

Optimal distribution network reconfiguration for harmonic mitigation using PSO Sungguminasa 165-bus system with DG and passive filters

Yuli Asmi Rahman¹, Muhira Dzar Faraby², Sofyan³, Sarma Thaha², Musfirah Putri Lukman²,
Muhammad Sahrul Ramadan², Firdaus³, Mansur⁴, Andi Fitriati⁵, Muhammad Rais⁶

¹Department of Electrical Engineering, Faculty of Engineering, Universitas Tadulako, Palu, Indonesia

²Department of Electrical Engineering, Politeknik Negeri Ujung Pandang, Makassar, Indonesia

³Department of Electrical Engineering, Faculty of Engineering, Universitas Negeri Makassar, Makassar, Indonesia

⁴Department of Electrical Engineering, Faculty of Engineering, Universitas Halu Oleo, Kendari, Indonesia

⁵Department of Mechatronic Engineering, Politeknik Bosowa, Makassar, Indonesia

⁶Department of Electrical Engineering, Faculty of Engineering, Universitas Patria Arta, Makassar, Indonesia

Article Info

Article history:

Received Dec 12, 2025

Revised Aug 26, 2026

Accepted Sep 4, 2026

Keywords:

Distributed generation

Harmonic mitigation

Particle swarm optimization

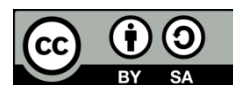
Passive harmonic filter

Reconfiguration

ABSTRACT

The increasing penetration of distributed generation (DG) and nonlinear loads in medium-voltage distribution networks have intensified harmonic distortion, causing poor power quality, higher losses, and potential equipment malfunction. This study proposes a comprehensive optimization framework that combines distribution system reconfiguration (DSR), optimal DG placement, and passive harmonic filter (PHF) allocation using an enhanced particle swarm optimization (PSO) method under coordinated scenarios. The framework simultaneously minimizes total harmonic distortion (THD), active power losses, and voltage deviation while satisfying operational constraints such as network radiality, %THDv limits, and acceptable voltage profiles. A case study is conducted on the 165-bus Sungguminasa distribution network using realistic load data and harmonic characteristics of nonlinear customers. Simulation results show that the proposed PSO-based multiobjective optimization reduces %THDv by 54.38%, decreases power losses by 34.26%, and improves the voltage profile by 0.65% compared with the base configuration. The coordinated application of DSR, DG, and PHF consistently outperforms individual mitigation strategies, demonstrating its practical and economic effectiveness for improving power quality in modern distribution systems. The framework therefore offers utilities a reliable approach for increasingly complex distribution networks.

This is an open access article under the [CC BY-SA](#) license.



Corresponding Author:

Yuli Asmi Rahman

Department of Electrical Engineering, Faculty of Engineering, Universitas Tadulako

Soekarno Hatta Street Km. 9, Tondo, Mantikulore, Palu, Central of Sulawesi, 94148, Indonesia

Email: yuli.asmi@untad.ac.id

1. INTRODUCTION

The rapid proliferation of power electronic-based equipment and distributed generation (DG) in medium-voltage distribution networks has significantly increased the level of harmonic distortion, especially where nonlinear loads such as adjustable-speed drives, switch-mode power supplies, and consumer electronics are widespread [1]. These harmonics deteriorate voltage and current waveforms, leading to higher losses, overheating of equipment, mis operation of protection devices, and accelerated ageing of insulation,

thereby posing a serious challenge to power quality in modern distribution systems [2]. In addition, inverter-interfaced renewable DG units, while beneficial for loss reduction and sustainability, are themselves recognized as significant harmonic sources when their switching patterns interact with network impedances and background distortion [3].

Passive harmonic filters (PHFs), particularly single-tuned passive filters (STPFs), remain one of the most widely adopted solutions for harmonic mitigation due to their simplicity, robustness, and cost-effectiveness relative to active filtering alternatives [4]. Recent studies have shown that accurate filter design and tuning are crucial to achieve substantial reductions in total harmonic distortion (THD) while preventing issues such as resonance and over-compensation [5]. Metaheuristic techniques, and particle swarm optimization (PSO) in particular, have been successfully applied to determine optimal PHF parameters and placements in industrial and distribution environments, demonstrating marked THD reduction under IEEE-519 constraints [6].

In parallel, distribution system reconfiguration (DSR) has emerged as a powerful operational tool for minimizing active power losses, improving voltage profile, and enhancing reliability through optimal adjustment of sectionalizing and tie switch statuses [7]. Comprehensive reviews highlight that metaheuristic-based DSR, including PSO variants and hybrid schemes, is now state-of-the-art for handling the highly non-convex, combinatorial nature of the reconfiguration problem, especially under high DG penetration [8]. However, most DSR contributions focus mainly on loss minimization and voltage regulation, treating harmonics only implicitly or ignoring them altogether. Concurrently, optimal siting and sizing of DG have been extensively studied using multi-objective PSO and other modern optimizers, with objectives such as loss reduction, voltage improvement, and reliability enhancement [9], [10]. Recent works consider simultaneous allocation of DG, capacitor banks, and other flexible resources, yet harmonic performance is often relegated to a secondary constraint or left unmodelled in the optimization framework [11]. More recent hybrid PSO-based approaches explicitly target power quality indices, showing that coordinated planning of compensation devices and network topology can significantly reduce THD while supporting voltage stability in renewable-rich networks [12].

Despite these advances, there is still a clear gap in the literature regarding fully integrated, multi-objective optimization frameworks that simultaneously; i) reconfigure the distribution system, ii) determine optimal DG placement and sizing, and iii) allocate PHF, all under explicit harmonic constraints and real operating conditions of practical feeders. Existing studies typically address only one or two of these aspects at a time—such as PHF planning in the presence of inverter-based DGs without topology changes [3], or joint DSR–DG planning without detailed harmonic modelling [12]—which limits their applicability to networks where harmonic distortion and power quality are critical concerns. Motivated by these limitations, this paper proposes a coordinated optimization framework for harmonic mitigation in radial distribution networks that couples DSR with optimal DG and PHF placement using an enhanced PSO algorithm. The proposed method formulates a multi-objective problem that jointly minimizes voltage THD, active power losses, and voltage deviation while enforcing operating constraints such as radiality, branch current limits, and IEEE-519 harmonic limits. The approach is validated on a real 165-bus medium-voltage distribution network in Sungguminasa subdistrict, considering actual loading conditions and representative nonlinear customer profiles. The main contributions of this work are:

- Development of an integrated PSO-based DSR–DG–PHF optimization model that explicitly incorporates harmonic power flow and THD indices in the objective function.
- A coordinated strategy that exploits network reconfiguration to re-shape harmonic propagation paths while DG and PHF locations are optimally selected to attenuate dominant harmonic orders.
- Comprehensive performance assessment in various scenarios, showing significant improvements in THD_v, loss reduction, and voltage profile compared to single technique strategies (DSR only, DG only, or PHF only) will be simulated in several scenarios of optimization technique combinations.

The remainder of this paper is organized as follows. Section 2 presents the mathematical formulation of the harmonic power flow, objective functions, and operational constraints. Section 3 describes the proposed enhanced PSO-based optimization framework and scenario design. Section 4 introduces the Sungguminasa 165-bus test system and data setup. Section 5 discusses the simulation results and comparative analysis, and section 6 concludes the paper with key findings and recommendations for practical implementation.

2. MODELLING PROBLEM FORMULATION

This section describes the mathematical formulation of the coordinated optimization framework integrating DSR, optimal DG placement, and PHF allocation. The problem is modeled as a multi-objective optimization under harmonic distortion constraints. Harmonic modeling follows established approaches from

recent literature on harmonic propagation and mitigation [13]–[17]. The DSR framework refers to state-of-the-art methodologies for reconfiguration in modern distribution systems [18], [19], while DG allocation follows multiobjective DG placement models reported in [20]–[24].

2.1. Harmonic power flow model

Harmonic analysis is performed using frequency-domain power flow, where each harmonic order h is solved independently and then superposed. The nodal is (1):

$$V_h = Z_h * I_h \quad (1)$$

Where, V_h , Z_h , and I_h are vector of bus voltage phasors at harmonic order h , network impedance matrix at harmonic order h , including line resistance–inductance (R–L) models and PHF admittances, and vector of injected harmonic currents at order h from nonlinear loads, DG inverter switching, and PHF branches. THD of voltage at bus i is expressed as (2) [13], [14];

$$THD_{v_i} = \frac{\sqrt{\sum_{h=2}^H V_{i,h}^2}}{V_{i,1}} \times 100\% \quad (2)$$

Where THD_{v_i} , $V_{i,h}^2$, $V_{i,1}$, H , and i are THD of voltage at bus i , RMS value of bus i voltage at harmonic order h , Fundamental voltage RMS value at bus i ($h=1$ harmonic component), maximum harmonic order considered in the analysis, and index of the bus under evaluation. Similarity, current harmonic distortion is (3):

$$THD_{I_i} = \frac{\sqrt{\sum_{h=2}^H I_{i,h}^2}}{I_{i,1}} \times 100\% \quad (3)$$

Where THD_{I_i} , $I_{i,h}^2$, and $I_{i,1}$ are THD of current at bus i , RMS value of injected current at bus i for harmonic order h , and fundamental current RMS value at bus i . PHF are modeled as single-tuned LC filters according to widely used design method [15]–[17] (4):

$$Y_{PHF}(h) = j \left(h\omega C - \frac{1}{h\omega L} \right) \quad (4)$$

Where $Y_{PHF}(h)$, j , h , ω , C , and L are admittance of the PHF at harmonic order h , imaginary unit representing a 90° phase shift, harmonic order, angular frequency of the fundamental waveform, filter capacitance, and filter inductance. The tuned harmonic order satisfies:

$$h_t = \frac{1}{\omega} \sqrt{\frac{1}{LC}} \quad (5)$$

Where h_t is tuned harmonic order (the harmonic frequency to which the PHF is tuned).

2.2. Model of distribution system reconfiguration

The distribution network consists of radial feeder structures, where switch statuses determine connectivity. The optimization identifies an optimal radial configuration by controlling tie and sectionalizing switches [18], [19]. A binary switch variable is defined:

$$s_k = \begin{cases} 1, & \text{if switch } k \text{ is closed} \\ 0, & \text{if switch } k \text{ is open} \end{cases} \quad (6)$$

Where s_k and *switch* k are binary decision variable representing the status of switch k and the k -th switching element (either sectionalizing or tie switch) in the distribution network. Power loss on branch k is (7):

$$P_{loss,k} = R_k \frac{P_k^2 + Q_k^2}{V_k^2} \quad (7)$$

Where $P_{loss,k}$, R_k , P_k^2 , Q_k^2 , and V_k^2 are active power loss on branch k , resistance of branch k , active power flowing through branch k , reactive power flowing through branch k and voltage magnitude at the sending end or receiving end of branch k (in volts). Total losses:

$$P_{loss} = \sum_{k=1}^{N_{br}} P_{loss,k} \quad (8)$$

Where P_{loss} , N_{br} , and $k = 1$ are total active power loss of the entire distribution system, total number of branches (lines) in the distribution network, and computer total losses by adding losses from each branch. Radiality constrain:

$$\sum s_k = N_{bus} - 1 \quad (9)$$

Where N_{bus} is total number of buses (nodes) in the distribution system.

2.3. Optimal distributed generation placement and sizing

DG units may operate in PQ or PV mode and can influence harmonic distortion depending on inverter characteristics [20], [21]. DG active power constrains:

$$P_{DG,i}^{min} \leq P_{DG,i} \leq P_{DG,i}^{max} \quad (10)$$

Where $P_{DG,i}^{min}$, $P_{DG,i}^{max}$ and $P_{DG,i}$ are the minimum, the maximum allowable active power output of DG unit i and the active power output of the DG unit located at bus i , expressed in kilowatts (kW) or megawatts. DG location affects losses, voltage regulation, and harmonic propagation pathways [22]–[24].

2.4. Passive harmonic filter allocation

PHF allocation involves determining the targeted harmonic order, selecting the optimal installation location, and specifying the required filter rating (Q-filter). Coordinating these three elements ensures effective harmonic suppression, appropriate reactive power support, and improved power quality while maintaining system stability and complying with operational constraints. Filter impedance:

$$Z_{PHF}(h) = \left| h\omega L - \frac{1}{h\omega C} \right| \quad (11)$$

Where $Z_{PHF}(h)$ is magnitude of the PHF impedance at harmonic order h . Capacitive reactive power at fundamental frequency:

$$Q_C = \frac{V^2}{X_C} \quad (12)$$

$$X_C = \frac{1}{\omega C} \quad (13)$$

Where Q_C , V , and X_C are reactive power supplied by the capacitor at the fundamental frequency, RMS voltage across the capacitor, and capacitive reactance at the fundamental frequency.

2.5. Multi objective optimization function

The optimization goal combines three objectives: harmonic distortion, power losses, and voltage deviation.

$$\min F = \alpha_1 THD_{avg} + \alpha_2 P_{loss} + \alpha_3 \Delta V \quad (14)$$

$$THD_{avg} = \frac{1}{N_{bus}} \sum_{i=1}^{N_{bus}} THD_{V_i} \quad (15)$$

$$\Delta V = \sum_{i=1}^{N_{bus}} |V_i - V_{nom}| \quad (16)$$

Where F , $\alpha_{1,2,3}$, THD_{avg} , and ΔV are composite multi-objective function to be minimized. It represents the weighted sum of harmonic distortion, power losses, and voltage deviation, weighting coefficients assigned to each objective (dimensionless), average voltage THD across all buses, and voltage deviation index, representing the deviation of bus voltages from their nominal value. THD_{V_i} , i , and V_{nom} are voltage THD at bus i , index representing the i -th bus in the network, and nominal voltage level of the distribution system.

2.6. Operational constraints

The optimization is conducted under several operational constraints to ensure that system performance, equipment ratings, and power quality standards are maintained throughout the reconfiguration and allocation process.

2.6.1. Voltage limit

Bus voltages must remain within the allowable minimum and maximum limits to ensure acceptable service quality and prevent undervoltage or overvoltage conditions in the network.

$$V_{min} \leq V_i \leq V_{max} \quad (17)$$

Where V_{min} , V_{max} , and V_i are minimum, maximum allowable voltage limit in the distribution system, typically set to maintain acceptable service quality, and voltage magnitude at bus i .

2.6.2. Branch thermal limits

Branch currents must not exceed their thermal capacity to avoid conductor overheating, equipment damage, and violations of network safety margins.

$$I_k \leq I_k^{max} \quad (18)$$

Where I_k and I_k^{max} are current magnitude flowing through branch k and maximum thermal or ampacity limit of branch k , determined by conductor size, insulation rating, and thermal constraints.

2.6.3. IEEE-519 harmonic limits

Voltage and current harmonic distortion levels must comply with IEEE-519, ensuring that $THD_{V_i} \leq 5\%$ and $THD_{I_i} \leq 8\%$ thus maintaining acceptable power quality and mitigating harmonic-related equipment stress.

$$THD_{V_i} \leq 5\%, THD_{I_i} \leq 8\% \quad (19)$$

2.6.4. Distributed generation and passive harmonic filter capacity limits

The reactive power capacity of PHF units must lie within predetermined minimum and maximum limits to ensure feasible operation and prevent excessive compensation or overloading.

$$Q_{PHF}^{min} \leq Q_{PHF} \leq Q_{PHF}^{max} \quad (20)$$

Where Q_{PHF}^{min} , Q_{PHF}^{max} , and Q_{PHF} are minimum, maximum permissible reactive power rating of the filter based on design or operational constraints, and reactive power capacity of PHF at the fundamental frequency.

3. PROPOSED OPTIMIZATION METHOD

The proposed methodology integrates DSR, DG placement, and PHF allocation into a unified multiobjective optimization framework. The method is designed to minimize harmonic distortion, active power losses, and voltage deviation while maintaining compliance with operational constraints. An enhanced PSO algorithm is adopted to solve the nonlinear, mixed-integer optimization problem, following approaches similar to those reported in harmonic mitigation and DG planning studies [25]-[27].

3.1. System modeling and data preparation

The distribution system is modeled using both fundamental and harmonic power flow formulations, where line impedances, transformer data, DG characteristics, and nonlinear load harmonic spectra are incorporated. Harmonic impedance matrices for each order are constructed considering line R-L parameters, DG inverter harmonic contributions, and PHF admittances, in line with commonly used modeling techniques from harmonic studies. Candidate locations for DG and PHF placement are selected based on voltage sensitivity, harmonic distortion magnitude, and accessibility. Switch-configurable branches are explicitly modeled to enable DSR as described in modern reconfiguration frameworks [28].

3.2. Solution encoding

Each candidate solution in the PSO swarm is represented by a hybrid decision vector combining binary, integer, and continuous variables:

$$X = [S_{DSR}, Loc_{DG}, P_{DG}, Loc_{PHF}, Q_{PHF}] \quad (21)$$

Where S_{DSR} , Loc_{DG} , P_{DG} , Loc_{PHF} , and Q_{PHF} are encodes switch statuses for network topology, location of DG, define DG setpoints, location of PHF, and rating of PHF. This encoding supports simultaneous optimization of topology, DG placement, and PHF design, consistent with multiobjective DG and filter allocation approaches in the literature [29].

3.3. Harmonic power flow

Harmonic power flow analysis is performed for each particle in the PSO swarm to evaluate the network's performance under the candidate DSR–DG–PHF configuration. The analysis adopts a two-stage approach; i) fundamental-frequency power flow and ii) harmonic-domain power flow. The fundamental power flow is computed using the forward–backward sweep (FBS) algorithm, which is well-suited for radial distribution systems due to its numerical robustness, fast convergence, and low computational burden. FBS iteratively updates branch currents in the backward sweep and node voltages in the forward sweep until convergence is reached. This ensures accurate estimation of $V_{i,1}$ and $I_{i,1}$ which are essential for calculating THD indices and PHF tuning parameters [30].

3.4. Enhanced particle swarm optimization algorithm

The enhanced PSO algorithm updates velocity and position according to:

$$v_i^{t+1} = w_t v_i^t + c_1 r_1 (P_{best_i} - x_i^t) + c_2 r_2 (G_{best} - x_i^t) \quad (22)$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \quad (23)$$

Where v_i^t is velocity of particle i at iteration t . v_i^{t+1} is updated velocity of particle i for the next iteration. x_i^t is current position (solution vector) of particle i at iteration t . x_i^{t+1} is updated position of particle i for the next iteration. w_t is inertia weight at iteration t . c_1, c_2 are cognitive acceleration coefficient, scaling the influence of the particle's own best historical position. r_1, r_2 is random numbers uniformly distributed in the interval $[0, 1]$, introducing stochastic behavior and preventing deterministic convergence. P_{best_i} is personal best position of particle i , representing the best solution it has found so far. G_{best} is global best position found by the entire swarm across all iterations [31].

3.5. Overall optimization procedure

The optimization procedure consists of the following steps:

- Initialize PSO parameters, including swarm size, inertia weight, and acceleration coefficients.
- Generate the initial population of candidate configurations.
- Perform harmonic power flow analysis for each candidate.
- Compute the objective function and apply constraint penalties.
- Update pbest and gbest solutions and update particle velocities and positions using enhanced PSO.
- Apply mutation and check feasibility.
- Repeat steps c–g until convergence.
- Output the optimal DSR configuration, DG placement, and PHF allocation.

This coordinated approach ensures that reconfiguration reshapes harmonic propagation paths, while DGs and PHFs operate synergistically to reduce both harmonic distortion and system losses.

4. CASE STUDY AND SIMULATION SETUP

This section presents the test system, data preparation, simulation parameters, and scenario configurations used to evaluate the proposed DSR–DG–PHF optimization framework. All analyses were conducted using the 165-bus medium-voltage distribution network of Sungguminasa subdistrict, selected due to its practical operational characteristics, significant penetration of nonlinear loads, and radial topology consistent with standard utility practices.

4.1. Test system description

The studied 165-bus distribution network operates at a nominal voltage of 20 kV and is supplied by a single primary substation feeding multiple lateral feeders. The system comprises a combination of overhead and underground lines modeled using frequency-dependent R–L parameters, distribution transformers, and a heterogeneous mix of residential, commercial, and small industrial loads. A portion of the demand exhibits nonlinear characteristics, resulting in harmonic current injections dominated by the 5th, 7th, 11th, 13th, and 17th orders. The network is equipped with sectionalizing and tie switches (TS) that enable feeder reconfiguration while preserving a radial topology. Load data and hourly consumption profiles were obtained from utility

records and converted into per-unit values for simulation consistency, while harmonic spectra for nonlinear loads were derived from measured total demand distortion (TDD) and representative harmonic current ratios commonly observed in distribution systems. The network belongs to customer service unit (ULP) Sungguminasa, supplying residential, commercial, and industrial customers in the surrounding area. Two feeders, Barombong and IPDN, were considered in this study, forming a 165-bus system with a total load of 12.325 MW and 7.64 MVAR. Single line diagram can be seen in Figure 1. Harmonic currents were injected at each load bus based on three representative nonlinear load categories: fluorescent lamp-based residential loads, inverter-based temperature control devices in high-end residential areas, and six-pulse variable frequency drives (VFDs) in industrial zones. The characteristics and magnitudes of these harmonic injections are summarized in Tables 1 and 2.

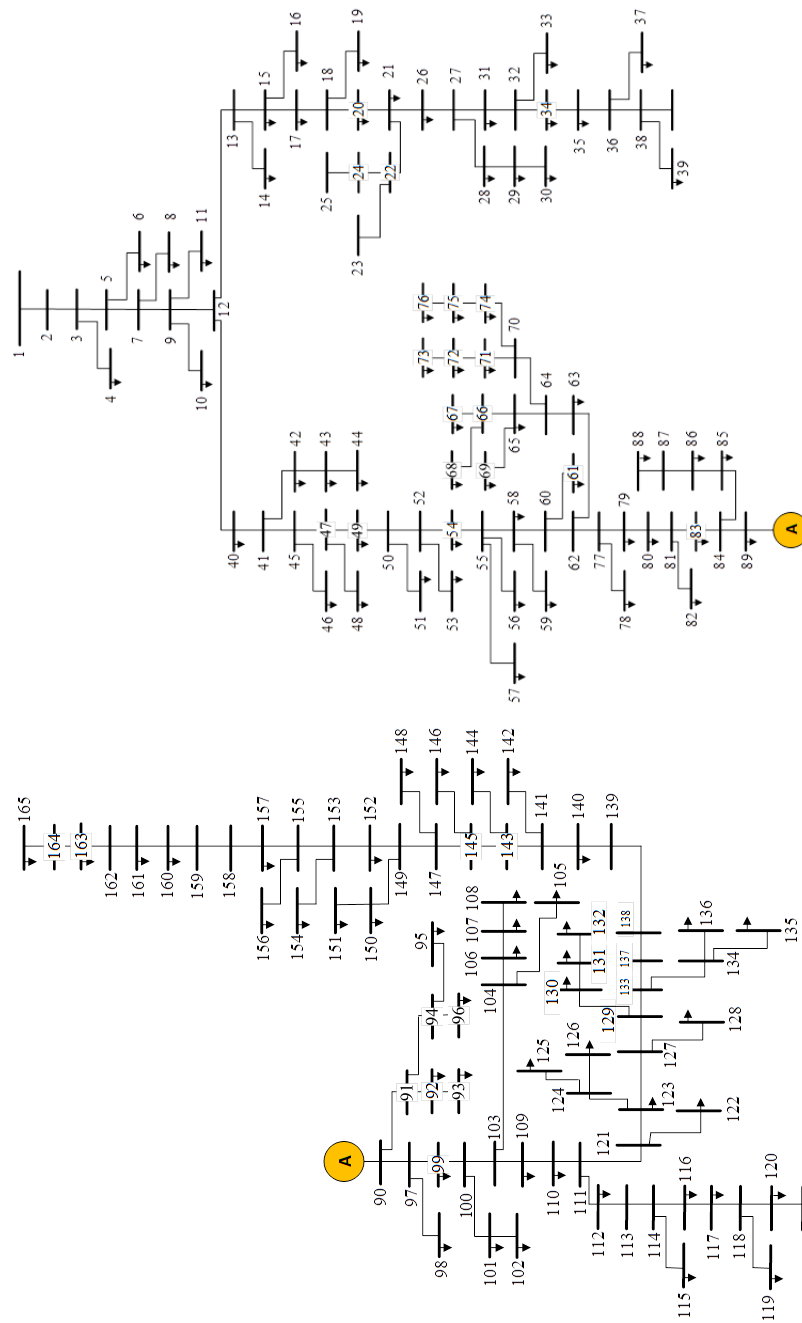


Figure 1. Single line diagram of ULP Sungguminasa 165-bus [32]

Table 1. The value of harmonic current injection [32]

Harmonic order	The types of harmonic injection		
	Industrial zone	Commercial area	Residential area
5 th	$98\angle 140^\circ$	$15.00\angle 0^\circ$	$10.00\angle 0^\circ$
7 th	$39.86\angle 113^\circ$	$10.00\angle 0^\circ$	$5.00\angle 0^\circ$
11 th	$18.95\angle -158^\circ$	$5.00\angle 0^\circ$	$1.00\angle 0^\circ$
13 th	$8.79\angle -178^\circ$	$3.00\angle 0^\circ$	$0.00\angle 0^\circ$
17 th	$2.5\angle -94^\circ$	$1.00\angle 0^\circ$	$0.00\angle 0^\circ$

Table 2. Harmonic load location [32]

Type of harmonic load	Load bus
VFD	36, 46, 53, 117, 121, 164
Inverting devices	5, 11, 15, 18, 20, 23, 25, 27, 30, 34, 38, 41, 44, 48, 59, 58, 64, 71, 73, 78, 82, 85, 88, 91, 94, 96, 100, 112, 119, 123, 128, 130, 138, 153
Fluorescent	3, 8, 9, 14, 16, 21, 22, 26, 29, 31, 32, 35, 40, 42, 49, 50, 51, 54, 56, 57, 62, 65, 67, 69, 70, 74, 75, 76, 77, 79, 81, 83, 87, 90, 97, 99, 102, 104, 106, 107, 108, 109, 111, 114, 115, 116, 118, 121, 125, 127, 132, 134, 136, 137, 142, 143, 146, 148, 151, 152, 155, 157, 159, 161, 162

The TS group load buses into several segments to facilitate the identification of the most optimal network configuration. Five clusters are defined using the TS and sectional switches (SS), which are subject to reconfiguration. These TS–SS combinations form the basis of the search space utilized during the optimization procedure. In the reconfiguration process, selected SS units are opened, enabling alternative paths to be formed through the closing of specific TS according to the solutions generated by the optimization algorithm [32]. TS and SS data is showed in Table 3.

Table 3. TS and SS data for DSR

Cluster for NR	TS	SS
1	44-67	41-42, 42-43, 43-44, 62-63, 63-64, 64-65, 65-66
2	23-76	20-21, 21-22, 22-23, 70-74, 74-75, 75-76
3	30-165	26-27, 27-28, 28-29, 29-30, 160-161, 161-162, 162-163, 163-164, 164-165
4	120-135	116-117, 117-118, 118-120, 133-134, 134-135
5	108-151	104-106, 106-107, 107-108, 149-150, 150-151

4.2. Distributed generation and harmonic filter modeling

DG units considered in the study consist of inverter-based photovoltaic systems and small synchronous generators with typical power ratings between 100 kW and 500 kW. Their electrical characteristics, including active/reactive power capability curves and harmonic emission profiles, were modeled based on manufacturer specifications and standards [29]. PHF are implemented as single-tuned LC circuits designed to target dominant harmonic orders. Candidate buses for PHF placement were selected based on high observed THD, network sensitivity indices, and proximity to nonlinear load clusters. The PHF ratings Q_{PHF} were varied within the limits defined in section 2 to avoid overcompensation and resonance effects [21].

4.3. Simulation parameters and computational setup

The FBS algorithm was used to solve the fundamental power flow due to its numerical stability and efficiency in radial networks. All computations were performed using MATLAB 2021b. Simulation parameters include:

- Number of harmonics considered: 1st, 5th, 7th, 11th, 13th, and 17th.
- Base power: 1 MVA and Convergence tolerance for FBS: 10^{-5} pu.
- PSO swarm size: 50 particles and maximum iterations is 150.
- Cognitive and social coefficients: $c_1 = c_2 = 2$.

4.4. Scenario design

To comprehensively evaluate the coordinated optimization strategy, seven simulation scenarios were developed:

- Case 1. Baseline network (no motogation)
- Case 2. PHF placement
- Case 3. DSR
- Case 4. DG placement

- Case 5. DG placement with DSR
- Case 6. HPF placement with DSR
- Case 7. DG and HPF Placement with DSR

This scenario design allows direct comparison of the proposed coordinated strategy against partial or conventional mitigation techniques.

5. RESULT AND DISCUSSION

This section presents the simulation results obtained from the coordinated optimization of DSR, DG placement, and HPF allocation on the 165-bus Sungguminasa distribution network. Comparison of optimization results from several case studies can be seen in Table 4, Figures 2 and 3.

The comparative results in Table 4 demonstrate the impact of different mitigation strategies on the performance of the 165-bus distribution network. The base case (Case 1) exhibits the weakest performance, with the lowest minimum voltage (0.948 p.u.), the highest active power loss (389.65 kW), and relatively high voltage harmonic distortion (THD_v max=3.133%). The application of a single HPF in Case 2 significantly reduces both voltage and current harmonic distortion, confirming the effectiveness of tuned passive filters in suppressing dominant harmonic components. DSR in Case 3 and DG integration in Case 4 substantially improve the voltage profile and reduce power losses due to better power flow distribution and localized generation support. However, these cases show limited or even adverse improvement in harmonic indices, indicating that DSR and DG alone do not inherently mitigate harmonic distortion and may alter harmonic propagation paths within the network.

Table 4. Comparative result for all scenarios

Parameter		Study case						
		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
DG	Cap (kW)	-	-	-	500, 500, 500	500, 500, 500	-	500, 500, 500
	Loc	-	-	-	127, 149, 159	47, 86, 152	-	40, 111, 165
HPF	Cap (kVAr)	-	680	-	-	-	645	620
	Loc	-	95	-	-	-	125	114
DSR-SS open				43-44, 22-23		43-44, 22-23	43-44, 22-23	43-44, 22-23
				29-30		29-30	29-30	29-30
				118-120		118-120	118-120	118-120
				150-151		150-151	150-151	150-151
V_{bus} (pu)	Min	0.948	0.950	0.950	0.954	0.954	0.953	0.957
	Avg	0.966	0.968	0.969	0.970	0.971	0.970	0.973
%THD _v	Max	3.133	1.799	3.120	3.261	3.247	2.071	1.757
	Avr	2.279	1.307	2.191	2.134	2.156	1.356	1.040
%THD _i	Max	1.337	0.567	1.336	1.278	1.335	0.559	1.147
	Avr	0.474	0.206	0.447	0.490	0.474	0.222	0.181
Tot P_{Loss} (kW)		389.65	364.57	357.7	304.27	297.99	331.5	267.97
Tot Q_{Loss} (kVAr)		510.8	449.38	472.52	411.8	402.92	421.16	335.8

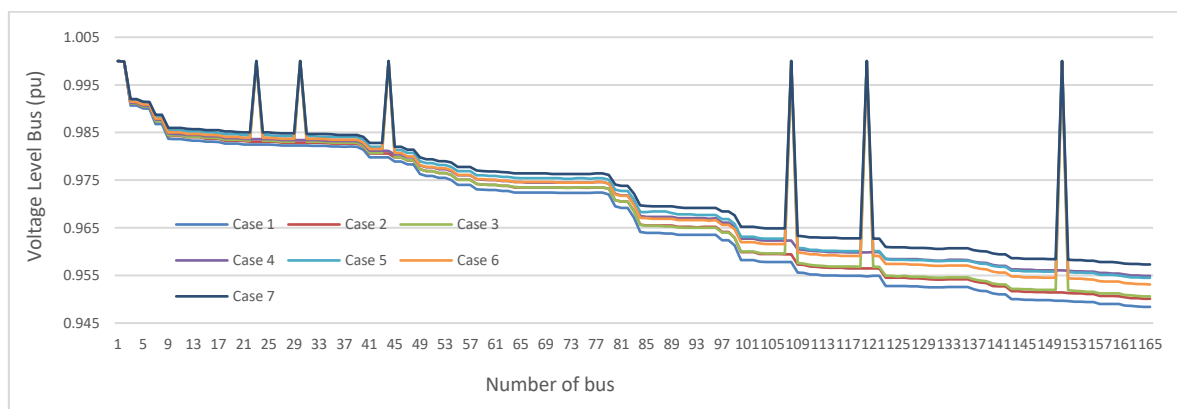


Figure 2. Voltage level bus in all study case

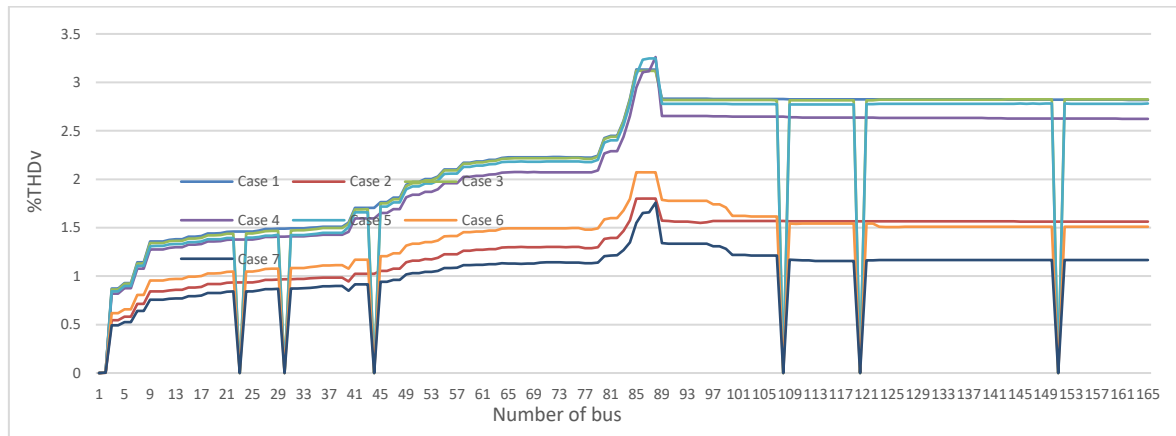


Figure 3. %THD_v value in all study case

The best overall performance is achieved through coordinated optimization, particularly in Case 7, which combines DSR, DG, and PHF. This scenario yields the highest minimum and average bus voltages (0.957 p.u. and 0.973 p.u.), the lowest total active and reactive power losses (267.97 kW and 335.8 kVAr), and the lowest average voltage and current harmonic distortion (THD_v avg=1.040%, THD_i avg=0.181%). These results highlight the synergistic effect of simultaneously optimizing network topology, DG placement, and harmonic filtering. The coordinated approach effectively balances voltage regulation, loss minimization, and harmonic mitigation, demonstrating its superiority over single-technique solutions for improving both power quality and operational efficiency in modern distribution networks.

The voltage-magnitude results show a consistent decline from upstream to downstream buses, while demonstrating that improvements vary across the network. Case 7 provides the strongest voltage support at nearly all buses, increasing the minimum end-of-feeder voltage from approximately 0.948 p.u. to 0.957 p.u. and shifting the overall voltage profile upward. This improvement is particularly important for long radial feeders, where downstream buses typically determine operational voltage margins. Several buses, including 23, 30, 44, 108, 120, and 151, remain fixed at exactly 1.0 p.u. in certain scenarios, indicating possible localized voltage regulation, DG support, or structural segmentation caused by network reconfiguration. These values should be interpreted carefully because they may represent enforced voltage setpoints, reference buses, or island-like equivalents rather than natural load-flow responses. Although voltage differences among cases are relatively small at upstream buses, they become increasingly pronounced downstream. Overall, the coordinated strategy primarily mitigates cumulative voltage drops and effectively strengthens voltage stability in the most electrically vulnerable feeder sections.

Figure 3 provides a bus-by-bus comparison of %THD_v across seven scenarios, showing that coordinated mitigation strategies outperform partial or isolated approaches. In the base condition, Case 1 records an average %THD_v of 2.28%, with peaks above 3.13% at downstream buses where higher network impedance intensifies harmonic propagation. Cases 3–5 produce only limited improvements, reducing average distortion to approximately 2.13–2.19%, which indicates insufficient impact on dominant harmonic sources and sensitive feeder sections. Greater improvements are observed in Cases 2 and 6, where average %THD_v decreases to 1.31% and 1.36%, respectively, demonstrating the effectiveness of targeted filtering and partial coordination. Case 7 achieves the best performance, lowering average %THD_v to 1.04%, or about 54% below the base case. It also suppresses distortion more uniformly and reduces critical downstream hotspots. These results confirm that coordinated DSR, optimal DG placement, and PHF provide the most robust system-wide harmonic mitigation while maintaining improved voltage quality throughout the entire medium-voltage radial distribution network under study.

The comparative results show that harmonic distortion along the feeder is influenced more by system-wide propagation than by local conditions. This explains why incremental interventions in Cases 3–5 provide only modest reductions in average distortion, although improvements occur at several specific buses. Distortion peaks above 3% in the base case, particularly at downstream locations, indicate that feeder impedance and resonance-like amplification along long radial sections strongly shape the harmonic profile. Consequently, mitigation measures that do not substantially modify the harmonic driving-point impedance at critical buses have limited system-wide effectiveness. Cases 2 and 6 achieve stronger reductions, with average distortion decreasing to approximately 1.31–1.36%, indicating that targeted filtering and strategic compensation can suppress dominant harmonic components. However, residual distortion remains because of

structural limitations associated with feeder topology. Case 7 delivers the best overall performance, reducing average distortion to about 1.04%, equivalent to an improvement of approximately 54% over Case 1, while also producing a more uniform reduction across the feeder by reshaping harmonic flow paths and limiting amplification at vulnerable downstream nodes more effectively overall.

Table 5 compares the harmonic mitigation performance of the proposed method with several representative studies from high-impact journals. The proposed coordinated strategy reduces the average voltage THD to 1.04%, corresponding to a 54% reduction from the base case. Compared with existing approaches such as harmonic filter optimization, source-tracing mitigation strategies, and optimal DG placement, the proposed integration of network reconfiguration, DG allocation, and passive filtering provides a more comprehensive solution for achieving uniform harmonic suppression across the feeder.

Nevertheless, the results alone do not guarantee robustness, as compliance may be sensitive to load variation, uncertainty in inverter harmonic spectra, and resonance conditions. Accordingly, while the findings support a coordinated, system-level mitigation approach as the most effective solution, the conclusions should be framed as contingent on the assumed operating point and validated under multiple loading scenarios and harmonic source models to ensure generalizable harmonic performance.

Table 5. Comparative study in harmonic mitigation

Study	Method	Test system	Reported % THDv	Key findings
In this study	Coordinated optimization of distribution network reconfiguration+optimal DG placement+PHF.	ULP Sungguminasa 165-bus.	1.04% (average).	Achieves ~54% reduction from base case (2.28%). Provides uniform mitigation across the feeder and suppresses downstream harmonic hotspots.
[3]	Optimal planning of single-tuned harmonic filters using water cycle algorithm (WCA).	Distribution system with inverter-based DG.	~1.3–1.6%.	Demonstrated significant reduction of harmonic distortion and improved power quality through optimal filter planning.
[33]	Source-tracing-oriented harmonic mitigation and optimization control.	IEEE 33-bus radial distribution system.	THD reduction ≈ 2.6% improvement.	Identifies dominant harmonic sources and coordinates mitigation nodes to reduce distortion and voltage fluctuation
[34]	Optimal DG allocation considering harmonic and voltage constraints.	IEEE 33-bus radial distribution system.	<3% (IEEE 519 compliant).	Optimal DG placement improves voltage profile and reduces harmonic propagation across the feeder.
[35]	Hybrid GWO-PSO algorithm for optimal DG placement.	Distribution network test system.	Significant THD and loss reduction.	Hybrid metaheuristic approach outperforms standalone algorithms in improving network performance.

6. CONCLUSION

This research presents a coordinated optimization framework for harmonic mitigation in medium-voltage distribution networks with high penetration of DG and nonlinear loads. The proposed method integrates DSR, optimal DG placement, and PHF allocation within an enhanced PSO algorithm to simultaneously reduce harmonic distortion, active power losses, and voltage deviation while satisfying practical operating constraints. Application to the 165-bus Sungguminasa DN, using realistic load and harmonic characteristics, shows that isolated mitigation strategies provide only limited improvements, whereas coordinated optimization produces substantially better and more uniform system performance. The results demonstrate a maximum reduction of 54.38% in voltage THD, a 34.26% decrease in active power losses, and an improved voltage profile compared with the base configuration. These findings confirm that jointly considering network topology, DG integration, and harmonic filtering is essential for effective power quality enhancement. Overall, the proposed framework offers a technically effective, systematic, and economically reasonable solution for utility implementation in modern distribution systems. Future research may extend the approach to dynamic operating conditions, uncertainty in harmonic sources and loads, renewable generation variability, and real-time or adaptive optimization schemes for increasingly complex distribution networks under changing network and operating conditions.

FUNDING INFORMATION

This research was made possible by funding from the Advanced Indonesia Innovation Research Program (RIIM Competition) Year 2, 2025, Agreement Number 9/IV/KS/05/2023, National Research and Innovation Agency (BRIN) - Indonesian Endowment Fund for Education (LPDP).

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
Yuli Asmi Rahman	✓	✓		✓	✓		✓		✓	✓	✓	✓	✓	
Muhira Dzar Faraby	✓	✓	✓		✓	✓		✓	✓	✓	✓			
Sofyan Sofyan	✓			✓	✓	✓	✓			✓	✓	✓		
Sarma Thaha	✓			✓			✓				✓	✓	✓	✓
Musfirah Putri Lukman		✓	✓		✓	✓		✓	✓	✓	✓			
Muhammad Sahrul Ramadan		✓	✓		✓	✓		✓	✓	✓			✓	
Firdaus	✓			✓		✓	✓	✓		✓	✓	✓	✓	
Mansur	✓	✓		✓	✓		✓	✓		✓	✓			
Andi Fitriati		✓	✓	✓		✓		✓	✓	✓	✓		✓	
Muhammad Rais			✓		✓	✓	✓	✓	✓	✓	✓			

C : Conceptualization	I : Investigation	Vi : Visualization
M : Methodology	R : Resources	Su : Supervision
So : Software	D : Data Curation	P : Project administration
Va : Validation	O : Writing - Original Draft	Fu : Funding acquisition
Fo : Formal analysis	E : Writing - Review & Editing	

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data supporting the findings of this study are available upon request from the corresponding author, YAR, MDF, and the ULP Sungguminasa PLN (Persero). Data containing information that could compromise the privacy of research participants are not publicly available due to certain restrictions.

REFERENCES

[1] V. Nuñez-Ramírez *et al.*, “Harmonic distortion caused by non-linear household loads: Measurement and modelling,” *Results in Engineering*, vol. 25, p. 104483, Mar. 2025, doi: 10.1016/j.rineng.2025.104483.

[2] J. Kaur and S. K. Bath, “Harmonic distortion in power systems due to electronic control and renewable energy integration: a comprehensive review,” *Discover Electronics*, vol. 2, no. 1, p. 67, Aug. 2025, doi: 10.1007/s44291-025-00111-9.

[3] A. S. Abbas *et al.*, “Optimal harmonic mitigation in distribution systems with inverter based distributed generation,” *Applied Sciences (Switzerland)*, vol. 11, no. 2, pp. 1–16, Jan. 2021, doi: 10.3390/app11020774.

[4] S. A. Hamza, M. A. Mosa, A. A. Ali, and S. M. E. Masry, “Optimal sizing and location of DG considering harmonics pollution and system losses,” in *2023 24th International Middle East Power System Conference (MEPCON)*, Mansoura, Egypt, 2023, pp. 1–6, doi: 10.1109/MEPCON58725.2023.10462457.

[5] M. T. M. Lim, R. H. G. Tan, N. Permal, and J. E. Chin, “Single-Tuned Harmonic Passive Filter Design for AC Electric Railway Traction Power Substation,” in *2023 Innovations in Power and Advanced Computing Technologies, i-PACT 2023*, Dec. 2023, pp. 1–6, doi: 10.1109/I-PACT58649.2023.10434590.

[6] H. Lotfi, M. E. Hajiabadi, and H. Parsadust, “Power Distribution Network Reconfiguration Techniques: A Thorough Review,” *Sustainability (Switzerland)*, vol. 16, no. 23, p. 10307, Nov. 2024, doi: 10.3390/su162310307.

[7] D. P. Somashekar, A. V. S. Kumar, M. Karthik, and N. Mohan, “A Novel Hybrid Optimization Technique for Network Reconfiguration with Dispersed Generators Placement in Distribution System,” in *2024 International Conference on Sustainable Power and Energy, ICSPE 2024*, Nov. 2024, pp. 1–6, doi: 10.1109/ICSPE62629.2024.10924333.

[8] P. Patel *et al.*, “Multi-objective particle swarm optimization algorithm-based method for optimal placement and sizing of distributed generations and shunt capacitors in a radial distribution network,” *Results in Engineering*, vol. 27, p. 106514, Sep. 2025, doi: 10.1016/j.rineng.2025.106514.

[9] A. B. Alyu, A. O. Salau, B. Khan, and J. N. Eneh, “Hybrid GWO-PSO based optimal placement and sizing of multiple PV-DG units for power loss reduction and voltage profile improvement,” *Scientific Reports*, vol. 13, no. 1, p. 6903, Apr. 2023, doi: 10.1038/s41598-023-34057-3.

[10] R. Shaikh, A. Stojcevski, M. Seyedmahmoudian, and J. Chandran, “A Multi-Objective Approach for Optimal Sizing and Placement of Distributed Generators and Distribution Static Compensators in a Distribution Network Using the Black Widow Optimization Algorithm,” *Sustainability (Switzerland)*, vol. 16, no. 11, 2024, doi: 10.3390/su16114577.

[11] M. Sanaei, H. Akbari, Z. Beheshtipour, and S. Mousavi, “New PSO-GWO-based model for enhancing power quality in electrical networks interconnected with photovoltaic sources,” *Frontiers in Energy Research*, vol. 12, Dec. 2024, doi: 10.3389/ferng.2024.1476638.

[12] H. Kiani, S. H. Hosseini, and A. Khorsandi, “Optimal Sizing and Siting of Renewable Energy Sources in a ADN Using Meta-Heuristic Algorithms Considering Participation in Energy Market and Resources Uncertainty,” in *2025 12th Iranian Conference*

- on Renewable Energies and Distributed Generation, *ICREDG 2025*, Feb. 2025, pp. 1–6, doi: 10.1109/ICREDG66184.2025.10966071.
- [13] N. C. Yang and E. W. Adinda, “Matpower-Based Harmonic Power Flow Analysis for Power Systems with Passive Power Filters,” *IEEE Access*, vol. 9, pp. 167322–167331, 2021, doi: 10.1109/ACCESS.2021.3135496.
 - [14] A. Arguello, R. Torquato, B. Rosado, and W. Freitas, “Modeling of Single-Phase Photovoltaic Generators for System-Wide Harmonic Power Flow Studies,” *IEEE Transactions on Energy Conversion*, vol. 38, no. 2, pp. 914–926, Jun. 2023, doi: 10.1109/TEC.2022.3218980.
 - [15] N. C. Yang and Y. W. Hsu, “OpenDSS-Based Harmonic Power Flow Analysis for Distribution Systems With Passive Power Filters,” *IEEE Access*, vol. 11, pp. 69190–69203, 2023, doi: 10.1109/ACCESS.2023.3292286.
 - [16] L. M. Caro, G. Ramos, K. Rauma, D. F. C. Rodriguez, D. M. Martinez, and C. Rehtanz, “State of Charge Influence on the Harmonic Distortion from Electric Vehicle Charging,” *IEEE Transactions on Industry Applications*, vol. 57, no. 3, pp. 2077–2088, May 2021, doi: 10.1109/TIA.2021.3057350.
 - [17] N. A. Rahman and A. A. Hairunizam, “Correlation of High Harmonic Distortion to Shunt Active Power Filter Operation and Performance,” in *2024 IEEE Symposium on Industrial Electronics and Applications, ISIEA 2024*, Jul. 2024, pp. 1–5, doi: 10.1109/ISIEA61920.2024.10607338.
 - [18] H. Ming *et al.*, “Active Distribution Network Reconfiguration Method Based on Photovoltaic Generation Prediction,” in *2022 IEEE International Conference on Electrical Engineering, Big Data and Algorithms, EEBDA 2022*, Feb. 2022, pp. 82–87, doi: 10.1109/EEBDA53927.2022.9744887.
 - [19] J. Gao, Z. Xu, H. Sun, L. Xu, D. Zhong, and W. Zhao, “Scenario-based distribution network reconfiguration using Cauchy-mutation invasive weed optimization: optimization considering reactive power and stochastic DG,” *Electric Power Systems Research*, vol. 250, p. 112101, Jan. 2026, doi: 10.1016/j.epsr.2025.112101.
 - [20] K. R. K. V. Prasad, R. Kollu, A. Ramkumar, and A. Ramesh, “A multi-objective strategy for optimal DG and capacitors placement to improve technical, economic, and environmental benefits,” *International Journal of Electrical Power and Energy Systems*, vol. 165, p. 110491, Apr. 2025, doi: 10.1016/j.ijepes.2025.110491.
 - [21] N. K. Yadav and S. Das, “Multi-Objective Optimization for Distributed Generator and Shunt Capacitor Placement Considering Voltage-Dependent Nonlinear Load Models,” *Swarm and Evolutionary Computation*, vol. 92, p. 101782, Feb. 2025, doi: 10.1016/j.swevo.2024.101782.
 - [22] H. P. C. K. Subbaramaiah, and P. Sujatha, “Optimal DG unit placement in distribution networks by multi-objective whale optimization algorithm & its techno-economic analysis,” *Electric Power Systems Research*, vol. 214, p. 108869, Jan. 2023, doi: 10.1016/j.epsr.2022.108869.
 - [23] T. Yuvaraj, M. Thirumalai, T. D. Suresh, S. B. Thanikanti, and M. Khishe, “Dynamic optimization of solar DG and shunt capacitor placement to mitigate the impact of EV charging stations on power distribution network,” *Results in Engineering*, vol. 27, p. 106804, Sep. 2025, doi: 10.1016/j.rineng.2025.106804.
 - [24] O. Valarezo, T. Gómez, J. P. Chaves-Ávila, C. Alcarraz, and P. Mancarella, “Co-optimizing network investment, reconfiguration, and third-party flexibility for congestion management in active distribution networks,” *International Journal of Electrical Power and Energy Systems*, vol. 172, p. 111094, Nov. 2025, doi: 10.1016/j.ijepes.2025.111094.
 - [25] A. Shaheen, A. Elsayed, A. Ginidi, R. El-Sehiemy, and E. Elattar, “Reconfiguration of electrical distribution network-based DG and capacitors allocations using artificial ecosystem optimizer: Practical case study,” *Alexandria Engineering Journal*, vol. 61, no. 8, pp. 6105–6118, Aug. 2022, doi: 10.1016/j.aej.2021.11.035.
 - [26] T. Hamadneh, B. Batiha, F. Werner, M. A. Kamarposhti, I. Colak, and E. M. Barhoumi, “Optimization of Reconfiguration and Resource Allocation for Distributed Generation and Capacitor Banks Using NSGA-II: A Multi-Scenario Approach,” *CMES - Computer Modeling in Engineering and Sciences*, vol. 143, no. 2, pp. 1519–1548, 2025, doi: 10.32604/cmcs.2025.063571.
 - [27] M. Mahdavi, A. Awaifo, M. Dini, S. Moradi, F. Jurado, and D. Vera, “A flexible loss reduction formulation for simultaneous capacitor placement and network reconfiguration in distribution grids,” *Electric Power Systems Research*, vol. 235, p. 110708, Oct. 2024, doi: 10.1016/j.epsr.2024.110708.
 - [28] T. Rajić and B. Stojanović, “Algorithm for distribution network reconfiguration and reactive power compensation with battery energy storage systems,” *Electric Power Systems Research*, vol. 244, p. 111547, Jul. 2025, doi: 10.1016/j.epsr.2025.111547.
 - [29] R. Prakash and S. Sivasubramani, “Optimal Planning of DG and Shunt Capacitor in a Harmonic Distorted Distribution Network,” in *2021 9th IEEE International Conference on Power Systems (ICPS)*, Kharagpur, India, 2021, pp. 1–6, doi: 10.1109/ICPS52420.2021.9670256.
 - [30] Taqiyuddin, Suwarno, M. Nurdin, and G. H. M. Sianipar, “Backward Forward Sweep Algorithm for Unbalanced Three-Phase Power Flow Analysis in Distribution Systems Containing Voltage Regulator,” in *2021 3rd International Conference on High Voltage Engineering and Power Systems, ICHVEPS 2021*, Oct. 2021, pp. 645–650, doi: 10.1109/ICHVEPS53178.2021.9600914.
 - [31] S. Rana, M. Sarwar, A. S. Siddiqui, and Prashant, “Particle swarm optimization: An overview, advancements and hybridization,” in *Optimization Techniques in Engineering: Advances and Applications*, Wiley, 2023, pp. 95–113, doi: 10.1002/9781119906391.ch6.
 - [32] M. D. Faraby *et al.*, “Network reconfiguration for improving performance system in ULP Sungguminasa considering nonlinear loads,” *International Journal of Electrical and Computer Engineering*, vol. 14, no. 6, pp. 6066–6075, Dec. 2024, doi: 10.11591/ijece.v14i6.pp6066-6075.
 - [33] S. Rahman, I. A. Khan, and A. Iqbal, “Impact of Harmonics of Distributed Generators on the Harmonic Profiling of Distribution Networks,” in *2023 IEEE Texas Power and Energy Conference (TPEC)*, College Station, TX, USA, 2023, pp. 1–6, doi: 10.1109/TPEC56611.2023.10078476.
 - [34] H. Amiri, “Effects of DG Sources on Distribution Network's Harmonics, Simulation Analysis and Comparison,” in *2025 6th International Conference on Optimizing Electrical Energy Consumption (OEEC)*, Najafabad, Iran, Islamic Republic of, 2025, pp. 1–6, doi: 10.1109/OEEC66525.2025.11100220.
 - [35] I. Khan, A. S. Vijay, and S. Doolla, “Nonlinear Load Harmonic Mitigation Strategies in Microgrids: State of the Art,” *IEEE Systems Journal*, vol. 16, no. 3, pp. 4243–4255, Sept. 2022, doi: 10.1109/JSYST.2021.3130612.

BIOGRAPHIES OF AUTHORS



Yuli Asmi Rahman    completed her S.T. degrees in 2003 from Department of Electrical Engineering at UNHAS, Indonesia. She completed M.T. degrees in 2010 from Department of Electrical Engineering at UGM, Indonesia. She completed Dr. Degree in 2020 from Department of Electrical Engineering UNHAS, Indonesia. Presently, she is a lecturer in Department of Electrical Engineering, Tadulako University, Indonesia. Her research focuses on optimization of renewable energy, power system protection and power electronic converters. She can be contacted at email: yuli.asmi@untad.ac.id.



Muhira Dzar Faraby    completed his S.T. and M.T. degrees in 2012 and 2014, respectively, from the Department of Electrical Engineering at Hasanuddin University (UNHAS), Indonesia. He earned his Dr degree in 2021 from the Department of Electrical Engineering at ITS Surabaya, Indonesia. Presently, he holds a position as a lecturer in the Department of Electrical Engineering at Polytechnic State of Ujung Pandang (PNUP), Indonesia. His research focuses on optimization of power quality (pq), and power distribution and transmission system. He can be contacted at email: muhiradzfaraby@poliupg.ac.id.



Sofyan    completed his S.T. and M.T. degrees in 2002 and 2010, respectively, from the Department of Electrical Engineering at UNHAS, Indonesia. Currently, he is pursuing a Ph.D. program in the Department of Electrical Engineering at UTM, Malaysia. Additionally, he serves as a lecturer in the Department of Electrical Engineering at PNUP, Indonesia. His research focuses on optimizing and operating power systems, managing energy demand within smart grid systems, and advancing technology related to renewable energy. He can be contacted at email: Sofyantato@poliupg.ac.id.



Sarma Thaha    completed her S.T and M.T. degrees in 2002 and 2011, respectively, from the Department of Electrical Engineering at UNHAS, Indonesia. She is a lecturer in the Department of Electrical Engineering at PNUP, Indonesia now. Her research focuses on protection in power system and stability in power system. She can be contacted at email: Sarmathaha@poliupg.ac.id.



Musfirah Putri Lukman    completed her S.T and M.T. degrees in 2011 and 2014, respectively, from the Department of Electrical Engineering at UNHAS, Indonesia. She is a lecturer in the Department of Electrical Engineering at PNUP, Indonesia now. Her research focuses on optimization based artificial intelligence, power system control, and internet of think. She can be contacted at email: musfirahputrilukman@poliupg.ac.id.



Muhammad Sahrul Ramadan    completed his S.T. degree at Muslim University of Indonesia in 2020 and obtained his M.T. degree from Hasanuddin University in 2023. He is currently a lecturer in the Department of Electrical Engineering at Ujung Pandang State Polytechnic, Indonesia, with a concentration in electrical energy. He can be contacted at email: m.sahrulramadan@poliupg.ac.id.



Firdaus    completed his S.Pd. degree in 2003 from the department education of electrical Engineering at Universitas Negeri Makassar, Indonesia. Completed his M.T. and Dr. degrees in 2006 and 2023, respectively, from the Department of Electrical Engineering at ITS Surabaya, Indonesia. Presently, he holds a position as a lecturer in the Department Education of Electrical Engineering at Universitas Negeri Makassar, Indonesia. His research focuses on optimization renewable energy resources, power distribution and transmissions system. He can be contacted at email: dauselektro@unm.ac.id.



Mansur    completed his S.T. degree in 1997 from the Department of Electrical Engineering at Indonesia Muslim of University Makassar, Indonesia. Completed his M.T. and Dr. degrees in 2005 and 2021, respectively, from the Department of Electrical Engineering at Hasanuddin University, Indonesia. Presently, he holds a position as a lecturer in the Department of Electrical Engineering at Halu Oleo University, Indonesia. His research focuses renewable energy resources, renewable energy generation, energy conversion. He can be contacted at email: mansur@uho.ac.id.



Andi Fitriati    finished the S.T and M.T. degree in 2004 and 2012 from the Department of Electrical Engineering, UNHAS, Indonesia. Currently, she's a lecturer of Mechatronic Engineering, Polytechnic of Bosowa (POLIBOS), Indonesia. Her research are optimization process using artificial intelligence, big data, and digital system. She can be contacted at email: and.fitriati@politeknikbosowa.ac.id.



Muhammad Rais    completed his S.Pd. degrees in 2003 from Department of Electrical Engineering Education at State University of Makassar, Indonesia. He completed M.T. degrees in 2010 form Department of Electrical Engineering at UNHAS, Indonesia. Presently, he is a lecturer in Department of Electrical Engineering, Patria Artha University, Indonesia. His research focuses on power system stability, green and renewable energy, and sustainable energy. He can be contacted at email: muh.raisazisnawawi@gmail.com.