Single-phase distributed generations for power balanced using adaptive real coded genetic algorithm

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ABSTRACT

Easy access to distributed generation (DG) technology is promoting the utilization of single-phase DGs for residential purposes. Surplus energy generated by household DGs can be shared or sold to other communities through existing networks. However, the interconnection of single-phase DGs from residential generators to the distribution network requires careful handling to secure the reliability and quality of the electric power system. This paper focuses on the optimal placement of single-phase multi-type DGs on unbalanced distribution systems that are connected to nonlinear loads. The objective of this study is to minimize the power losses and voltage unbalances in the distribution networks. To verify the efficacy of this method in reducing voltage unbalances and harmonics, an optimization approach is also presented using three-phase DG. Optimal placement of DG is performed on a modified Kaliasin distribution system using an adaptive real coded genetic algorithm (ARC-GA). Simulation results demonstrate that the installation of single-phase DGs is highly effective in reducing power losses and voltage unbalances in the distribution networks.

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1. INTRODUCTION

The need for inexpensive and reliable electricity has led to the widespread use of energy-based distributed generation (DG) systems. In 2016, the global installation of DG systems saw a significant growth of 183% [1], with these systems contributing 20 to 30% of the total electricity production [2]. The recent changes in power system management regulations have shifted the control of power plants away from the government, allowing communities to have their own generators and even sell surplus energy to local areas using established networks. This development is anticipated to become a prevailing trend in the future.

DG in a distribution system can be used to minimize active power loss [3], reduce voltage deviation [4], and minimize costs [2], [5]. The integration of DG into a distribution system is commonly performed using a balanced system approach, where harmonics and load imbalances are often disregarded. Electrical power system in general is an unbalanced system [6]. Modifying an unbalanced system to a balanced system does not represent a real system. A significant voltage unbalance in the distribution system causes various issues, such as overheating, harmonics and interference on the three-phase equipment [7]. The problem of load imbalance has been discussed by several researchers with different approaches, positive voltage ratio [8], reinforce learning [9], Cuckoo search [10], improved particle swarm optimization [11], crisscross optimization algorithm [12], optimal power flow [13], open distribution system simulator [14], and symbiotic organisms search (SOS) [15]. These studies do not discuss nonlinear loads. However, the number of nonlinear loads in a power system can reach 40-41% of the load [16]. Harmonics in the distribution system can increase power loss [17], decrease insulation life, increase temperature, and reduce power factor [18].

The interconnection of DG into the distribution system considering harmonics and imbalances has been performed by several researchers with different methods: genetic algorithm [19], real-coded genetic algorithm (RC-GA) [20], harmony search [21], biogeography-based optimization [22], and modified group experience of teaching learning-based optimization [23]. All these studies use three-phase DG so that the injection of three-phase power into an unbalanced distribution system has a less significant effect on voltage unbalance, even in some cases, it can increase voltage unbalance and harmonic.

The effect of single-phase DG in an unbalanced distribution system has been studied by Amirullah *et al*. [24], Pinthurat and Hredzak [25], and Jiao *et al*. [26], but DG type and harmonics are not considered. This paper explores the most advantageous positioning of various types of single-phase DG units in unbalanced distribution systems. The objective of this study is to minimize power losses, reduce the voltage unbalanced, and maintain the voltage and harmonics at an acceptable limit. The contributions of this research are: i) optimal placement of DG in addition to considering the imbalance also considers the harmonics, ii) using single-phase DG and it compares with three-phase DG for harmonic and unbalanced mitigation, and iii) the optimization method uses the ARC-GA method which has better performance than the standard GA. The remaining sections of this paper are organized as follows: in the second section, the ARC-GA, objectives, DG modeling and optimization algorithms are discussed thoroughly. The third section discusses the optimization results and the performance of the methods. The conclusions are discussed in the last section.

2. METHOD

2.1. Adaptive real coded genetic algorithm

Studies indicate that the genetic algorithm does not always ensure convergence to the global optimum. To address this issue, the ARC-GA method is proposed, which adjusts the probabilities of crossover (p_c) and mutation (p_m) based on changes in individual fitness values [2]. When individual variability is low, pc and pm are increased. This increase in pc and pm results in the generation of more new individuals, thereby enhancing individual variability. Conversely, if individual variability is high, p_c and p_m are reduced. This decrease in p_c and p_m reduces the rate at which new individuals are created through crossover and mutations. The probability formulas for crossover and mutation are as (1) and (2) [2].

$$p_c = p_c^o\left(1 + a\frac{F_{ag}N}{(F_{max}-F_{ag})N+F_{ag}N}\right) \tag{1}$$

$$p_m = p_m^o\left(1 + b\frac{F_{ag}N}{(F_{max}-F_{ag})N+F_{ag}N}\right) \tag{2}$$

p_c^o and p_m^o are crossover and mutation probabilities. F_{min}, F_{max}, and F_{avg} are the minimum, maximum, and average fitness of individual respectively. N, a, and b are real numbers.

2.2. The objective

2.2.1. Active power loss

The power losses in the distribution networks are influenced by two main factors: the current flowing through the system and the impedance of the lines. The line current is influenced by the composition of the load, while the line impedance is determined by various factors such as the material used, the length of the distribution lines, and their diameter. The active power loss in an unbalanced distribution system can be formulated as (3).

$$P_{loss} = \sum_{F=A,B,C}\left(\sum_{i=1}^{n}\sum_{j=1}^{n} V_i^{(F)}V_j^{(F)}Y_{ij}^{(F)}(Cos(\theta_i^{(F)} - \theta_j^{(F)}{}_i - \delta_j^{(F)})\right) \tag{3}$$

P, V, and Y are power, voltage, and admittance respectively. While n, θ, and δ are the number of buses, phase voltage angle, and phase admittance angle. DG placement is intended to reduce power loss on the distribution system. The objective function associated with power loss can be defined in (4).

$$F_1 = min\left[\frac{P_{DG}}{P_B}\right] \tag{4}$$

P_B and P_{DG} are power loss before and after DG installation.

2.2.2. Voltage profile

In addition to reducing power losses, DG can also improve the voltage level at each bus. The phase voltage on each bus is expected to be close to or equal to 1 pu. The objective function related to the voltage profile on each bus is formulated as (5).

$$F_2 = min(\,|V_{ref} - V_{P\_i}|) \tag{5}$$

V_{ref} and V_{P_i} are voltage reference and phase voltage at bus i.

2.2.3. Voltage unbalance

The unbalanced loading in the distribution system leads to an imbalance of inter-phase voltages. The objective function related to the voltage unbalanced is formulated as (6).

$$F_3 = \frac{\mathrm{Max}(|V_i^k\text{-}V_i^{\mathrm{mean}}|)}{|V_i^{\mathrm{mean}}|} \times 100\% \tag{6}$$

V_i, V_i^{mean}, and k are voltage bus i, average voltage bus i, and phase respectively.

2.2.4. Harmonic

The presence of harmonics can negatively impact the precision of measuring instruments, particularly single-phase devices that rely on a disc mechanism. These instruments tend to exhibit approximately 2% faster movement when subjected to harmonic loads. Harmonics can also lead to alterations in currents, frequencies, and impedances, which may trigger the operation of protective equipment like relays even in the absence of actual disturbances [27]. The IEEE-519 standard sets the permissible individual harmonic distortion (iHD) at 3%, while the total harmonic distortion (THD) must remain below 5% [19]. The levels of total harmonics and individual harmonics are formulated as (7) and (8).

$$N_{iHD_j} = \begin{cases} 1, \, if \, iHD_j \le 3 \\ exp(\alpha|3 - iHD_j|) \, if \, iHD_j > 3 \end{cases} \tag{7}$$

$$N_{THD_i} = \begin{cases} 1, \, if \, THD_i \le 5 \\ exp(\alpha|5\text{-}THD_i|) \, \, if \, THD > 5 \end{cases} \tag{8}$$

N_{THD} and N_{iHD} are total harmonics and individual harmonics level. i, j, and α are individual, order harmonics, bus number and constanta respectively. The individual and total harmonics limit violations can be formulated as (9) and (10).

$$N_i = \prod_{j=1}^{k} N_{\mathrm{iHD}} \tag{9}$$

$$N_T = \prod_{i=1}^{n} N_{\mathrm{THD}} \tag{10}$$

The objective function pertaining to harmonics can be computed utilizing as (11).

$$F_4 = \prod_{j=1}^{k} N_{\mathrm{iHD}} \times \prod_{i=1}^{k} N_{\mathrm{THD}} \tag{11}$$

If both THD and iHD meet the specified standards, then F4 is assigned a value of 1. However, if either THD or iHD fails to meet the standards, F4 will yield a significantly large number. The objective function in this study is a composite of active power loss, voltage profile, voltage unbalance, and harmonics, formulated as (12).

$$F = w_1F_1 + w_2F_2 + w_3F_3 + w_4F_4 \tag{12}$$

F is the objective function while w_1, w_2, w_3, and w_4 are weights.

2.3. DG modelling

DG performance in the power system is highly determined by location, type, and rating of DG. In this paper, single-phase DG is modeled into four types [3]: type I DG: supplying active power only; type II DG: supplying reactive power only; type III DG: supplying active and reactive power; and type IV DG:

supplying active power but absorbing reactive power. The maximum size of DG type I and type II are 100 kVar and 100 kW respectively. The maximum size of DG type III is 100 kVA with power factor 0.95 leading, while maximum size of DG type IV is 100 kVA with power factor 0.95 lagging. The maximum penetration of DG into the power system is 30% and the maximum number of DG is 6.

2.4. Optimization algorithm

The optimization of the location and size of single-phase DG is performed simultaneously. Individual is modeled into four strings, namely location, phase, type, and size. The location string represents the bus number where the DG will be located. This string contains integers representing the number of buses in the distribution system. The second string is a phase string representing the phase in which DG will be placed. This string contains integers 1, 2, and 3 representing phase a, b, and phase c respectively. The third string is the DG type string. This string contains integers between 1 and 4 according to the number of DG types. The fourth string is DG size string. This string contains a real number between 0 and 1. 0 and 1 indicate the minimum and maximum size of DG. The DG size is obtained through the decoding process using (13).

$$R_{DG} = rf \; x \; R_{max} \tag{13}$$

R_{DG}, rf, and R_{max} are actual size, string size, and maximum DG size.

ARC-GA is employed to enhance the performance of the genetic algorithm (GA). Adaptations in the crossover and mutation operators are introduced to be responsive to variations in individual fitness. When individual variability is high, the likelihood of crossover and mutation is reduced, and vice versa. The optimization approach for determining the optimal placement, phase, size, and type of DG is outlined as follows:

– Step 1: Read parameters of GA, DG types, DG number (nDG), bus data and load data
– Step 2: Run fundamental and harmonic load flow to find the initial condition of the system, including bus voltages, network losses, IHD, THD and voltage unbalanced
– Step 3: Initialize population with size (nDG, nPopulation). Individual is represented by four number strings: DG location, phase, type, and size
– Step 4: Determine DG size through decoding process using (13)
– Step 5: Read system data and injection of harmonic currents
– Step 6: Update system data by size, location, phases, and DG type of individual chromosome
– Step 7: Run harmonic load flow to determine voltages, network losses, harmonics and voltage unbalanced
– Step 8: Determine the fitness of all individuals using (12)
– Step 9: Verify if the termination condition is met. If it is met, go to step 14. Otherwise, go to step 10
– Step 10: Update the worst individual using the fittest individual from the population
– Step 11: Individual selection using roulette whee method
– Step 12: Exchange of parental chromosomes using adaptive crossover
– Step 13: Change a few genes in a chromosome using adaptive mutations
– Step 14: Determine the optimal location, phase, size, and type of DGs

3. RESULTS AND DISCUSSION

3.1. Data test system

The modified Kaliasin radial distribution system comprises 10 buses and 9 lines. The medium voltage network is linked to five load buses via 20/0.380 kV transformers. The overall load connected to the system amounts to 2.2068 MW and 1.468 MVAR. All loads on the distribution system are supplied through bus 1. The information regarding bus data, line data, transformer data, and harmonic current injection of the nonlinear load is taken from [20].

3.2. Before placement of DG

Load flow analysis reveals that all system bus voltages meet the standard 1±0.05 pu. The highest voltage on bus 1 which is 20 kV (1 pu) and the lowest is on bus 10 phase a (10a) which is 19.907 kV. Active and passive power losses are 5.352 kW and 2.556 kVar respectively. THD on all buses and phases are less than 5% so they meet the IEEE standards. The highest THD is 4.2398% on bus 7(b). The lowest THD is 3.237% on bus 1(a). Individual harmonics of the order 7, 11, and 13 are all below 3%. Individual harmonic order 5 in phase b of all buses exceeds 3% so it does not meet IEEE standards.

3.3. Single-type DG placement

Figure 1 illustrates the optimization outcomes for the arrangement of six single-phase DG units. It is evident from Figure 1 that each DG type exhibits a distinct best fitness value. Specifically, DG types I, II, III, and IV possess the best fitness values of 9.4803, 8.5002, 8.2450, and 8.9737, respectively. The optimization results highlight that DG type III demonstrates superior performance compared to the other four DG types in terms of reducing power losses, voltage unbalance, and harmonics.

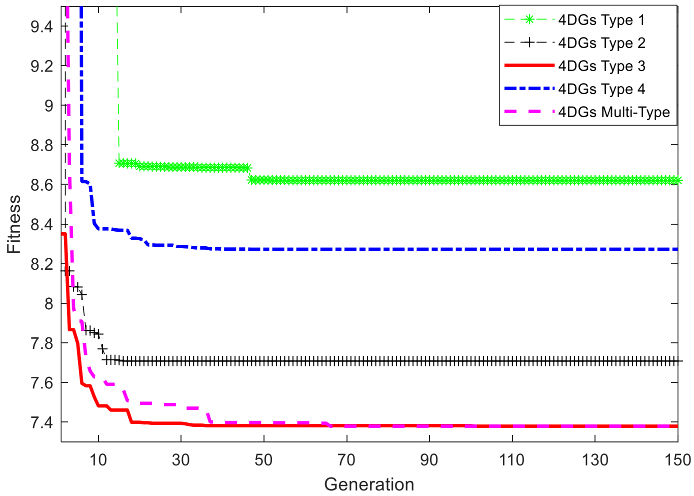

Figure 1. Single and multi-type DG convergence characteristic

Table 1 presents the optimal size and location of four types of DG at penetration rates of 13.6% and 27.27%. At 13.6% penetration rate, placement of three DG type III on bus 10(a), 10(b), 10(b) able to reduce active and passive power loss of 22.08% and 21.93% respectively. The same outcomes are observed at a penetration rate of 27.27%. DG type III provides the best performance in reducing power losses. DG type III can reduce active and passive power loss by 40.30% and 40.17% respectively.

Table 1. Single-phase DG optimization result

DG penetration	Scheme	Location	Size	Ploss (kW)	Qloss (kVar)	Ub (%)	iHD Violation
Base case	-	-	-	5.352	2.556	0.35400	169.76
	Type I	8b, 10b, 10b	3×100 kVar	4.7471	2.2693	0.33475	2.031
	Type II	10a, 10b, 10b	3×100 kW	4.3595	2.0837	0.31607	1.000
13.60%	Type III	10a, 10b, 10b	3× (95 kW+31.23 kVar)	4.1704	1.9954	0.31195	1.000
	Type IV	8b, 10b, 10b	3× (95 kW-31.23 kVar)	4.6891	2.2365	0.32404	1.005
	Multi-type	10a, 10b, 10b	3× (95 kW+31.23 kVar)	4.1704	1.9954	0.31195	1.000
	Type I	8b, 8b, 10a, 10b, 10b, 10c	6×100 kVar	4.2762	2.0461	0.31545	1.000
	Type II	8b, 10a, 10b, 10c, 10a, 10b	6×3100 kVar	3.5596	1.7012	0.27826	1.000
27.27%	Type III	8b, 10a, 10b, 10c, 10b, 10b	6× (95 kW+31.23 kVar)	3.1952	1.5293	0.27004	1.000
	Type IV	8b, 8b, 10a, 10b, 10b, 10c	6× (95 kW-31.23 kVar)	4.1642	1.9829	0.29410	1.000
	Multi-type	8b, 10a, 10b, 10c, 10b, 10b	6× (95 kW+31.23 kVar)	3.1952	1.5293	0.27004	1.000

In addition to reducing power losses, single-phase DG placement in the distribution system is also expected to reduce the voltage unbalance significantly. The optimization results show that DG type III gives the best performance in reducing voltage unbalance and the worst is DG type I. DG type III and type I can reduce the voltage unbalance of 5.44% and 11.88% respectively at 13.60% penetration level. For penetration rate of 27.27% DG type III and type I reduce voltage unbalance by 10.89% and 23.72% respectively.

Figure 2 shows that the penetration of single-phase DG significantly increases the voltage at each bus. The largest increase is observed in phase A, while the other two phases show a similar increase. Figures 3 and 4 display the iHD and THD before and after the DG placement respectively. In the base case, the iHD at phase B of all buses is greater than 3%, while the other two phases are less than 3%. As for the THD, in the base case, all buses have a THD value smaller than 5%, which means they meet the IEEE-519 standard. However, when single-phase DG is deployed, it results in an increased fundamental bus voltage, which in turn leads to lower iHD and THD levels. All single-phase DG deployment schemes meet the IEEE-

519 standard, except when DG type I reaches a penetration level of 13.6%. At this point, there is an iHD violation of 2.031 indicating the presence of a bus with iHD greater than 3%.

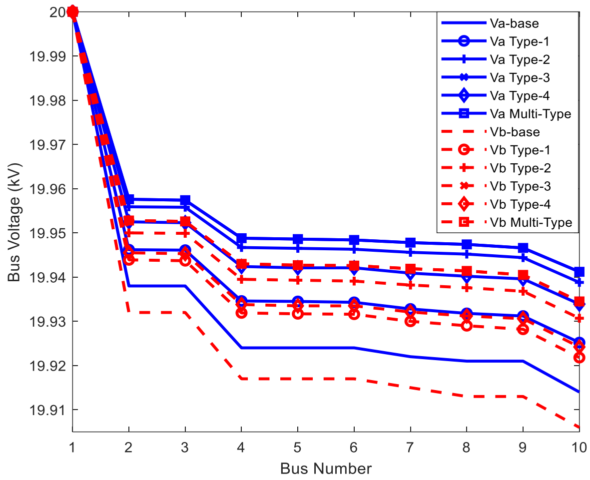

Figure 2. Bus voltage before and after placement of 6 single-phase DG

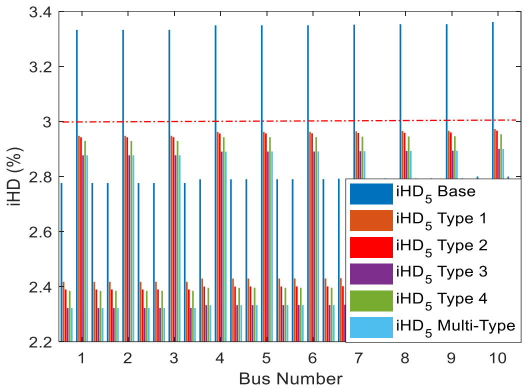

Figure 3. iHD before and after DG placement

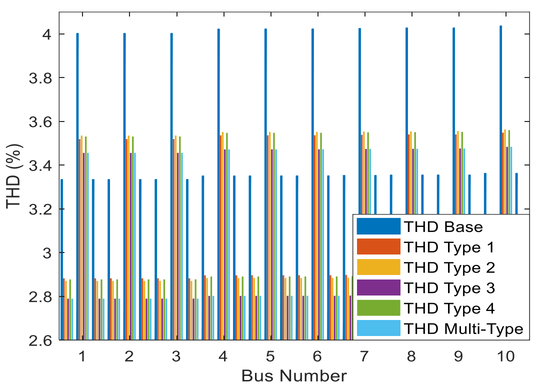

Figure 4. THD before and after DG placement

3.4. Multi-type DG placement

Multi type optimization results are shown in Table 1. Table 1 indicates that optimal placement of multi type DG and DG type III into distribution systems has the same results regarding location, size, and influence on the reduction power losses, voltage unbalanced and harmonics. The only difference lies in the speed of ARCGA in reaching the optimum point. The multi-type of DG placement scheme is slower to reach the optimum point than the single DG type scheme since the multi-type of optimization problem becomes more complex with the inclusion of DG types in the optimization scheme.

3.5. Three phase DG optimization

Three-phase DG placement optimization is performed to compare single-phase and three-phase DG performance in reducing voltage unbalances, power losses and harmonics. Three-phase DG optimization is executed at the same penetration level as single-phase DG. The three-phase DG optimization results are shown in Table 2. Table 2 shows that for a penetration level of 13.60%, all DG optimization schemes do not meet iHD standard. The iHD violation for three-phase DG is greater than single-phase DG at the same penetration level. In single-phase DG scheme, only type I and type IV schemes do not meet the standard. The iHD violation values for type I and type IV are 2.031 and 1.005. Unbalanced voltage and power losses for the three-phase DG scheme are slightly lower than the single-phase DG scheme. This difference is due to the priority level of each objective function. In this optimization scheme, harmonics occupy the main priority, then unbalanced voltage, voltage profile, and power losses. For penetration levels 27.27%, single-phase DG provides better results in reducing harmonics, voltage unbalance and losses than three-phase DG scheme.

Table 2. Three phase DG optimization result

DG Penetration	Scheme	Location	Size	Ploss (kW)	Qloss (kVar)	Ub (%)	iHD Violation
Base case	-	-	-	5.3520	2.556	0.35400	169.762
13.60%	Type I	10	300 kVar	4.7171	2.2571	0.33470	29.354
	Type II	10	300 kW	4.3965	2.102	0.31607	10.699
	Type III	10	285 kW+93 kVar	4.2231	2.021	0.31195	6.588
	Type IV	10	285 kW-93 kVar	4.6741	2.2323	0.32398	23.285
	Multi-type	10	285kW+93 kVar	4.2231	2.021	0.31195	6.588
27.27%	Type I	8, 10	2×300 kVar	4.2426	2.0322	0.31556	6.595
	Type II	8, 10	2×300 kW	3.5879	1.715.3	0.27840	1.000
	Type III	8, 10	2×(285 kW+93.69 kVar)	3.2458	1.5556	0.27020	1.000
	Type IV	8, 10	2×(285 kW-93.69 kVar)	4.1384	1.9735	0.29420	4.056
	Multi-type	8, 10	2×(285 kW+93.69 kVar)	3.2458	1.5556	0.27020	1.000

4. CONCLUSION

ARCGA is used in this paper to determine the location, phase, size, and type of four single-phase DG types in the distribution system. The simulation results show that the placement of 6 single-phase DG type III provides the best performance in reducing voltage unbalances, power losses and harmonics compared to the other three DG types. The multi-type of single-phase DG optimization provides the same result as DG type III scheme. Single-phase DG optimization also performs better in reducing harmonics, voltage imbalances and power losses than the three-phase DG scheme at the same penetration level.

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REFERENCES

[1] A. Colmenar-Santos, C. Reino-Rio, D. Borge-Diez, and E. Collado-Fernández, “Distributed generation: A review of factors that can contribute most to achieve a scenario of DG units embedded in the new distribution networks,” *Renewable and Sustainable Energy Reviews*, vol. 59, pp. 1130–1148, 2016, doi: 10.1016/j.rser.2016.01.023.

[2] Umar, Firdaus, A. Soeprijanto, and O. Penangsang, “Optimal expenditure and benefit cost based location, size and type of DGs in microgrids systems using adaptive real coded genetic algorithm,” *Telkomnika (Telecommunication Computing Electronics and Control)*, vol. 16, no. 1, pp. 10–17, 2018, doi: 10.12928/telkomnika.v16i1.6761.

[3] Firdaus, Umar, R. S. Wibowo, and O. Penangsang, “Optimal Placement of Intermittent Dg Renewable Energy and Capacitor Bank for Power Losses Reduction and Voltage Profile Improvement in Microgrids Systems,” *Journal of Engineering Science and Technology*, vol. 17, no. 5, pp. 3539–3554, 2022.

[4] Rekha and S. C. Byalihal, “Optimal allocation of solar and wind distributed generation using particle swarm optimization technique,” *International Journal of Electrical and Computer Engineering*, vol. 13, no. 1, pp. 229–237, 2023, doi: 10.11591/ijece.v13i1.pp229-237.

[5] F. Faanzir, M. Ashari, S. Soedibyo, S. Suwito, and U. Umar, “The Design of DC Micro Grid with a Load-Based Battery Discharge Method for Remote Island Electrification Utilizes Marine Currents and Solar Photovoltaic,” *Kinetik: Game Technology, Information System, Computer Network, Computing, Electronics, and Control*, vol. 7, no. 4, pp. 409–420, 2022, doi: 10.22219/kinetik.v7i4.1576.

[6] P. U. Reddy, S. Sivanagaraju, and P. Sangameswararaju, “Power Flow Analysis of Three Phase Unbalanced Radial Distribution System,” *International Journal of Advances in Engineering & Technology*, vol. 514, pp. 514–524, 2012.

[7] R. Yan and T. K. Saha, “Investigation of voltage imbalance due to distribution network unbalanced line configurations and load levels,” *IEEE Transactions on Power Systems*, vol. 28, no. 2, pp. 1829–1838, 2013, doi: 10.1109/TPWRS.2012.2225849.

[8] N. Hayat, S. R. Ghatak, S. R. Pani, and S. Mishra, “Performance Improvement of Three Phase Unbalance Distribution System Using DG and DSTATCOM,” in *2020 IEEE Calcutta Conference, CALCON 2020 - Proceedings*, 2020, pp. 200–205, doi: 10.1109/CALCON49167.2020.9106473.

[9] Y. Yoon and S. Choi, “Application of Reinforcement Learning to Operate the Unbalanced Distribution System,” in *International Conference on ICT Convergence*, 2022, pp. 347–349, doi: 10.1109/ICTC55196.2022.9953017.

[10] T. Wang, Y. Wang, Y. Hou, F. Gu, S. Hou, and W. Jin, “Optimization of Unbalanced Active Distribution Systems Using Cuckoo Search Algorithm,” in *2021 9th IEEE International Conference on Smart Energy Grid Engineering, SEGE 2021*, 2021, pp. 129–133, doi: 10.1109/SEGE52446.2021.9534957.

[11] R. Bonela, S. R. Ghatak, N. Hayat, S. C. Swain, and A. Mohapatra, “Optimal planning framework of three phase unbalanced distribution system using multiple DG and DSTACOM under different loading condition,” *7th IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering, UPCON 2020*, 2020, doi: 10.1109/UPCON50219.2020.9376508.

[12] L. Luan, H. Peng, W. Mo, Y. Wang, and Z. Xu, “Location Method for Three Phase Unbalance Sources in Distribution Network Based on CSO Optimized Deep Belief Network,” in *Proceedings - 2021 International Conference on Power System Technology: Carbon Neutrality and New Type of Power System, POWERCON 2021*, 2021, pp. 1986–1990, doi: 10.1109/POWERCON53785.2021.9697787.

[13] M. A. A. Al-Ja'Afreh and G. Mokryani, "Voltage unbalance mitigation in low voltage distribution networks using time series three-phase optimal power flow," *2021 56th International Universities Power Engineering Conference: Powering Net Zero Emissions, UPEC 2021 - Proceedings*, 2021, doi: 10.1109/UPEC50034.2021.9548248.

[14] R. Bonela, S. R. Ghatak, N. Hayat, S. C. Swain, and A. Mohapatra, "Techno-Economic planning framework of three phase unbalanced distribution system using multiple DG and Capacitor," *1st Odisha International Conference on Electrical Power Engineering, Communication and Computing Technology, ODICON 2021*, pp. 1–6, 2021, doi: 10.1109/ODICON50556.2021.9428933.

[15] G. Setyawan, Umar, A. Soeprijanto, and O. Penangsang, "Symbiotic Organism Search for Sizing and Optimal Location of Distributed Generation Using Novel Sensitivity Factor," in *IOP Conference Series: Materials Science and Engineering*, 2019, vol. 588, no. 1, doi: 10.1088/1757-899X/588/1/012021.

[16] A. Kalair, N. Abas, A. R. Kalair, Z. Saleem, and N. Khan, "Review of harmonic analysis, modeling and mitigation techniques," *Renewable and Sustainable Energy Reviews*, vol. 78, pp. 1152–1187, 2017, doi: 10.1016/j.rser.2017.04.121.

[17] M. J. Ghorbani and H. Mokhtari, "Impact of harmonics on power quality and losses in power distribution systems," *International Journal of Electrical and Computer Engineering*, vol. 5, no. 1, pp. 166–174, 2015, doi: 10.11591/ijece.v5i1.pp166-174.

[18] Z. Hu, Y. Han, A. S. Zalhaf, S. Zhou, E. Zhao, and P. Yang, "Harmonic Sources Modeling and Characterization in Modern Power Systems: A Comprehensive Overview," *Electric Power Systems Research*, vol. 218, 2023, doi: 10.1016/j.epsr.2023.109234.

[19] A. A. Abdelsalam, A. A. Zidan, and E. F. El-Saadany, "Optimal DG Allocation in Radial Distribution Systems with High Penetration of Non-linear Loads," *Electric Power Components and Systems*, vol. 43, no. 13, pp. 1487–1497, 2015, doi: 10.1080/15325008.2015.1043601.

[20] Umar, Firdaus, and O. Penangsang, "Simultaneously placement and sizing of multiple DGs and shunt capacitor banks in unbalanced distribution systems using real coded GA," in *Proceeding - 2016 International Seminar on Intelligent Technology and Its Application, ISITIA 2016: Recent Trends in Intelligent Computational Technologies for Sustainable Energy*, 2017, pp. 487–492, doi: 10.1109/ISITIA.2016.7828708.

[21] K. Muthukumar and S. Jayalalitha, "Harmony search approach for optimal capacitor placement and sizing in unbalanced distribution systems with harmonics consideration," in *IEEE-International Conference on Advances in Engineering, Science and Management, ICAESM-2012*, 2012, pp. 393–398.

[22] N. Ghaffarzadeh and H. Sadeghi, "A new efficient BBO based method for simultaneous placement of inverter-based DG units and capacitors considering harmonic limits," *International Journal of Electrical Power and Energy Systems*, vol. 80, pp. 37–45, 2016, doi: 10.1016/j.ijepes.2016.01.030.

[23] M. Kumawat, N. Gupta, N. Jain, and R. C. Bansal, "Optimal planning of distributed energy resources in harmonics polluted distribution system," *Swarm and Evolutionary Computation*, vol. 39, pp. 99–113, 2018, doi: 10.1016/j.swevo.2017.09.005.

[24] Amirullah, M. Ashari, O. Penangsan, and A. Soeprijanto, "Multi units of single phase distributed generation combined with battery energy storage for phase power balancing in distribution network," *Jurnal Teknologi*, vol. 78, no. 10–4, pp. 27–33, 2016, doi: 10.11113/jt.v78.9887.

[25] W. Pinthurat and B. Hredzak, "Strategy for compensation of unbalanced powers in LV residential distribution networks using distributed single-phase battery systems," *Electric Power Systems Research*, vol. 211, 2022, doi: 10.1016/j.epsr.2022.108253.

[26] W. Jiao, Q. Wu, S. Huang, J. Chen, C. Li, and B. Zhou, "DMPC based distributed voltage control for unbalanced distribution networks with single-/three-phase DGs," *International Journal of Electrical Power and Energy Systems*, vol. 150, 2023, doi: 10.1016/j.ijepes.2023.109068.

[27] W. M. Grady and S. Santoso, "Understanding Power System Hannonics," *IEEE Power Engineering Review*, vol. 21, no. 11, pp. 8–11, Nov. 2001, doi: 10.1109/MPER.2001.961997.

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