approach for DG allocation in primary distribution network,” *International Journal of Electrical Power and Energy Systems (IJEPES)*, vol. 28, no. 10, pp. 669–678, Dec. 2006, doi: 10.1016/j.ijepes.2006.02.013.

[20] N. Upadhayay and A. K. Mishra, “A method of determination of suitable location and capacity of DG units in a distribution system,” In *2010 20th Australasian Universities Power Engineering Conference*, 2010.

[21] M. A. Kashem, V. Ganapathy, G. B. Jasmon, and M. I. Buhari, “A novel method for loss minimization in distribution networks,” in *DRPT2000. International Conference on Electric Utility Deregulation and Restructuring and Power Technologies. Proceedings (Cat. No.00EX382)*, 2002, pp. 251–256, doi: 10.1109/drpt.2000.855672.

[22] A. C. Rueda-Medina, J. F. Franco, M. J. Rider, A. Padilha-Feltrin, and R. Romero, “A mixed-integer linear programming approach for optimal type, size and allocation of distributed generation in radial distribution systems,” *Electric Power Systems Research*, vol. 97, pp. 133–143, Apr. 2013, doi: 10.1016/j.epsr.2012.12.009.

[23] Y. M. Atwa, E. F. El-Saadany, M. M. A. Salama, and R. Seethapathy, “Optimal renewable resources mix for distribution system energy loss minimization,” *IEEE Transactions on Power Systems*, vol. 25, no. 1, pp. 360–370, Feb. 2010, doi: 10.1109/TPWRS.2009.2030276.

[24] N. Kanwar, N. Gupta, K. R. Niazi, A. Swarnkar, and R. C. Bansal, “Simultaneous allocation of distributed energy resource using improved particle swarm optimization,” *Applied Energy*, vol. 185, pp. 1684–1693, Jan. 2017, doi: 10.1016/j.apenergy.2016.01.093.

[25] Z. Moravej and A. Akhlaghi, “A novel approach based on cuckoo search for DG allocation in distribution network,” *International Journal of Electrical Power and Energy Systems (IJEPES)*, vol. 44, no. 1, pp. 672–679, Jan. 2013, doi: 10.1016/j.ijepes.2012.08.009.

[26] S. H. Lee and J. W. Park, “Selection of optimal location and size of multiple distributed generations by using Kalman Filter algorithm,” *IEEE Transactions on Power Systems*, vol. 24, no. 3, pp. 1393–1400, Aug. 2009, doi: 10.1109/TPWRS.2009.2016540.

[27] L. D. Arya, A. Koshti, and S. C. Choube, “Distributed generation planning using differential evolution accounting voltage stability consideration,” *International Journal of Electrical Power and Energy Systems (IJEPES)*, vol. 42, no. 1, pp. 196–207, Nov. 2012, doi: 10.1016/j.ijepes.2012.04.011.

BIOGRAPHIES OF AUTHORS

Bharath Suriyakumar received bachelor's degree in B.E. Electrical and Electronics Engineering during the year 2010 from Anna University, Chennai and Master's degree in M.E. Power Systems Engineering during the year 2013 from Anna University, Chennai. He is currently pursuing his Ph.D., degree in Electrical Engineering in Anna University, Chennai. He has 12 years' experience in teaching and working as Assistant professor in the Department of Electrical and Electronics Engineering at SNS College of Technology (Autonomous), Coimbatore from 2010 to till date. He has published more than 20 research articles in well reputed and refereed international journals. He also presented more than 25 research articles in National and International Conferences. He has filled and published 9 Indian Product and design Patents in IPR website, governed by Ministry of Commerce and Industry, Government of India. His areas of interests include artificial intelligence, power systems, renewable energy, distributed generation, smart grids, and electric vehicles. He can be contacted at email: bharathbhadri@gmail.com.

Vasuki Arumugam Professor, Department of Electronics and Communication Engineering, completed B.E in Electronics and Communication Engineering from PSG College of Technology, Coimbatore, in 1989. She has a postgraduate degree in M.E. Applied Electronics from Coimbatore Institute of Technology, Coimbatore, in 1991. She has done her Ph.D. in image compression from PSG College of Technology under Anna University Chennai in 2010. She has 31 years of teaching, research, and academic administration experience. Her research interests are signal processing, image processing, communications and optimization. she has published 1 book, 3 book chapters, 40 National and International Journal papers and 60 National and International Conference papers. She has guided over 30 PG projects and 50 UG projects. She is an approved Research Supervisor under Anna University Chennai. She can be contacted at email: vasuki.a.ece@kct.ac.in.