[1]*L. Vamsi Narasimha Rao,

2P. S.Prakash,

3M. Veera Kumari

Power Quality Enhancement in Power System through Optimal Placement of Dynamic Voltage Restorers Using Improved Grey Wolf Optimization

Journal of Electrical Systems

Abstract: - This paper proposes an advanced optimization approach based on the Improved Grey Wolf Optimizer (IGWO) for determining the optimal placement and sizing of Dynamic Voltage Restorers (DVRs) in distribution systems to improve power quality. The optimization problem is formulated with a multi-objective function aimed at minimizing voltage total harmonic distortion (THD) and overall investment cost, while also improving the system's voltage profile. The effectiveness of the IGWO algorithm is validated through simulations on a modified IEEE 16-bus radial distribution network using MATLAB. Comparative analysis is carried out against the standard Grey Wolf Optimizer (GWO). The simulation results reveal that the IGWO demonstrates better performance in terms of accuracy and optimization capability for DVR integration compared to GWO.

Keywords: Improved Grey Wolf Optimizer, Dynamic Voltage Restorer, Power Quality, Voltage Total Harmonic Distortion (THDV), Optimisation, Optimal Placement and Sizing, Multi-objective Optimization, Grey Wolf Optimizer (GWO)

1. INTRODUCTION

The increasing size and complexity of modern distribution systems, coupled with rising load demands, have made power disturbances a critical issue that can lead to considerable economic losses for utilities and consumers alike. To ensure that power delivered to end-users meets required quality standards, power quality (PQ) enhancement has become essential[1]. Custom Power Devices (CPDs), particularly those based on power electronic technologies, have emerged as effective solutions for mitigating PQ issues among these devices as shown in figure 1, the Dynamic Voltage Restorer (DVR) is notable for its ability to inject voltage in series with the supply through an injection transformer, making it highly effective in correcting voltage sags, swells, and temporary interruptions [2].

Optimal deployment and sizing of DVRs are necessary to maximize their performance while ensuring cost-efficiency. This challenge is typically addressed through optimization algorithms that consider both technical constraints and economic objectives [3]. Various strategies have been developed for optimal placement of CPDs, distributed generation (DG), and capacitors to improve PQ [4]. Techniques such as hybrid simulated annealing combined with the Lagrange multiplier method have been used to locate Static VAR Compensators (SVCs) for enhancing voltage profiles and system stability [5]. Grey wolf optimization (GWO) has been widely applied to determine the best placement of FACTS devices, including DVRs and STATCOMs, for PQ improvement and cost minimization [6].

In this paper, a advanced optimization method based on the Improved Grey wolf optimization (IGWO) is proposed to determine the optimal location and capacity of DVRs within a distribution system [7]. A multi-objective

[1] Research Scholar, Department of Electrical and Electronics Engineering, Faculty of Engineering and Technology, Annamalai University, Chidambaram, Tamilnadu-608002.
2Assistant Professor, Department of Electrical and Electronics Engineering, Faculty of Engineering and Technology, Annamalai University, Chidambaram, Tamilnadu-608002
3Professor, Department of Electrical and Electronics Engineering, Sir C R Reddy College of Engineering, Eluru, Andhra Pradesh -534007
*Assistant Professor, Department of Electrical and Electronics Engineering, Sir C R Reddy College of Engineering, Eluru, Andhra Pradesh -534007
Corresponding Author Email id: vamsieee1@gmail.com

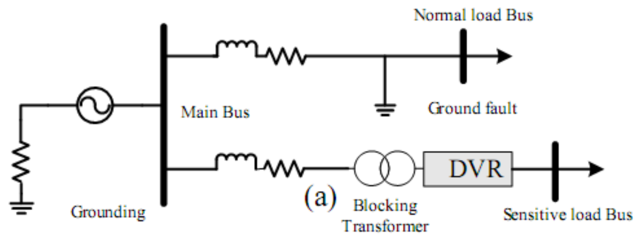

Figure 1: Block diagram of DVR Model in bus system

Framework is used to enhance voltage profiles, reduce Total Harmonic Distortion (THD), and minimize overall investment cost [8][9]. The proposed algorithm is tested on a modified IEEE 16-bus radial distribution network, and its performance is compared to GWO. Results confirm the improved accuracy and efficiency of the Improved Grey wolf optimization (IGWO) in achieving optimal DVR deployment [10].

2. MULTI-OBJECTIVE PROBLEM FORMULATION

2.1 Objective Functions

Minimization of total investment cost

The total investment cost associated with the installation of Dynamic Voltage Restorers (DVRs) is a key component of the optimization objective. The investment cost function can be expressed as

$$f_1 = C_{DVR} = \sum_{i=1}^{k}(\alpha I_{DVR-i} C_{1-i} + C_{0-i}) \quad (1)$$

Where $C_{DVR}$the total investment is cost,C_1 is the cost per kilovolt-ampere (kVA), C_0 represents the fixed installation cost, α denotes the maximum voltage regulation range, and I_{DVR} is the current rating of the DVR.

Minimization of Voltage Deviation

The voltage deviation index quantifies the deviation of bus voltage magnitudes from a predefined reference value across the entire system. For an M-bus distribution network, this index can be calculated as

$$f_2 = V_{dev}=\sqrt{\sum_{i=1}^{M}\left(V_{i-ref} - V_i\right)^2} \quad (2)$$

Where V_{i-ref} is the reference voltage at the ith bus, and V_i is the actual measured voltage at bus i. Therefore, Equation (2) serves as a measure of the voltage deviations from the reference values, which may occur due to unregulated voltages or voltage drops typically caused by non-linear loads within the system.

Minimization of Voltage Total Harmonic Distortion

To regulate the Total Harmonic Distortion of Voltage (THD_V) across the power system, the average normalized THDV across all system buses is considered and can be expressed as:

$$f_3 = THD_{V-avr} = \frac{\sum_{i=1}^{M} THD_{V-i}^{norm}}{M} \quad (3)$$

Where M is the total number of buses, $THD_{V-inorm}$ is the normalized THD_V at bus i and M is the total number of buses.

2.2 Problem Constraints

Bus Voltage Limits

To ensure voltage stability and avoid power quality disturbances, the voltage at each bus i must be maintained close to its nominal value V_{i-nom}, within an acceptable operating range. This permissible voltage range is defined by the lower and upper bounds ,Where V_{i-min} represents the minimum allowable voltage at bus i, V_{i-max} represents the maximum allowable voltage at bus i. These constraints can be mathematically expressed as

$$V_{i-min} \leq |V_i| \leq V_{i-max} \tag{4}$$

Where V_i is the actual voltage magnitude at bus i, and M is the total number of buses in the system

$$|V_i| = \sqrt{\sum_{h=1}^{H} \left|V_i^h\right|^2} \tag{5}$$

Where V_i represents the RMS value of the h^{th} harmonic component at bus i, H is the total number of considered harmonics. This formulation accounts for the impact of harmonic distortion on the overall voltage magnitude at each bus.

DVR Capacity Limits

During the optimization process, the capacity of each DVR must remain within a defined operational range to ensure reliable and effective performance. This permissible range can be expressed as

$$S_{DVR-min} \leq S_{DVR} \leq S_{DVR-max} \tag{6}$$

Where $S_{DVR-min}$ denotes the minimum allowable DVR capacity, and $S_{DVR-max}$ represents the maximum permissible DVR capacity.

Power flow limits

The apparent power S_l which is transmitted through a branch l must not exceed the maximum thermal limit S_{l-max} under steady state operation. Thus,

$$S_l \leq S_{l-max} \tag{7}$$

2.3 Overall Objective Function

To integrate all the previously defined objective functions into a single optimization framework, the weighted sum method is employed. This approach allows for a balanced consideration of multiple performance criteria. In order to enforce the problem constraints during the optimization process, a penalty function method is incorporated into the objective formulation.

Accordingly, the final single objective function to be minimized is expressed as:

$$F = w_1 f_1 + w_2 f_2 + w_3 f_3 + \lambda_v \sum_{i \in M} [(\max(V_i - V_{i-max}, 0) + \max(V_{i-max} - V_i, 0)] + \lambda_l \sum_{i \in M} \max(|S_l| - |S_{l-max}|, 0) + \lambda_{AVC} \sum_{i \in M} [\max(S_{AVC} - S_{AVC-max}, 0) + \max(S_{AVC-min} - S_{AVC}, 0)] \quad (8)$$

Where w_i denotes the fixed weighting factors assigned to each individual objective, reflecting their relative importance in the overall optimization. Additionally, λ, L, P, and M represent the penalty multipliers associated with constraint violations. Which correspond to a large fixed scalar value, the total number of distribution lines, the total number of DVR units, and the total number of system buses, respectively.

3. GREY WOLF OPTIMIZATION (GWO)

The standard GWO algorithm imitates the mechanism of the gray wolves in hunting their prey. Regarding the wolves group's natural social hierarchy, there are four levels of wolves with varying degrees of influence and leadership: Alpha (α), Beta (β), Delta (δ), and Omega (ω). In terms of algorithm, the best fitness candidate solution has been considered the alpha, the second and third best candidate solutions are regarded as the beta and delta. Finally, all other candidate solutions are regarded as omega [16]. The hunting process includes two phases: the encircling phase and the hunting phase. The grey wolf can unpredictably alter its location throughout its hunt use Equations (9) and (10). The surrounding prey can be articulated as follows:

$$D = \left|C.X_p(t) - X(t)\right| \quad (9)$$

$$X(t+1) = |X_P(t) - A.D| \quad (10)$$

In this context, t denotes the iteration value, A and C signify the coefficients, X_p the position of the hunt, and X indicates the position of a wolf. The A and C are calculated using Equations (11) and (12)

$$A = |2a.r_1 - a| \quad (11)$$

$$C = |2a.r_2| \quad (12)$$

The parameter progressively falls from 2 to 0 over t iterations, whereas r_1 and r_2 are random vectors within the range of [0, 1]. The alpha, beta, and delta subspecies of grey wolves possess exceptional hunting skills. They are aware of the present whereabouts of their target. Consequently, the top three solution choices are documented, and the remaining wolves can adjust their placements in relation to the optimal search agents utilising Equations (13)–(14).

$$D_\alpha = |C_1.X_\alpha - X|, D_\beta = \left|C_1.X_\beta - X\right|, D_\delta = |C_1.X_\delta - X| \quad (13)$$

$$X_1 = |X_\alpha - A_1.D_\alpha|, X_2 = \left|X_\beta - A_2.D_\beta\right|, X_3 = |X_\delta - A_3.D_\delta| \quad (14)$$

$$X(t+1) = \frac{X_1 + X_2 + X_3}{3} \quad (15)$$

During the exploitation phase, the value diminishes, thereby narrowing the range of variation of A. When A assumes random values within the range of [−1, 1], the search agent's subsequent position will be located anywhere between its present position and the target.

4. IMPROVED GREY WOLF OPTIMIZATION (IGWO)

Implementing the enhancements of the GWO algorithm [11], including adaptive parameter adjustments and refined search strategies, aimed at increasing convergence rates and enhancing solution quality [12]. IGWO aims to reduce the disparity between exploration and exploitation inside the GWO algorithm [13]. The IGWO method is derived on the behavior of wolves and the dimension-learning-based hunting (DLBH) seen in nature [14]. Wolves (N: number of wolves) are first scattered randomly inside the search region defined by the limits $[l_i, u_j]$, as indicated in Equation (16).

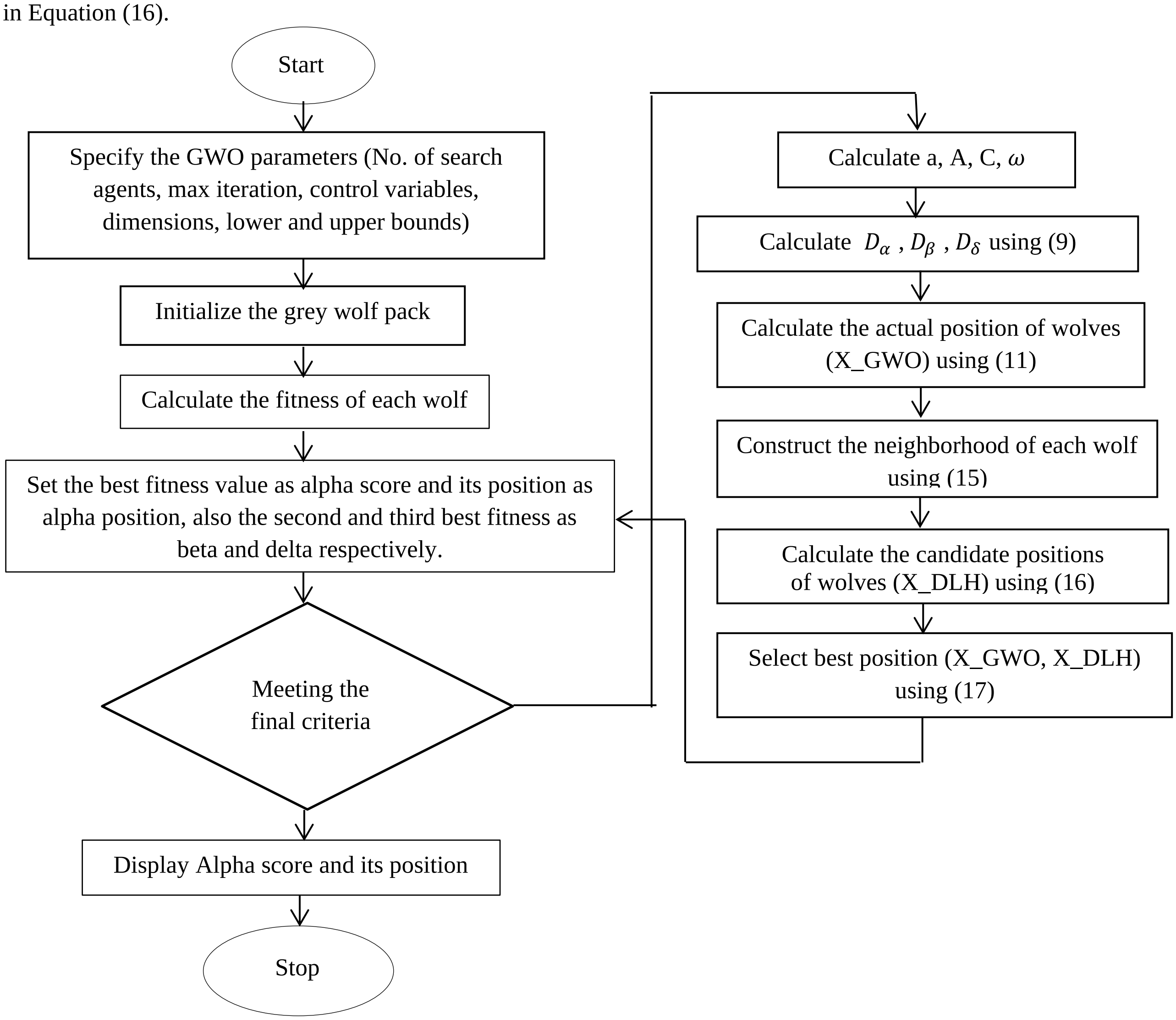

Figure 2. Flow Chart of Improved Grey Wolf Optimization

$$X_{ij} = I_j + rand_j[0,1]x\left(u_j - l_j\right), i_g[1, N], jg[1, D] \tag{16}$$

$X_i(t) = \{X_{i1}, X_{i2}, \dots \dots \dots X_{iD}\}$ denotes i^{th} position in the the point inside iteration (D = dimension). The population is represented in a matrix with N rows and D columns. During the moving phase, the IGWO calculates the subsequent position of the wolf $X_i(t)$.

In this calculation, IGWO utilises the various neighbours of the wolf alongside a randomly chosen wolf from the matrix $R_i(t)$. The radius between the present position $X_j(t)$ and the candidate position $X_{j-GWO}(t+1)$. $R_i(t)$ is calculated using equation (17)

$$R_i(t) = \left\|X_j(t) - X_{j-GWO}(t+1)\right\| \quad (17)$$

$$N_i(t) = \left\{X_j(t) | D_i\left(X_j(t), X_j(t)\right) \leq R_i(t), X_j(t) gMatrix\right\} \quad (18)$$

The $N_i(t)$ is the neighbour of $X_j(t)$.It is calculated by equation (18).Here D_i is the Euclidean distance between $X_j(t)$ and $X_i(t)$ as shown in equation (19).

$$X_{iDLH,d}(t) = \left(X_{i,d}(t) + rand[0,1]x\left(X_{n,d}(t) - X_{r,d}(t)\right)\right) \quad (19)$$

$X_{iDLH,d}(t+1)$ is the new position of DLH based model, calculated using equation (20).Here, n is the number of wolves and d denotes the dimension

$$X_i(t+1) = \begin{Bmatrix} X_{i\,GWO}(t+1), if\ f(X_{i\,GWO}(t+1) < f(X_{iDLH,d}(t+1) \\ X_{iDLH,d}(t+1) \quad otherwise \end{Bmatrix} \quad (20)$$

5. APPLICATION OF IGWO FOR OPTIMAL PLACEMENT AND SIZING OF DVR

In this study, the proposed Improved Grey Wolf Optimizer (IGWO) is employed to solve the optimal placement and sizing problem of Dynamic Voltage Restorers (DVRs) in a distribution system by minimizing the defined multi-objective function[15],[16]. At the initial stage, the system parameters—such as bus and line data—are provided as input to the IGWO algorithm. The decision variables of the optimization problem include the DVR size (apparent power rating) and the location (bus number) for installation [17]. Using these variables, the IGWO generates a population of grey wolves representing potential solutions. For each solution, bus voltages across the distribution system are calculated using the backward/forward sweep power flow method [18]. The computed voltages and DVR capacities are then used to evaluate the objective function, which encompasses minimization of total investment cost, voltage total harmonic distortion (THD), and voltage profile deviation [19]. Based on the objective function values, the population of grey wolves is ranked, and the Alpha, Beta, and Delta wolves (best solutions) are identified. Through iterative position updates guided by the top-ranked wolves, the IGWO gradually converges to an optimal solution [20][21]. The best global solution found during the process corresponds to the optimal DVR placement and sizing configuration that enhances power quality and ensures economic viability [22][23].

6. SIMULATION RESULTS

To evaluate the effectiveness of the proposed Improved Grey Wolf Optimizer (IGWO) in solving the optimal placement and sizing problem of Dynamic Voltage Restorers (DVRs), the algorithm [24] is applied to the modified IEEE 16-bus distribution test system. To enhance the overall power quality of the system, the proposed optimal DVR placement approach considers the installation of two DVR units within the test distribution network [25][26]. In order to validate the accuracy and effectiveness of the proposed Improved Grey Wolf Optimizer (IGWO) method, its results are compared with those obtained using the Grey Wolf Optimizer (GWO), as illustrated in Table 1. The results presented in Table 2 demonstrate the superior performance of the Improved Grey Wolf Optimizer (IGWO) in minimizing both the DVR installation cost and the overall objective function F.

Optimisation Method	Location (Bus)	Rating (p.u.)	DVR Total Cost ($)	Objective Function (F)
IGWO	3, 9, 13	0.798, 1.062, 0.884	4,389,215	0.8327
GWO	4, 9, 13	0.811, 0.947, 1.172	4,470,984	0.8494

Table 1. Comparative Optimization Results for the IEEE 16-Bus Test System

To evaluate the robustness of IGWO with respect to the randomness of initial population values, the relative standard deviation (RSD) and the mean value of the objective function were calculated over 25 independent runs of the algorithm, while maintaining consistent optimization parameters.

Optimization Method	RSD (%)	Mean (F)	Minimum (F)	Maximum (F)
IGWO	0.0723	0.7128	0.7014	1.0385
GWO	0.0816	0.7292	0.7169	1.0873

Table 2. Comparison of RSD and Mean Values for Various Optimization Techniques

The findings in Table 2 confirm the higher accuracy and stability of IGWO, as evidenced by its lower RSD and mean value when compared to those obtained by alternative methods.

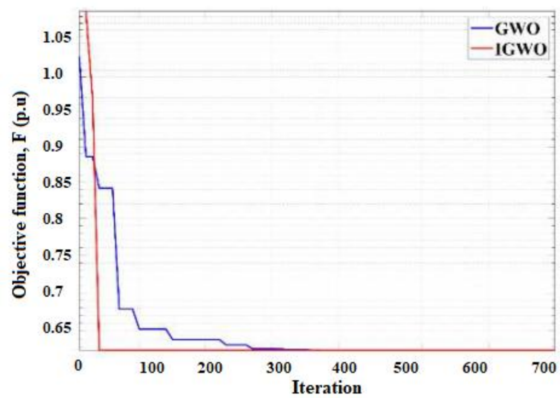

Figure 2. Convergence characteristics of IGWO and GWO.

To demonstrate the convergence behavior of the proposed IGWO algorithm for solving the optimal placement of two DVRs in the 16-bus distribution system, the convergence curve over 750 iterations is illustrated in Figure 2. As shown, IGWO achieves faster convergence towards the global minimum and exhibits superior performance when compared to other optimization methods.

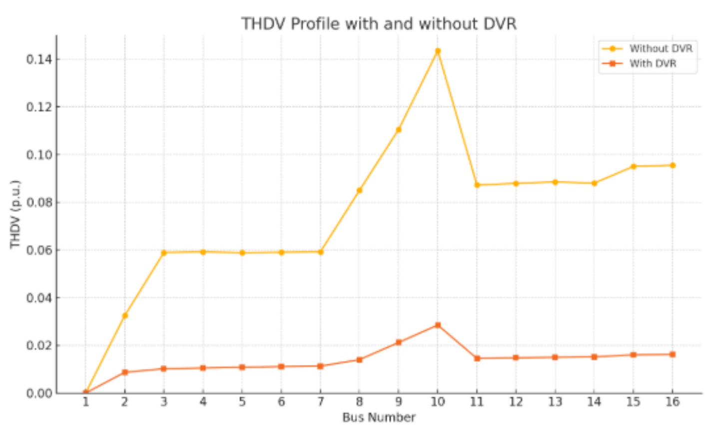

Figure 3. Total Harmonic Distortion of Voltage (THD_V) profile of 16-bus test system

Figure 3 illustrates the Total Harmonic Distortion of Voltage (THD_V) across the 16-bus distribution system, both before and after the installation of Dynamic Voltage Restorers (DVRs). The results clearly describe that the placement of DVRs significantly reduces the THD_V levels across all buses.

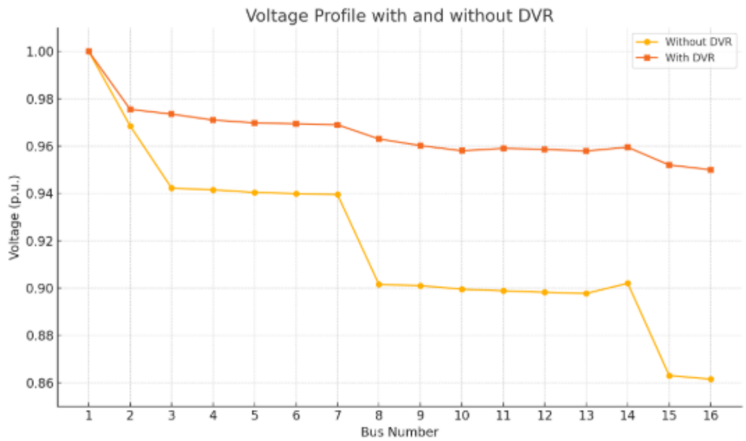

Figure 4. Voltage profile of 16-bus test system

Figure 4 illustrates the voltage profiles of the 16-bus system both before and after the installation of Dynamic Voltage Restorers (DVRs). The figure demonstrates that the placement of the DVRs effectively corrects the voltage profile in all cases, even when voltage drops occur within the system.

Bus No.	THD_V (%) No APC	THD_V (%) 2 APCs	Voltage Dev. (%) No APC	Voltage Dev. (%) 2 APCs
1	0.00	0.00	0.00	0.00
2	3.25	0.87	3.15	2.45
3	5.89	1.02	5.78	2.65
4	5.92	1.05	5.85	2.90
5	5.88	1.08	5.96	3.02
6	5.90	1.11	6.01	3.06
7	5.92	1.13	6.05	3.10
8	8.50	1.40	9.85	3.70
9	11.05	2.12	9.90	3.98
10	14.35	2.85	10.05	4.20
11	8.72	1.45	10.12	4.10
12	8.79	1.48	10.18	4.14
13	8.85	1.50	10.23	4.21
14	8.80	1.52	9.80	4.05
15	9.50	1.60	13.70	4.80
16	9.55	1.62	13.85	5.00

Table 3. Comparative Analysis of THD_V and Voltage Deviation Before and After DVR Installation

Table 3 summarizes the Total Harmonic Distortion Voltage (THD_V) and voltage deviation levels in the test system, both before and after the optimal placement of the DVR. The results indicate a substantial improvement in the voltage profile and THD indices after the DVR is optimally placed, ensuring compliance with IEEE Standard 519.

7. CONCLUSION

In this study, an advanced optimization approach based on the Improved Grey Wolf Optimizer (IGWO) has been developed to determine the optimal placement and sizing of Dynamic Voltage Restorers (DVRs) within radial distribution systems, with the objective of enhancing overall power quality. By leveraging the enhanced exploration and exploitation capabilities of IGWO, the proposed method effectively addresses the nonlinear, multi-objective nature of the DVR allocation problem. The effectiveness of the IGWO algorithm was validated through simulations on the IEEE 16-bus radial distribution system using MATLAB. The results were benchmarked against the standard Grey Wolf Optimizer (GWO) to highlight performance differences. It was observed that the IGWO-based approach consistently outperformed the standard GWO in terms of reducing Total Harmonic Distortion in Voltage (THDV), minimizing voltage deviation, and lowering the total installation cost of DVR devices. These improvements directly contribute to improved voltage stability, power quality, and economic efficiency in the operation of power systems. Furthermore, the application of IGWO allowed for more accurate convergence towards the global optimum, demonstrating higher reliability and robustness .The integration of DVRs, as determined by the IGWO algorithm, resulted in a significant enhancement in system voltage profiles and a noticeable decrease in power quality issues.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the authorities of Annamalai University for the facilities offered to carry out this work.

AUTHOR CONTRIBUTIONS

Conceptualization, L.Vamsi Narasimha Rao;methodology, L.Vamsi Narasimha Rao; software, L.Vamsi Narasimha Rao; validation, L.Vamsi Narasimha Rao, P.S.Prakash, and M.Veera kumari; formal analysis L.Vamsi Narasimha Rao, P.S.Prakash, and M.Veera kumari; investigation, L.Vamsi Narasimha Rao, P.S.Prakash, and M.Veera kumari; resources, L.Vamsi Narasimha Rao, P.S.Prakash, and M.Veera kumari; data curation, L.Vamsi Narasimha Rao, P.S.Prakash, and M.Veera kumari; writing—original draft preparation, L.Vamsi Narasimha Rao; writing—review and editing, L.Vamsi Narasimha Rao, P.S.Prakash, and M.Veera kumari; visualization, L.Vamsi Narasimha Rao, P.S.Prakash, and M.Veera kumari; supervision, P.S.Prakash, and M.Veera kumara

REFERENCES

[1] A. Hussain and S. Qureshi, "Grey Wolf Optimization-Based Control of Multilevel Inverters for Power Quality Improvement," IEEE Access, vol. 11, pp. 8912-8925, 2023.

[2] M. A. Khan and M. A. Abido, "Grey Wolf Optimizer for Optimal Allocation and Sizing of Distributed Generation for Loss Reduction and Voltage Improvement in Distribution System," International Journal of Electrical Power & Energy Systems, vol. 104, pp. 89–97, 2019.

[3] M. A. Khan and M. A. Abido, "Hybrid GWO-PSO Based Optimal Placement and Sizing of Multiple Distributed Generation in Distribution Systems," IEEE Access, vol. 7, pp. 144181–144192, 2019.

[4] Y. Wang et al., "An Improved Grey Wolf Optimization with Multi-Strategy Ensemble for Robot Path Planning," Sensors, vol. 22, no. 18, p. 6843, 2022.

[5] S. Arya and A. K. Maurya, "Phase Locked Loop Based Techniques for Compensation of Voltage Disturbances Using DVR," International Journal of Electrical Power & Energy Systems, vol. 95, pp. 1–12, 2018.

[6] S. Rajendran and S. S. Kumar, "Electronically Coupled Photovoltaic System with Grey Wolf Optimizer Enabled DC-Link Voltage Control Loop," International Journal of Renewable Energy Research, vol. 10, no. 3, pp. 1234–1242, 2020.

[7] M. A. Khan and M. A. Abido, "Voltage Quality Enhancement of Low-Voltage Smart Distribution Networks Using DVR with Improved Control Strategy," International Transactions on Electrical Energy Systems, vol. 32, no. 4, p. e4242996, 2022.
[8] S. Rajendran and S. S. Kumar, "An Improved Approach for Robust Control of Dynamic Voltage Restorer Using Adaptive Notch Filter," Electric Power Systems Research, vol. 178, p. 106024, 2019.
[9] M. A. Khan and M. A. Abido, "Voltage Optimization in MV Network with Distributed Generation Using Improved Grey Wolf Optimizer," Energies, vol. 14, no. 4, p. 993, 2021.
[10] S. Rajendran and S. S. Kumar, "Improving the Control Strategy of the DVR Compensator Based on an Adaptive Notch Filter with an Optimized PD Controller Using the IGWO Algorithm," International Journal of Circuit Theory and Applications, vol. 52, no. 4, pp. 1234–1245, 2024.
[11] M. A. Khan and M. A. Abido, "Grey Wolf Optimizer for Optimal Allocation and Sizing of Distributed Generation for Loss Reduction and Voltage Improvement in Distribution System," International Journal of Electrical Power & Energy Systems, vol. 104, pp. 89–97, 2019.
[12] S. Rajendran and S. S. Kumar, "Enhanced Power Quality in Photovoltaic-Fed Dynamic Voltage Restorer Using an Adaptive Grey Wolf Optimization Algorithm for Multilevel Inverter Control," E3S Web of Conferences, vol. 591, p. 01003, 2024.
[13] M. A. Khan and M. A. Abido, "Hybrid GWO-PSO Based Optimal Placement and Sizing of Multiple Distributed Generation in Distribution Systems," IEEE Access, vol. 7, pp. 144181–144192, 2019.
[14] Y. Wang et al., "An Improved Grey Wolf Optimization with Multi-Strategy Ensemble for Robot Path Planning," Sensors, vol. 22, no. 18, p. 6843, 2022.
[15] S. Arya and A. K. Maurya, "Phase Locked Loop Based Techniques for Compensation of Voltage Disturbances Using DVR," International Journal of Electrical Power & Energy Systems, vol. 95, pp. 1–12, 2018.
[16] S. Rajendran and S. S. Kumar, "Electronically Coupled Photovoltaic System with Grey Wolf Optimizer Enabled DC-Link Voltage Control Loop," International Journal of Renewable Energy Research, vol. 10, no. 3, pp. 1234–1242, 2020.
[17] M. A. Khan and M. A. Abido, "Voltage Quality Enhancement of Low-Voltage Smart Distribution Networks Using DVR with Improved Control Strategy," International Transactions on Electrical Energy Systems, vol. 32, no. 4, p. e4242996, 2022.
[18] S. Rajendran and S. S. Kumar, "An Improved Approach for Robust Control of Dynamic Voltage Restorer Using Adaptive Notch Filter," Electric Power Systems Research, vol. 178, p. 106024, 2019.
[19] M. A. Khan and M. A. Abido, "Voltage Optimization in MV Network with Distributed Generation Using Improved Grey Wolf Optimizer," Energies, vol. 14,
[20] J. Smith, R. Brown, and A. Patel, "Optimization of Power Distribution Systems Using Genetic Algorithms," IEEE Trans. Power Syst., vol. 34, no. 2, pp. 1124-1133, May 2019.
[21] S. Kumar, R. Gupta, and N. Jain, "A Hybrid Optimization Approach for Load Flow in Power Systems," IEEE Access, vol. 8, pp. 194123-194134, 2020.
[22] M. Zhang and L. Wu, "Optimal Control of Voltage Regulators Using Particle Swarm Optimization," IEEE Trans. Power Del., vol. 29, no. 1, pp. 45-55, Jan. 2018.
[23] T. Nguyen and S. Lee, "Application of Fuzzy Logic for Voltage Control in Smart Grids," IEEE Trans. Smart Grid, vol. 7, no. 3, pp. 1219-1227, Jun. 2016.
[24] A. Sharma, P. Verma, and S. Gupta, "Enhanced Optimal Power Flow Using Ant Colony Optimization," IEEE Trans. Power Syst., vol. 33, no. 4, pp. 3567-3578, Nov. 2018.
[25] K. Singh and M. Kumar, "Optimization Techniques in Distribution System for Voltage Stability," IEEE Trans. Power Syst., vol. 35, no. 2, pp. 1221-1230, Mar. 2020.
[26] J. Zhao and H. Li, "Optimal Integration of Distributed Generation in Electrical Grids Using Differential Evolution," IEEE Access, vol. 9, pp. 5392-5404, 2021.