Indonesian Journal of Electrical Engineering and Computer Science
Vol. 39, No. 3, September 2025, pp. 1459~1466
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v39.i3.pp1459-1466

Performance evaluation of distribution network with change of load by connecting wind DG

Swathi Sankepally, Sravana Kumar Bali
Department of Electrical and Electronics Engineering, GITAM Deemed to be University, Vishakhapatnam, India

Article Info

Article history:

Received Sep 10, 2024
Revised Apr 21, 2025
Accepted Jul 2, 2025

Keywords:

Distributed generation
Distribution network
Load flow analysis
Load variation
PSO algorithm
Wind turbine generators

ABSTRACT

The aim of this research is to determine the optimal location and size of a minimum number of distributed generators (DGs) needed to maintain the stable operation of an IEEE 85-bus distributed network. The main objective is to ensure the stability of the distribution network by optimizing the placement and capacity of DGs. This is accomplished through the utilization of particle swarm optimization (PSO). The stability of the distribution network is checked by evaluating the voltages and power losses using load flow. The stability of the distribution network is assessed using boundary criteria that are not altered by more than 5% of the nominal voltage value. The distribution network voltage stability is assessed using various case studies, one of that involves a change in load driven by connecting WDG and the other by a change in power supply from wind DGs due to varying wind speed. The PSO is implemented in IEEE-85 bus distribution network using MATLAB software.

Corresponding Author:

Swathi Sankepally
Department of Electrical and Electronics Engineering, GITAM Deemed to be University
Vishakhapatnam, India
Email: ssrreddy15@gmail.com

1. INTRODUCTION

Distributed generation can improve the reliability of the electrical grid by reducing the risk of widespread outages. Since power is generated locally, disruptions in one area are less likely to affect other areas. Distributed generation can provide ancillary services to the grid, such as voltage support, frequency regulation, and reactive power control. By actively managing distributed energy resources, grid operators can improve the stability and efficiency of the electrical grid. Voltage and frequency regulation algorithms are employed to ensure that the output of distributed generators (DGs) systems matches the grid's voltage and frequency. Proportional-integral-derivative (PID) control algorithms are commonly used for voltage and frequency regulation, adjusting the output of the DG system based on grid measurements. Synchronization algorithms are used to synchronize the output of the DG system with the grid before connection. Phase-locked loop (PLL) algorithms are frequently used for synchronization, detecting the phase and frequency of the grid and adjusting the output of the DG system accordingly. Anti-islanding algorithms are essential to detect and prevent DG systems from operating in islanded mode when grid connection is lost [1].

Passive methods, such as impedance measurement and frequency deviation detection, as well as active methods, such as disturbance injection and rate of change of frequency (ROCOF) detection, are used for anti-islanding detection [2]. Active power control algorithms enable DG systems to regulate their active power output based on grid conditions and control signals [3]. Droop control algorithms are commonly used for active power control, adjusting the output of the DG system in proportion to frequency deviations from the nominal value [4], [5]. Reactive power control algorithms are used to regulate the reactive power output of DG systems to support voltage regulation and power factor correction [6], [7]. Voltage regulation algorithms adjust the reactive power output of the DG system based on grid voltage measurements to maintain voltage within acceptable limits [8]. Active power filters and voltage regulation algorithms are used to compensate for harmonics and voltage fluctuations caused by non-linear loads or grid disturbances. MPPT algorithms optimize the output of renewable energy-based DG systems, such as solar photovoltaic (PV) and wind turbines, by tracking the maximum power point of the renewable energy source [9].

The performance of distribution network is evaluated by connecting photovoltaic (PV) using different optimization algorithms [10], [11]. Power quality enhancement algorithms improve the quality of power delivered by DG systems by mitigating harmonics, voltage sags, and other disturbances [12]. Load balancing and demand response algorithms optimize the operation of DG systems to match generation with local demand and grid conditions. Predictive algorithms, machine learning techniques, and optimization algorithms are employed to forecast load demand and adjust the operation of DG systems accordingly [13], [14]. Particle swarm optimization (PSO) is one of the popular optimization technique which is used for optimal location and size of DGs [15], [16].

2. PSO ALGORITHM

The PSO technique is modelled after the social interactions and dynamic motions of insects, birds, and fish. A swarm of agents, or particles, is used in this method to move throughout the search space in search of the optimal location. Based on both its own and other particles' flying experiences, every particle in search space modifies its flight path. The particle with the highest fitness value is in the best position globally. Position, velocity, and previous best position are the three parameters for every particle. Gathering of flying particles (swarm)-search for evolving solutions.

Every member of the population and associated particle in PSO has a variable velocity that determines how it travels around the search space in D-dimensional space, the 'i' th particle is (1).

$$X_{i_i} = \{x_{i1}, x_{i2}, \dots, x_{id}\} \quad (1)$$

The relevant velocity is represented by another D-dimensional vector is given (2).

$$V_i^{t+1} = W * V_i^t + \alpha * \text{r and }()* \left(X^{\text{pbest}} - X_i^t\right) + \beta * \text{rand }()* \left(X^{\text{Gbest}} - X_i^t\right) \quad (2)$$

The position of each particle is updated every generation is given (3).

$$X_i^{t+1} = X_i^t + V_i^{t+1} \quad (3)$$

In this work, the particle is represented as DG location and size as shown in Figure 1.

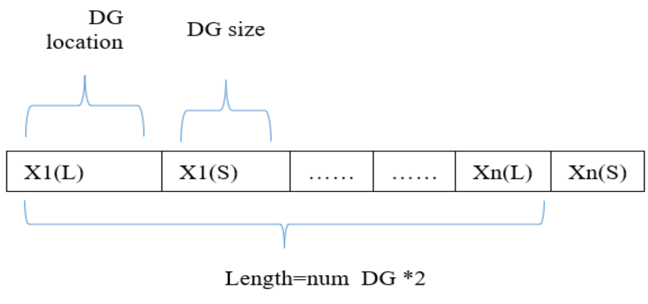

Figure 1. Individual particle

The variable parameters of the PSO algorithm are given as follows:
Maximum number of iterations = 100
Number of DG units = 10
particle size=40
α =2
β =2

$$W = W_{max} - \left(\frac{W_{max} - W_{min}}{iter_{max}}\right) * iter$$

Where W_{max} =0.9 and W_{min} = 0.4.

3. WIND POWER GENERATION

In the production of wind electricity for the wind power system to operate safely and steadily, it is important to plan ahead and coordinate the active and reactive power of wind farms with the grid [17], [18]. Slow manual reserves can be used to compensate for the wind power lost as a result of WTs shutting down during the storm [18], [19]. Because wind turbine rotors are totally disconnected from the grid, they are unable to adapt to changes in system frequency or take part in power system frequency control [20], [21]. The wind generator’s output power is zero when the wind speed is below the critical speed. Using realistic data, a power estimation method based on Gaussian regression accurately describes various turbine types and locations [22], [23]. a model to depict the correlation between wind speed and wind turbine outage probabilities [24], [25].

4. RESULTS AND ANALYSIS

The PSO method has been applied to a radial distribution network for optimal location and power supply of ten wind DG. The results of the study of wind generator’s locations and power supplies are presented in a Table 1. The following case studies are used to assess and explain the distribution network’s performance.

Table 1. Optimal location and power supply of 10 wind distributed generators

Wind generators number	PSO	
	Bus No.	Supply power (kVA)
Wind Generator-1	83	291.237
Wind Generator-2	53	297.733
Wind Generator-3	51	284.483
Wind Generator-4	29	274.201
Wind Generator-5	85	221.702
Wind Generator-6	63	298.447
Wind Generator-7	82	289.089
Wind Generator-8	29	286.471
Wind Generator-9	69	197.508
Wind Generator-10	82	275.431

4.1. Case study 1: DN voltages at 125% of full load

With the change in load, the voltages and power losses in the DN are computed when DG units are connected. Once DGs are connected in DN, their positions should not be changed. The voltages and power losses are calculated when loads change. Figure 2 shows the DN voltages at 125% of full load, the minimum voltage is 0.956 per unit at bus number 75.

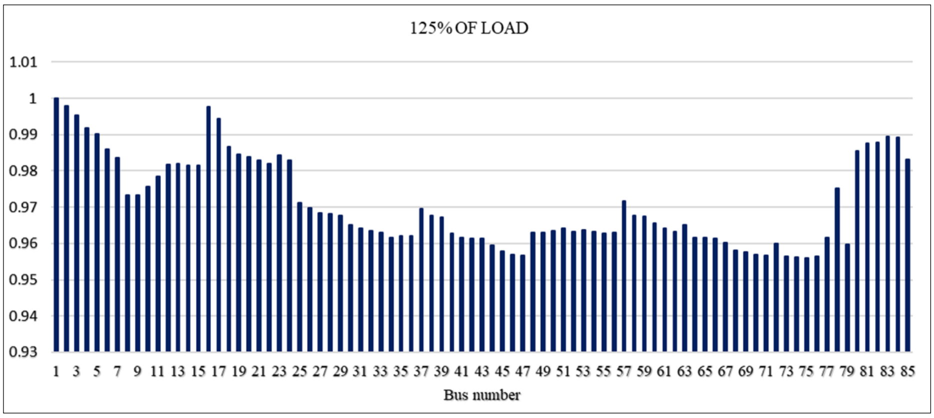

Figure 2. Voltages (P.U) of DN at 125% full load

4.2. Case study 2: DN voltages at 100% of full load

The voltage results are displayed in Figure 3. Bus number 84 has a maximum distribution network voltage of 1.012 per unit, while bus number 75 has the lowest voltage of 0.982 per unit. All buses' voltages are within the acceptable range (0.95 < V < 1.05).

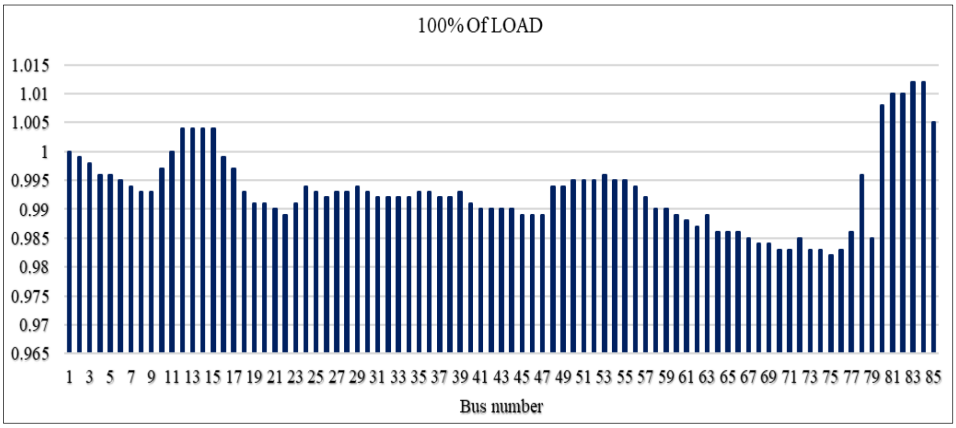

Figure 3. Per unit voltages of DN at 100% full load

4.3. Case study 3: DN voltages at 75% of full load

The voltage results at 75% of the full load is shown in Figure 4. Bus number 22 has a minimum distribution network voltage of 0.995 per unit, whereas bus number 84 has a maximum voltage of 1.033 P.U. The distribution network operates steadily as a result.

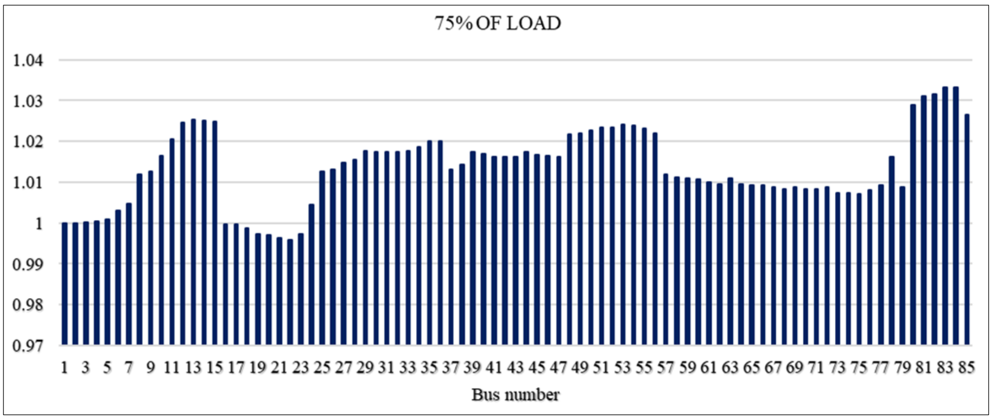

Figure 4. Per unit voltages of DN at 75% full load

4.4. Case study 4: DN voltages at 50% of full load

The voltage results at 50% of full load shown in Figure 5. Bus number 84 has the maximum DN voltage of 1.054 per unit, while bus number 16 has the lowest voltage of 1.00 per unit. The distribution network is unstable in this case study because the maximum voltage of 1.056 exceeds the maximum boundary limit of 1.05 P.U.

The voltage stability of DN is investigated from the aforementioned case studies and shown in the Table 2. The distribution network became unstable when the voltage boundary limit exceeded at 50% of full load. The changes in load have an impact on power losses. The power losses resulting from changes in the load are given in Table 3.

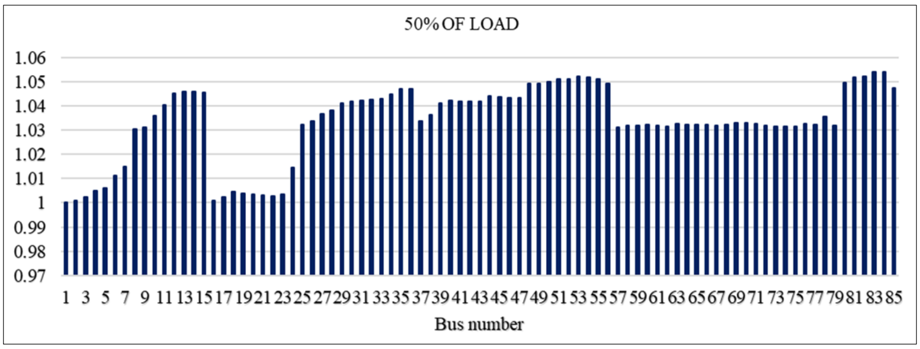

Figure 5. Per unit voltages of DN at 50% full load

Table 2. The change in voltages at variable loads

Load	Minimum per unit voltage	Maximum per unit voltage	The average voltage of 85 buses	Deviation of minimum voltage (%)	Deviation of maximum voltage (%)
125%	0.956	1	0.970	4.4 (drop)	0
100%	0.982	1.012	0.993	1.8 (drop)	1.2(rise)
75%	0.995	1.033	1.013	0.5 (drop)	3.3(rise)
50%	1	1.054	1.033	0	5.4 (rise)

Table 3. Power losses of DN with the change of loads

Change of load (%)	Power losses(kW)
125	47.4
100	18.8
75	22.0
50	52.3

The connection of DG units with fixed locations and sizes leads to abnormal voltage changes and loss of power with load changes, which leads to damage to the loads and a decrease in the efficiency of the DN. This problem has been overcome by controlling the supply power of the DG units when the load changes. The fixed locations and different sizes of DG units are connected in DN with load changes using PSO for a reliable and high-quality power supply. The fixed locations and different sizes of DG units with load changes are indicated in Table 4. The voltages of DN for different sizes of DG units with load changes are shown in Figure 6.

Table 4. Variable power supply of DG units in DN with the change of loads

DG number	Bus number	Power supply of DGs units (kVA)			
		125% Load	100% Load	75% Load	50% Load
DG -1	83	304	291.2	40.4	52.3
DG -2	53	132.7	297.7	178.9	190.2
DG -3	51	304	284.4	224.9	16.0
DG -4	29	304	274.2	304	166.6
DG -5	85	279.7	221.7	45.6	140.6
DG -6	63	78.5	298.4	304	185.5
DG -7	82	128.0	289.0	188.2	48.4
DG -8	29	304	286.4	304	304
DG -9	69	304	197.5	304	251.4
DG -10	82	304	275.4	304	93.8

Table 5 shows the mean values of 85 bus voltages, as well as the percentage variation of the minimum and maximum voltages from the nominal voltage. All voltages are within bounds and close to unity. The power losses during load changes are given in Table 6.

Figure 7 shows a comparison of the power losses of DN between fixed-size DG units and variable-size DG units during load changes. The active power losses are very high with DGs of a fixed size during load changes compared to DGs of variable size.

Figure 6. Comparison of voltages at different buses for various loads

Table 5. The change of voltages at variable loads

Change of load (%)	Minimum per unit voltage	Maximum per unit voltage	Avg voltage of Per unit 85 buses	Deviation of minimum voltage (%)	Deviation of maximum voltage (%)
125	0.967	1.000	0.979	3.3	0
100	0.982	1.012	0.993	1.8	1.2
75	0.994	1.006	0.999	0.6	0.6
50	0.995	1.001	0.999	0.5	0.1

Table 6. Power losses of DN at a fixed location and variable power sizes of DG units with the change of loads

Loads	Active power losses (kW)
125% of load	34.806
100% of load	18.728
75% of load	6.042
50% of load	2.488

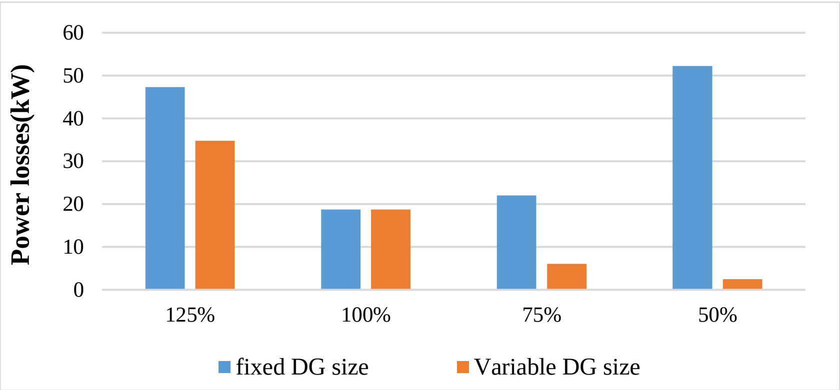

Figure 7. Comparison of active power losses for fixed size and variable size DG

5. CONCLUSION

The PSO technique has been applied on an IEEE-85 bus radial distribution network to determine the optimal position and dimensions for a wind DG. When the wind DGs are connected, the distribution network's voltages and power losses are calculated during load variations of 125%, 100%, 75%, and 50%. The distribution network becomes unstable when the highest voltage exceeds the maximum boundary limits at 50% of full load.

FUNDING INFORMATION

Authors state no funding involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Swathi Sankepally	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	
Sravana Kumar Bali		✓		✓		✓		✓		✓	✓	✓	✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The Authors have no other rlevent affiliations or financial involvement with any organization or entity with a direct or indirect financial interest in the subject matter discussed in the manuscript.

DATA AVAILABILITY

Simulation of this research obtained from the mentioned research content in "references".

REFERENCES

[1] 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, doi: 10.1016/j.protcy.2016.08.173.

[2] M. Yousif, Q. Ai, Y. Gao, W. A. Wattoo, Z. Jiang, and R. Hao, "An optimal dispatch strategy for distributed microgrids using PSO," *CSEE Journal of Power and Energy Systems*, vol. 6, no. 3, pp. 724–734, Jun. 2019, doi: 10.17775/CSEEJPES.2018.01070.

[3] L. Zhang, H. Zheng, Q. Hu, B. Su, and L. Lyu, "An Adaptive Droop Control Strategy for Islanded Microgrid Based on Improved Particle Swarm Optimization," *IEEE Access*, vol. 8, pp. 3579–3593, 2020, doi: 10.1109/ACCESS.2019.2960871.

[4] Q. Kang, M. Zhou, J. An, and Q. Wu, "Swarm Intelligence Approaches to Optimal Power Flow Problem With Distributed Generator Failures in Power Networks," *IEEE Transactions on Automation Science and Engineering*, vol. 10, no. 2, pp. 343–353, Apr. 2013, doi: 10.1109/TASE.2012.2204980.

[5] N. Ghadimi, M. Afkousi-Paqaleh, and A. Nouri, "PSO Based Fuzzy Stochastic Long-Term Model for Deployment of Distributed Energy Resources in Distribution Systems With Several Objectives," *IEEE Systems Journal*, vol. 7, no. 4, pp. 786–796, Dec. 2013, doi: 10.1109/JSYST.2013.2252865.

[6] S. Roy Ghatak, S. Sannigrahi, and P. Acharjee, "Comparative Performance Analysis of DG and DSTATCOM Using Improved PSO Based on Success Rate for Deregulated Environment," *IEEE Systems Journal*, vol. 12, no. 3, pp. 2791–2802, Sep. 2018, doi: 10.1109/JSYST.2017.2691759.

[7] S. R. Biswal, G. Shankar, R. M. Elavarasan, and L. Mihet-Popa, "Optimal Allocation/Sizing of DGs/Capacitors in Reconfigured Radial Distribution System Using Quasi-Reflected Slime Mould Algorithm," *IEEE Access*, vol. 9, pp. 125658–125677, 2021, doi: 10.1109/ACCESS.2021.3111027.

[8] T. Gush, C.-H. Kim, S. Admasie, J.-S. Kim, and J.-S. Song, "Optimal Smart Inverter Control for PV and BESS to Improve PV Hosting Capacity of Distribution Networks Using Slime Mould Algorithm," *IEEE Access*, vol. 9, pp. 52164–52176, 2021, doi: 10.1109/ACCESS.2021.3070155.

[9] O. Pathak and P. Prakash, "Load Flow Solution for Radial Distribution Network," *2018 2nd IEEE International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, Delhi, India, 2018, pp. 176-181, doi: 10.1109/ICPEICES.2018.8897305.

[10] A. Naderipour et al., "Deterministic and probabilistic multi-objective placement and sizing of wind renewable energy sources using improved spotted hyena optimizer," *Journal of Cleaner Production*, vol. 286, p. 124941, 2021, doi: 10.1016/j.jclepro.2020.124941.

[11] S. Kumar and A. Kumar, "Optimal Allocation and Sizing of Distributed Generation in IEEE-85 BUS System Considering Various Load Models Using Multi-objective Metaheuristic Algorithms," *Decarbonisation and Digitization of the Energy System*, pp. 15-31, doi: 10.1007/978-981-99-7630-0_2.

[12] T. Senjyu, Y. Miyazato, A. Yona, N. Urasaki, and T. Funabashi, "Optimal Distribution Voltage Control and Coordination With Distributed Generation," *IEEE Transactions on Power Delivery*, vol. 23, no. 2, pp. 1236–1242, Apr. 2008, doi: 10.1109/TPWRD.2007.908816.

[13] H. Yoshida, K. Kawata, Y. Fukuyama, S. Takayama, and Y. Nakanishi, "A particle swarm optimization for reactive power and voltage control considering voltage security assessment," *IEEE Transactions on Power Systems*, vol. 15, no. 4, pp. 1232–1239, 2000, doi: 10.1109/59.898095.

[14] A. Ibrahim *et al.*, "PV maximum power-point tracking using modified particle swarm optimization under partial shading conditions," *Chinese Journal of Electrical Engineering*, vol. 6, no. 4, pp. 106–121, Dec. 2020, doi: 10.23919/CJEE.2020.000035.

[15] E. A. Almabsout, R. A. El-Sehiemy, O. N. U. An, and O. Bayat, "A Hybrid Local Search-Genetic Algorithm for Simultaneous Placement of DG Units and Shunt Capacitors in Radial Distribution Systems," *IEEE Access*, vol. 8, pp. 54465–54481, 2020, doi: 10.1109/ACCESS.2020.2981406.

[16] S. Ganguly and D. Samajpati, "Distributed Generation Allocation on Radial Distribution Networks Under Uncertainties of Load and Generation Using Genetic Algorithm," *IEEE Transactions on Sustainable Energy*, vol. 6, no. 3, pp. 688–697, Jul. 2015, doi: 10.1109/TSTE.2015.2406915.

[17] S. M. R. H. Shawon, X. Liang and M. Janbakhsh, "Optimal placement of distributed generation units for microgrid planning in distribution networks," in *IEEE Transactions on Industry Applications*, vol. 59, no. 3, pp. 2785-2795, May-June 2023, doi: 10.1109/TIA.2023.3236363.

[18] K. Das, F. Guo, E. Nuno, and N. A. Cutululis, "Frequency Stability of Power System with Large Share of Wind Power under Storm Conditions," *Journal of Modern Power Systems and Clean Energy*, vol. 8, no. 2, pp. 219–228, 2020, doi: 10.35833/MPCE.2018.000433.

[19] M. R. Nayak, D. Behura, and K. Kasturi, "Optimal allocation of energy storage system and its benefit analysis for unbalanced distribution network with wind generation," *Journal of Computational Science*, vol. 51, p. 101319, 2021, doi: 10.1016/j.jocs.2021.101319.

[20] M. Hashem, M. A. Salam, M. Th. El. Mohandes, M. Nayel and M. Ebeed, "Optimal Placement and Sizing of Wind Turbine Generators and Superconducting Magnetic Energy Storages in a Distribution System," *Journal of Energy Storage*, vol. 38, 2021, p. 102497, doi: 10.1016/j.est.2021.102497.

[21] Li Wang, Tai-Her Yeh, We-Jen Lee, and Zhe Chen, "Benefit Evaluation of Wind Turbine Generators in Wind Farms Using Capacity-Factor Analysis and Economic-Cost Methods," *IEEE Transactions on Power Systems*, vol. 24, no. 2, pp. 692–704, May 2009, doi: 10.1109/TPWRS.2009.2016519.

[22] M. Liu *et al.*, "A Slime Mold-Ant Colony Fusion Algorithm for Solving Traveling Salesman Problem," *IEEE Access*, vol. 8, pp. 202508–202521, 2020, doi: 10.1109/ACCESS.2020.3035584.

[23] H. M. H. Farh, A. M. Al-Shaalan, A. M. Eltamaly, and A. A. Al-Shamma'A, "A Novel Crow Search Algorithm Auto-Drive PSO for Optimal Allocation and Sizing of Renewable Distributed Generation," *IEEE Access*, vol. 8, pp. 27807–27820, 2020, doi: 10.1109/ACCESS.2020.2968462.

[24] H. Mohammed and C. O. Nwankpa, "Stochastic analysis and simulation of grid-connected wind energy conversion system," *IEEE Transactions on Energy Conversion*, vol. 15, no. 1, pp. 85–90, Mar. 2000, doi: 10.1109/60.849121.

[25] Z. Jin, F. Li, X. Ma, and S. M. Djouadi, "Semi-definite programming for power output control in a wind energy conversion system," *IEEE Transactions on Sustainable Energy*, vol. 5, no. 2, pp. 466–475, 2014, doi: 10.1109/TSTE.2013.2293551.

BIOGRAPHIES OF AUTHORS

Swathi Sankepally was born in Thirumalagiri Village, Suryapet District, Telangana State, India. She received M.Tech. degree from Jawaharlal Nehru Technology University Hyderabad (JNTUH). Currently, she is working as an assistant professor in the Department of Electrical Engineering, Bhoj Reddy Engineering college for women, JNTUH. She has more than 12 years of experience in teaching. Her research area is applications of optimization techniques in power systems. She can be contacted at email: ssrreddy15@gmail.com.

Dr. Sravana Kumar Bali received Ph.D. degree in Electrical and Electronics Engineering from JNTUK, Andhra Pradesh, India in 2019. He is currently working as an Assistant Professor with the GITAM Deemed to be University, Visakhapatnam, Andhra Pradesh. His research interests include power systems-network contingency, FACTS devices placement, metaheuristic methods, and applications of optimization. In these areas, he has published over 37 Scopus database publications. He can be contacted at email: sbali@gitam.edu.