International Journal of Electrical and Computer Engineering (IJECE)
Vol. 14, No. 6, December 2024, pp. 6066~6075
ISSN: 2088-8708, DOI: 10.11591/ijece.v14i6.pp6066-6075

Network reconfiguration for improving performance system in ULP Sungguminasa considering nonlinear loads

Muhira Dzar Faraby[1], Yuli Asmi Rahman[2], Sofyan[3], Sarma Thaha[1], Musfirah Putri Lukman[1], Asma Amaliah[4], Mustika[5], Mochammad Apriyadi Hadi Sirad[6], Anisya Sonita[7]
[1]Department of Electrical Engineering, Politeknik Negeri Ujung Pandang, Makassar, Indonesia
[2]Department of Electrical Engineering, Universitas Tadulako, Makassar, Indonesia
[3]Faculty of Electrical Engineering, Universiti Teknologi Malaysia, Johor, Malaysia
[4]Department of Telecommunication Engineering, Politeknik Negeri Ujung Pandang, Makassar, Indonesia
[5]Department of Computer Engineering, Universitas Muhammadiyah Metro, Lampung, Indonesia
[6]Department of Electrical Engineering, Universitas Khairun, Ternate, Indonesia
[7]Department of Informatic Engineering, Universitas Muhammadiyah Bengkulu, Bengkulu, Indonesia

Article Info

Article history:

Received Mar 12, 2024
Revised Jul 11, 2024
Accepted Jul 17, 2024

Keywords:

%THDv
Losses
Network reconfiguration
Nonlinear load
Particle swarm optimization

ABSTRACT

Network reconfiguration is a very economical technique that can improve electrical system performance. The development of semiconductor electrical equipment technology to meet human needs and work, known as nonlinear loads, has had a negative impact in the form of the spread of harmonic distortion which can accelerate the aging process and even damage equipment. In this paper, the effect of the optimization results of network reconfiguration techniques on the Sungguminasa 165-bus Executive Unit Service or *Unit Layanan Pelanggan* (ULP) electrical system is contaminated with harmonic distortion due to the use of nonlinear loads. This technique was optimized using the particle swarm optimization (PSO) method with a multi objective function in the form of minimizing %THDv and total losses with several limitations. Simulation results from the optimization process of several study cases are shown by activating the five tie switches from the network reconfiguration process on the Sungguminasa 165-bus ULP system which is able to improve power quality by reducing the average %THDv by 3.89% and total losses by 8.19%.

Corresponding Author:

Muhira Dzar Faraby
Department of Electrical Engineering, Politeknik Negeri Ujung Pandang
Jl. Perintis Kemerdekaan KM. 10, Makassar, 90245, Indonesia
Email: muhiradzarfaraby@poliupg.ac.id

1. INTRODUCTION

The radial distribution system (RDS) is the simplest and most economical network topology to operate [1]. In the RDS, there are tie switches (TS) and sectional switches (SS) that play a crucial role in altering network reconfiguration (NR). These switches are considered essential for enhancing the performance and reliability of the electric power system [2]. The network reconfiguration (NR) optimization technique has been in existence for an extended period. However, it is acknowledged for its capability to enhance system performance, including reducing losses, improving bus voltage levels, and ensuring the continuous supply of electrical energy to customers. This, in turn, contributes to an increase in system reliability [3]. Today, distribution automation (DA) is employed in RDS networks for the network reconfiguration (NR) optimization process [4], [5]. In DA, operators are significantly assisted in evaluating current operational conditions to make optimal decisions [6].

Power quality (PQ) is one of the important parameters in the analysis of automation systems on RDS [7]. Semiconductor devices which play an important role in technological progress also have a negative effect on PQ in RDS [8]. Harmonic currents originating from the use of nonlinear loads from semiconductor equipment, switching processes, florescent lamps [9]. The effects that can occur include increased losses, decreased bus voltage levels, high heating, faster aging of equipment, damage to the insulating properties of equipment and even permanent damage to electrical equipment [10]. A combination of forward backward sweep (FBS) and harmonic load flow (HLF) power flow methods is used to analyze the distribution and effects of using nonlinear loads on the RDS [11]. The FBS method is used to obtain bus voltage values, current for each channel and channel power losses at basic frequencies, while the HLF method is used to obtain values for bus voltage, current for each channel and channel power losses at multiples of the frequency, which is called the harmonic order [12]–[14].

The simplified control and operational processes, along with the efficiency achieved by customers with the use of semiconductor devices and switching processes, necessitate that RDS have intricate requirements for controlling the PQ index, particularly addressing the effects of propagating harmonic distortion [15]. The electricity distribution network in Indonesia utilizes a radial network configuration. PT. PLN (Persero), as the key player in distributing and operating the electric power system, encounters challenges in maintaining system performance in accordance with predefined operating standards [16].

Although considered an optimization method with a long history, the NR method is still widely used as an evolving breakthrough, both in terms of single optimization techniques and in combination with other optimization methods to enhance system performance, including addressing issues related to the spreading of harmonic distortion [17]. Fundamentally, NR alone is unable to mitigate the spreading of harmonic distortion. The control of tie switches (TS) and tie transformers (TT) is crucial in regulating current flow and impedance values of feeder configuration connections in the radial distribution system (RDS) [18]. In several studies utilizing the IEEE 33-bus RDS test system, methods such as load curtailment [19], particle swarm optimization (PSO) [20], ant colony method [21], genetic algorithm [22], fireflies algorithm [23], and simulated annealing [24], which are artificial intelligence (AI)-based methods, are considered effective in reducing harmonic spreading indices, decreasing losses, and improving bus voltage levels using NR techniques. The NR optimization technique is also deemed effective in enhancing power quality (PQ), as demonstrated in tests on the Executive Unit Service or *Unit Layanan Pelanggan* (ULP) Way Halim 88-bus system in Bandar Lampung City, Indonesia, using the multi-objective PSO method. Both test systems exhibit significantly different electricity demand values in their respective feeders [25]. The type of harmonic source greatly influences the magnitude of harmonic current injection, and this is also highly dependent on the electrical energy magnitude in the feeder [26].

The ULP Sungguminasa, located in the Gowa Regency, oversees several feeders. One of them is the Barombong-IPDN feeder with a total of 165 buses. The load types in this system include households, elite residential areas, and industrial zones, each utilizing different harmonic load types. Households constitute are majority of the load types in this system [27]. In a study [28], it was noted that power flow analysis revealed several feeders with bus voltage levels below 0.95 pu. Considering the harmonic source types resulting from the load characteristics in this system, this research attempts to optimize the NR method in various scenarios. This technique is optimized using the PSO method with the objective of minimizing the total harmonic distortion voltage (%THDv) and total losses within predefined standards. The optimization results are anticipated to make a substantial contribution to the effects of NR, considering the load characteristics in the RDS. The structure of this paper is as follows: section 2 is research methods is divided into four parts namely objectives and constrains, ULP Sungguminasa 165-bus, NR methods and PSO method. Simulation result and discussion are shown in section 3. Section 4 is conclusion.

2. METHOD

2.1. Objectives and constrains

Each optimization technique to be optimized has an objective function (OF). The OF in this research aims to minimize %THDv and total losses.

$$OF = min\, f(x)_1 + min\, f(x)_2 \quad (1)$$

$$OF = min\left(\frac{V_{d,i}}{V_{rms,i}} * 100\%\right)_1 + min\left(\sum_{i=1}^{nb} P_{Loss_i}{}^{(1)} + \sum_{i=1}^{nb}\sum_{h=h_0}^{h_{max}} P_{Loss_i}{}^{(h)}\right)_2 \quad (2)$$

$V_{d,i}$ and $V_{rms,i}$ are voltage bus in fundamental frequency and voltage rms on bus i, h_{max} and h_0 are the max and min harmonic orders and $P_{Loss_i}{}^{(1)}$ and $P_{Loss_i}{}^{(h)}$ are the losses of fundamental and harmonic orders.

Boundary conditions need to be met to enhance the selectivity of the optimization process.

- The electrical network topology remains radial before and after NR.
- V_{min} and V_{max} are the minimum and maximum voltage level bus needs to be kept within operational limits.

$$(0.95\,pu) \leq V_{rms_i} \leq (1.05\,pu) \quad (3)$$

- The limit for %THDv adhere to the standards outlined in IEEE std 95. THD_i and THD_{max} are total harmonic distortion in maximum and bus i.

$$\%THD_{max} \geq \%THD_i \quad (4)$$

2.2. ULP Sungguminasa 165-bus

The ULP Sungguminasa operates at a voltage of 20 kV. It provides electric power to residents, businesses, and industrial clients in the neighboring vicinity, as illustrated in Figure 1. In this research, the employed feeders were Barombong and IPDN feeders, comprising a total of 165 buses. The aggregate load on its amounts to 12,325 MW and 7.64 MVAR. Harmonic currents will be introduced to each load bus. Three categories of harmonic loads include fluorescent lamps for residential areas, inverting devices associated with temperature control equipment for elite residential areas, and six-pulse variable frequency drives (VFD) for industrial areas. The magnitude and type of harmonic load injection are detailed in Tables 1 and 2.

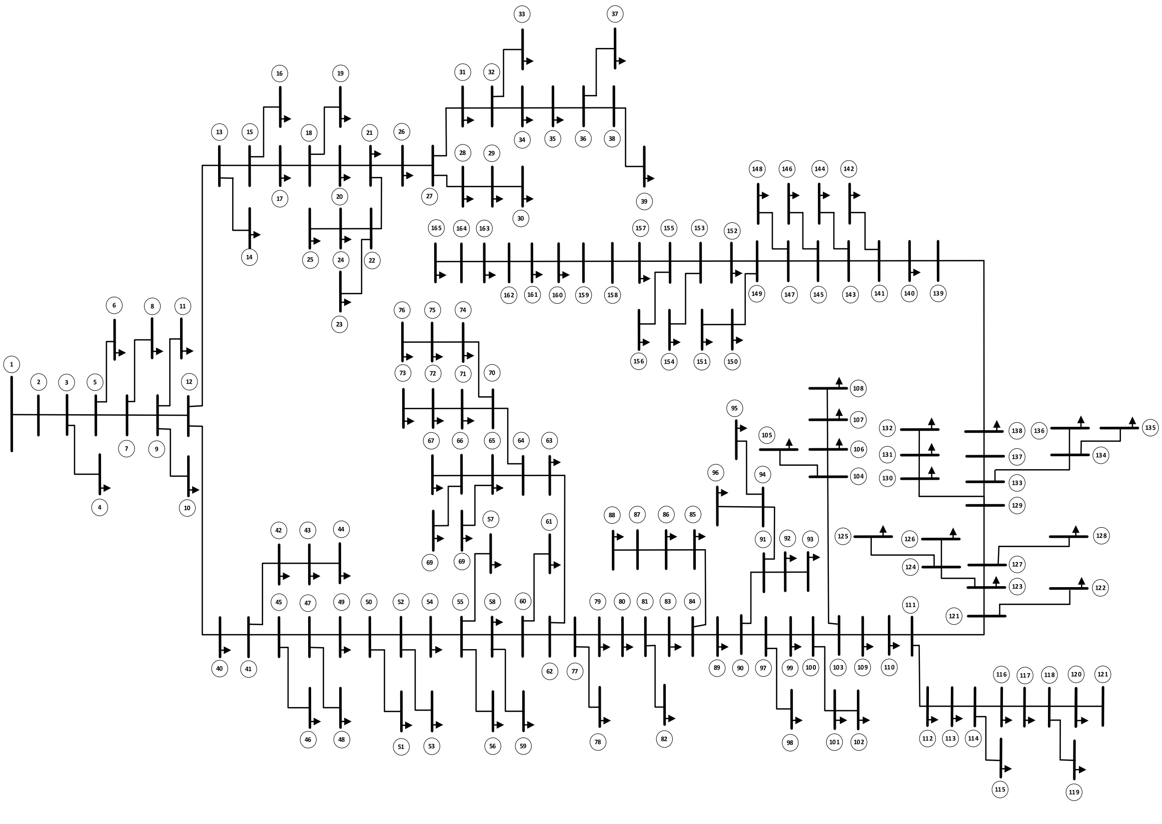

Figure 1. ULP Sungguminasa 165-bus RDS [28]

Table 1. The value of harmonic current injection from the harmonic loads [27]

Harmonic order	The types of harmonic injection		
	VFD	Inverting devices	Fluorescent
5th	$98\angle140^0$	$15.00\angle0^0$	$10.00\angle0^0$
7th	$39.86\angle113^0$	$10.00\angle0^0$	$5.00\angle0^0$
11th	$18.95\angle-158^0$	$5.00\angle0^0$	$1.00\angle0^0$
13th	$8.79\angle-178^0$	$3.00\angle0^0$	$0.00\angle0^0$
17th	$2.5\angle-94^0$	$1.00\angle0^0$	$0.00\angle0^0$

Table 2. Location of harmonic load [27]

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

2.3. NR method and study case

The TS connect load buses into groups to identify the most optimal combination [29]. There are five clusters determined based on TS and SS will undergo reconfiguration. The combination of TS and SS switches is employed to establish the search space in the optimization process [30]. The SS will be disconnected, allowing a new circuit to be connected through the TS closure process based on the search results from the optimization process [31], [32]. Cluster data is presented in Table 3.

Table 3. Cluster data for NR in ULP Sungguminasa

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

Several simulated case studies have been conducted to assess the effectiveness of NR optimization techniques optimized using PSO. The case studies include:

- Case 1. Activation of 1 TS from cluster 1.
- Case 2. Activation of 2 TS from cluster 1 and 2.
- Case 3. Activation of 3 TS from cluster 1, 2 and 3.
- Case 4. Activation of 4 TS from cluster 1, 2, 3 and 4.
- Case 5. Activation of 5 TS from cluster 1, 2, 3, 4 and 5.

2.4. PSO method

In PSO, each particle navigating the D-dimensional problem hyperspace represents a potential solution for a specific problem. For each of the i two vectors, X_i is the position vector, and V_i is the velocity vector. Additionally, each particle i can remember its personal best experience ever encountered, represented by the personal best position vector P_i. The position attained by the best particle in the community is denoted as P_g. Mathematically, in the $(t+1)$ iteration of the search process, the dth dimension of particle i's velocity, $V_{i,d}(t+1)$, and position $X_{i,d}(t+1)$ are updated as follow [33], [34].

$$V_{id}(t+1) = V_{id}(t) + c_1 rand_1(P_{id}(t) - X_{id}(t)) + c_2 rand_2\left(P_{gd}(t) - X_{id}(t)\right) \quad (5)$$

$$OX_{id}(t+1) = X_{id}(t) + V_{id}(t+1) \quad (6)$$

V_{id} is speed of particle, $c_1$and c_2 are acceleration coefficient, $rand_1$ and $rand_2$ are position of random particle, X_{id} is position of particle, t is iteration, P_{id} is position of local best and P_{gd} is position of global best [35], [36]. The value of $c_1 = c_2 = 2$, iteration = 100 and population = 100 is used in PSO parameters. Considering the harmonic injection values provided by the type of nonlinear load based on the load categories at ULP Sungguminasa, a new network topology is proposed by activating a combination of the existing TS and SS functions using the PSO method. This method seeks the objective function with the specified constraints.

3. RESULTS

When nonlinear loads inject harmonic currents into an electrical system, the level of harmonic distortion generated is contingent upon the amount of electrical power consumed by the load bus. As the power consumption increases, the severity of harmonic distortion also escalates, causing greater disruption within the system. This distortion then propagates throughout the entire network, affecting the performance and efficiency of other components, as illustrated in Table 4 and Figure 2.

Table 4. Comparison active and reactive power before and after injection of harmonic current

Parameter	Before injection	After injection
P (kW)	379.52	389.65
Q (kVAr)	446.19	510.8

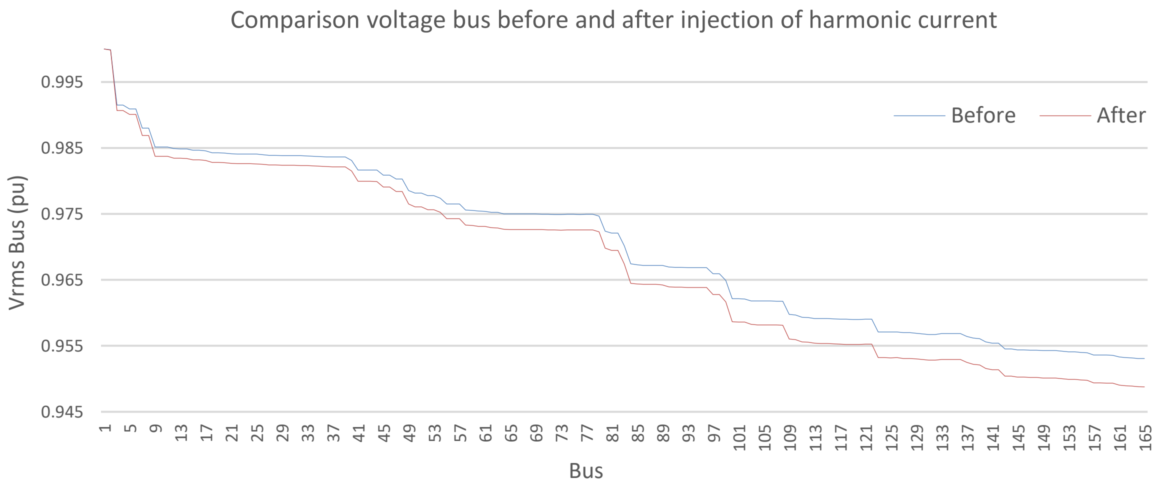

Figure 2. Comparison of voltage bus before and after injection of harmonic current

Table 4 presents a comparison of the harmonic current penetration effects from various types of nonlinear loads at ULP Sungguminasa. There is an increase in P_{Loss} by 10.13 kW or 2.66% and Q_{Loss} by 64.61 kVAr or 14.48%. The same phenomenon occurs in the bus voltage level in Figure 2. There is a decrease in the bus voltage level averaging 0.0027 pu or 0.28%. This demonstrates that harmonic current injection can degrade the system's performance. The simulation results indicate that the extent of harmonic distortion spread is significantly influenced by the type of nonlinear load, based on the harmonic current injection values, and the load power values at each bus in the RDS. The exploration for solutions using the proposed optimization technique employing the PSO method in all of study cases to determine the objective function within predefined boundaries is illustrated in Table 5, Figure 3 and Figure 4.

Table 5 illustrates the simulation results of NR optimization using the PSO method. The optimization results from all case studies indicate an enhancement in the system's performance. The reduction in total P_{Loss}, as one of the objective functions, amounts to 5.55 kW or 1.42% in case 1, 6.69 kW or 1.71% in case 2, 9.16 kW or 2.35% in case 3, 15.89 kW or 4.07% in case 4, and 31.95 kW or 8.19% in case 5. Additionally, the total Q_{Loss} also experiences a decrease of 7.64 kVAr or 1.49% in case 1, 8.88 kVAr or 1.73% in case 2, 12.59 kVAr or 2.46% in case 3, 20.17 kVAr or 3.94% in case 4, and 38.28 kVAr or 7.49% in case 5.

Figure 3 illustrates a comparison of the bus voltage level values after the optimization process. Improvement is evident with an increase in the bus voltage level across all buses in all cases. The average increase in bus voltage level is 0.00038 pu or 0.040% in case 1, 0.00054 pu or 0.056% in case 2, 0.00076 pu or 0.078% in case 3, 0.00131 pu or 0.136% in case 4, and 0.00254 pu or 0.2635% in case 5.

Table 5. The results of simulation for all scenario

Parameter	Normal Case	Case 1	Case 2	Case 3	Case 4	Case 5
Open SS	-	43-44	43-44, 22-23	43-44, 22-23, 29-30	43-44, 22-23, 29-30, 118-120	43-44, 22-23, 29-30, 118-120, 150-151
Total P_{Loss} (kW)	389.65	384.1	382.92	380.49	373,76	357,7
Total Q_{Loss} (kVAr)	510.8	503.16	501.92	498.21	490,63	472,52
Min voltage rms (p.u)	0.94878	0.94907	0.94913	0.94923	0.9497	0.95101
%THDv max	3.13348	3.13201	3.13839	3.12671	3.12529	3.12003
%THDi max	1.33719	1.33721	1.34032	1.33572	1.33599	1.33605

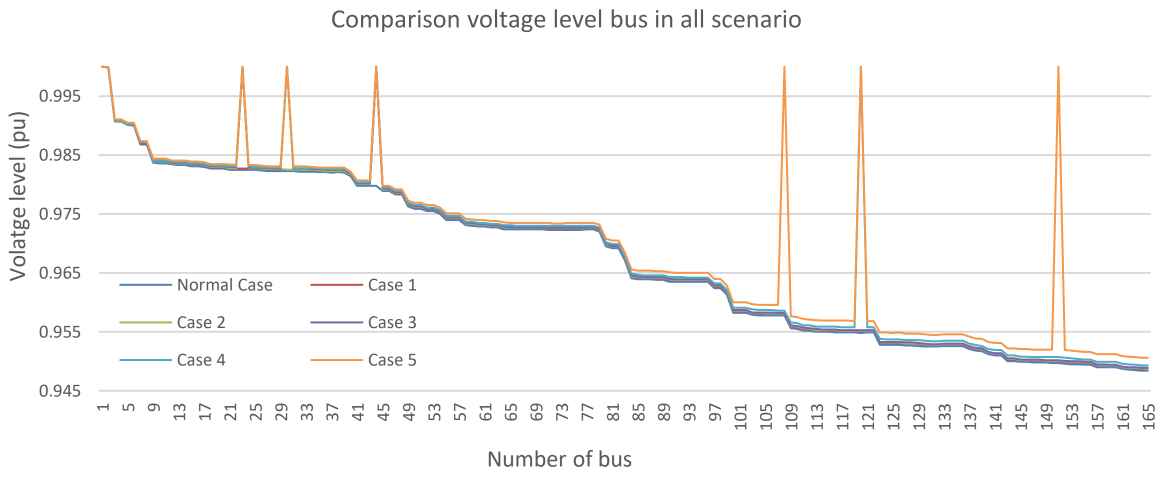

Figure 3. Comparison voltage bus level in all study case

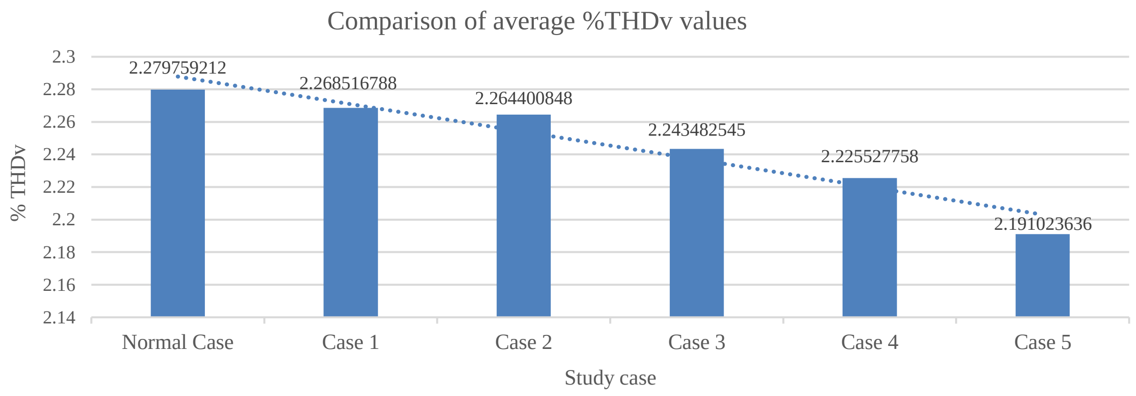

Figure 4. Comparison of average %THDv values in all study case

Figure 4 illustrates an improvement in the %THDv values, which is a parameter representing harmonic distortion spread. As one of the objective functions in the optimization process, NR optimization can reduce the spread of harmonic distortion. This can be observed with a decrease in the average %THDv values by 0.011% or 0.493% in case 1, 0.015% or 0.673% in case 2, 0.036% or 1.591% in case 3, 0.054% or 2.378% in case 4, and 0.088% or 3.892% in case 5.

The simulation results of the optimization show that the NR method is effective in enhancing system performance. This effectiveness is evident in the values, demonstrating a significant reduction in total P_{Loss}, total Q_{Loss}, and %THDv, while the bus voltage level increases, approaching 1 pu. For instance, the reduction in total P_{Loss} and Q_{Loss} directly correlates with improved system efficiency and stability. Additionally, the decrease in %THDv indicates a substantial reduction in harmonic distortions, further supporting the method's efficacy.

When compared to previous studies on similar optimization techniques tested on the IEEE 33-bus, IEEE 69-bus, and ULP Way Halim systems, the NR method achieved effectiveness levels above 80% in those cases. However, for the ULP Sungguminasa 165-bus test object, the effectiveness was only up to 8.19%. This discrepancy is due to substantial variations in load power and the types of harmonic loads, such as VFDs, in the test objects. The ULP Sungguminasa system presents unique challenges due to its specific load characteristics, which differ sharply from those in the other systems studied. While this study highlights the NR method's capability in reducing losses and improving voltage levels, it also exposes its limitations in handling diverse load types and power variations.

In summary, the study aimed to evaluate the effectiveness of the NR method in optimizing the ULP Sungguminasa 165-bus system. The findings underscore the importance of considering load characteristics and harmonic load types in optimization processes. While the NR method showed potential, its varying effectiveness across different systems suggests the need for tailored approaches to optimization. Future research should explore more adaptive techniques that can accommodate the diverse load profiles and harmonic disturbances present in complex power systems like ULP Sungguminasa. Unanswered questions remain regarding the specific adjustments required to enhance the NR method's performance in such contexts.

4. CONCLUSION

In this study, we investigated the impact of nonlinear loads, such as VFDs, inverting devices, and fluorescent lamps, on the 165-bus ULP Sungguminasa system, specifically focusing on the resulting harmonic distortions and their effect on system performance. The NR optimization technique, utilizing the PSO method, was employed to minimize %THDv and total losses within predefined limits. Our findings indicate that Case 5, which involved the activation of all tie switches, demonstrated the highest level of effectiveness among all simulated case studies. This was evidenced by a significant reduction in total P_Loss by 31.95 kW (8.19%), Q_Loss by 38.28 kVAr (7.49%), and the average %THDv by 0.088% (3.892%). Additionally, the average bus voltage level increased by 0.00254 pu (0.2635%). These results highlight the potential of the NR optimization technique in enhancing system performance, albeit with varying degrees of effectiveness compared to previous research on other systems. The relatively lower effectiveness observed in our study underscores the critical impact of load characteristics and the types of nonlinear loads on the optimization process. This suggests that while the NR method is beneficial, it may require integration with other optimization techniques to address the unique challenges posed by different power systems effectively. The contributes of research to the field by providing a nuanced understanding of how different types of nonlinear loads affect the performance of power systems and the effectiveness of optimization techniques like the NR method. These findings emphasize the need for tailored optimization strategies that consider the specific load profiles and harmonic characteristics of each system. Future research should focus on combining various optimization techniques to further enhance system performance, particularly in reducing harmonic distortions. Additionally, investigating the impact of strategic placement of charging stations for electric vehicles could offer new insights into managing harmonic loads and improving overall system stability and efficiency. By addressing these areas, we can develop more robust and adaptive optimization approaches that cater to the evolving demands of modern power systems, ultimately contributing to improved reliability and performance for the community.

ACKNOWLEDGEMENTS

Financial support for this study is provided by the Advanced Indonesia III Innovation Research Program (RIIM 3 - BRIN)-LPDP Indonesia.

REFERENCES

[1] H. Azadi, B. Akbari, and M. S. Sepasian, "Power quality enhancement in distribution systems using feeder reconfiguration," *2018 Smart Grid Conference (SGC)*. IEEE, Nov. 2018, doi: 10.1109/sgc.2018.8777854.

[2] M. J. H. Moghaddam, A. Kalam, J. Shi, S. A. Nowdeh, F. H. Gandoman, and A. Ahmadi, "A new model for reconfiguration and distributed generation allocation in distribution network considering power quality indices and network losses," *IEEE Systems Journal*, vol. 14, no. 3, pp. 3530–3538, Sep. 2020, doi: 10.1109/jsyst.2019.2963036.

[3] S. O. Ayanlade, A. Jimoh, E. I. Ogunwole, A. Aremu, A. B. Jimoh, and D. E. Owolabi, "Simultaneous network reconfiguration and capacitor allocations using a novel dingo optimization algorithm," *International Journal of Electrical and Computer Engineering*, vol. 13, no. 3, pp. 2384–2395, Jun. 2023, doi: 10.11591/ijece.v13i3.pp2384-2395.

[4] O. Penangsang, S. B. Panuntun, B. P. Vita Lystianingrum, and I. Suryawati, "State estimation for radial passive distribution system using hamiltonian cycle theory based on geographic information system (GIS)," *2018 International Seminar on Intelligent Technology and Its Applications (ISITIA)*. IEEE, Aug. 2018, doi: 10.1109/isitia.2018.8710876.

[5] W. Sunderman, N. Heine, B. Deaver, J. Robinson, and J. Graff, "Optimal distribution automation switch placement," *2020 IEEE/PES Transmission and Distribution Conference and Exposition (T&D)*. IEEE, Oct. 2020, doi: 10.1109/td39804.2020.9299906.

[6] Y. Siregar, T. S. Jaya Tambun, S. P. Panjaitan, K. Tanjung, and S. Yana, "Distribution network reconfiguration utilizing the particle swarm optimization algorithm and exhaustive search methods," *Bulletin of Electrical Engineering and Informatics*, vol. 13, no. 2, pp. 821–831, Apr. 2024, doi: 10.11591/eei.v13i2.6206.

[7] Umar, Firdaus, M. Ashari, and O. Penangsang, "Optimal location, size and type of DGs to reduce power losses and voltage deviation considering THD in radial unbalanced distribution systems," *2016 International Seminar on Intelligent Technology and Its Applications (ISITIA)*. IEEE, Jul. 2016, doi: 10.1109/isitia.2016.7828724.

[8] K. Gholami, A. Azizivahed, A. Arefi, M. M. Rahman, and M. R. Islam, "Power quality enhancement of smart reconfigurable grids by integrating renewable energy sources," *2022 IEEE Global Conference on Computing, Power and Communication Technologies (GlobConPT)*. IEEE, Sep. 2022, doi: 10.1109/globconpt57482.2022.9938282.

[9] F. B. Bottura, M. Oleskovicz, T. D. Le, and M. Petit, "Optimal positioning of power quality meters for monitoring potential conditions of harmonic resonances in a MV distribution system," *IEEE Transactions on Power Delivery*, vol. 34, no. 5, pp. 1885–1897, Oct. 2019, doi: 10.1109/tpwrd.2019.2923365.

[10] IEEE Power and Energy Society, "IEEE Standard for harmonic control in electric power systems," *IEEE Power and Energy Society*, vol. 2022, pp. 403–456, 2022.

[11] B. M. Gianesini, I. N. Santos, and P. F. Ribeiro, "Comparison of methods for determining harmonic distortion contributions using the IEEE benchmark test system," *IEEE Transactions on Power Delivery*, vol. 38, no. 4, pp. 2398–2407, Aug. 2023, doi: 10.1109/tpwrd.2023.3242942.

[12] B. Adineh, R. Keypour, P. Davari, and F. Blaabjerg, "Review of harmonic mitigation methods in microgrid: From a hierarchical control perspective," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 9, no. 3, pp. 3044–3060, Jun. 2021, doi: 10.1109/jestpe.2020.3001971.

[13] A. Taghvaie, T. Warnakulasuriya, D. Kumar, F. Zare, R. Sharma, and D. M. Vilathgamuwa, "A comprehensive review of harmonic issues and estimation techniques in power system networks based on traditional and artificial intelligence/machine learning," *IEEE Access*, vol. 11, pp. 31417–31442, 2023, doi: 10.1109/access.2023.3260768.

[14] S. Sofyan *et al.*, "Optimal inverter-based distributed generation in ULP Way Halim considering harmonic distortion," *International Journal of Electrical and Computer Engineering*, vol. 13, no. 6, pp. 6058–6067, Dec. 2023, doi: 10.11591/ijece.v13i6.pp6058-6067.

[15] "IEEE approved draft recommended practice for power quality data interchange format (PQDIF) - Corrigendum 1," *IEEE Std 1159.3-2019/Cor 1-2024 (Corrigendum to IEEE Std 1159.3-2019)*, pp. 1–15, 2024, doi: 10.1109/IEEESTD.2024.10497558.

[16] V. M. Lopez-Martin, F. J. Azcondo, and A. Pigazo, "Power quality enhancement in residential smart grids through power factor correction stages," *IEEE Transactions on Industrial Electronics*, vol. 65, no. 11, pp. 8553–8564, Nov. 2018, doi: 10.1109/tie.2018.2813965.

[17] M. R. Islam, H. Lu, M. J. Hossain, and L. Li, "Mitigating unbalance using distributed network reconfiguration techniques in distributed power generation grids with services for electric vehicles: A review," *Journal of Cleaner Production*, vol. 239, p. 117932, Dec. 2019, doi: 10.1016/j.jclepro.2019.117932.

[18] C. Wang *et al.*, "Estimating the harmonic impacts of multiple harmonic-producing loads considering network impedance variations," *IEEE Transactions on Power Delivery*, vol. 38, no. 6, pp. 3950–3958, Dec. 2023, doi: 10.1109/tpwrd.2023.3298382.

[19] M. D. Faraby and O. Penangsang, "A study of harmonic spreading against distribution network reconfiguration in passive radial distribution systems," *2018 4th International Conference on Science and Technology (ICST)*. IEEE, Aug. 2018, doi: 10.1109/icstc.2018.8528665.

[20] M. D. Faraby, O. Penangsang, R. S. Wibowo, and A. Fitriati, "Coordinated planning in improving power quality considering the use of nonlinear load in radial distribution system," *International Journal of Electrical and Computer Engineering*, vol. 11, no. 6, pp. 4610–4621, 2021, doi: 10.11591/ijece.v11i6.pp4610-4621.

[21] J. G. Daud, M. Kondoj, and M. Patabo, "Reconfiguration distribution network with ant colony," *2018 International Conference on Applied Science and Technology (iCAST)*. IEEE, Oct. 2018, doi: 10.1109/icast1.2018.8751227.

[22] 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, Sep. 2022, doi: 10.1109/jsyst.2021.3130612.

[23] R. V. Doyran, M. Sedighizadeh, A. Rezazadeh, and S. M. M. Alavi, "Optimal allocation of passive filters and inverter based DGs joint with optimal feeder reconfiguration to improve power quality in a harmonic polluted microgrid," *Renewable Energy Focus*, vol. 32, pp. 63–78, Mar. 2020, doi: 10.1016/j.ref.2019.12.001.

[24] M. D. Faraby, O. Penangsang, R. S. Wibowo, and A. Sonita, "Improved performance network reconfiguration in coordinated planning in radial distribution system considering harmonic distortion," *International Review on Modelling and Simulations (IREMOS)*, vol. 14, no. 2, p. 146, Apr. 2021, doi: 10.15866/iremos.v14i2.20472.

[25] M. D. Faraby, S. Sofyan, A. R. Idris, Usman, A. Fitriati, and Isminarti, "Optimization of network reconfiguration in the ULP Way Halim distribution system, Bandar Lampung City considering the use of nonlinear loads," *2023 International Conference On Cyber Management And Engineering (CyMaEn)*. IEEE, Jan. 2023, doi: 10.1109/cymaen57228.2023.10050958.

[26] T. Xu, J. Duan, Y. Jin, and P. Ju, "Simplified modeling of power electronic interfaced load considering harmonics," *2023 3rd International Conference on Energy Engineering and Power Systems (EEPS)*. IEEE, Jul. 2023, doi: 10.1109/eeps58791.2023.10256784.

[27] N. Naningsi, I. Kitta, Z. Muslimin, and M. D. Faraby, "Allocation of reactive power with capacitor bank placement considering the use of nonlinear loads using particle swarm optimization," *2023 International Conference on Advanced Mechatronics, Intelligent Manufacture and Industrial Automation (ICAMIMIA)*. IEEE, Nov. 2023, doi: 10.1109/icamimia60881.2023.10427935.

[28] S. S. Akhmad *et al.*, "Placement and sizing distributed generation using K-means clustering in ULP Sungguminasa 165-bus radial distribution system," *AIP Conference Proceedings*. AIP Publishing, 2024, doi: 10.1063/5.0222882.

[29] X. Xiao, Z. Li, Y. Wang, and Y. Zhou, "A practical approach to estimate harmonic distortions in residential distribution system," *IEEE Transactions on Power Delivery*, vol. 36, no. 3, pp. 1418–1427, Jun. 2021, doi: 10.1109/tpwrd.2020.3008700.

[30] X. Liang and C. Andalib -Bin- Karim, "Harmonics and mitigation techniques through advanced control in grid-connected renewable energy sources: A review," *IEEE Transactions on Industry Applications*, vol. 54, no. 4, pp. 3100–3111, Jul. 2018, doi: 10.1109/tia.2018.2823680.

[31] B. Khan and Z. M. Ali, "Optimal network reconfiguration of active distribution network," in *Active Electrical Distribution Network*, Elsevier, 2022, pp. 329–342, doi: 10.1016/b978-0-323-85169-5.00003-4.

[32] D. Sosic, T. Rajic, P. Stefanov, and B. Stojanovic, "Distribution network reconfiguration using the open switch moving register method," *2021 IEEE PES Innovative Smart Grid Technologies Conference - Latin America (ISGT Latin America)*. IEEE, Sep. 2021, doi: 10.1109/isgtlatinamerica52371.2021.9543011.

[33] R. Sellami, R. Neji, and T. Bouktir, "Enhancing radial distribution network performance by optimal reconfiguration with PSO algorithm," *2019 16th International Multi-Conference on Systems, Signals & Devices (SSD)*. IEEE, Mar. 2019, doi: 10.1109/ssd.2019.8893158.

[34] S. Rifai, Syafaruddin, A. Achmad, and I. S. Areni, "Optimization of generating unit system locations to convert conventional loop distribution networks to radial using particle swarm optimization algorithm," *2023 4th International Conference on High Voltage Engineering and Power Systems (ICHVEPS)*. IEEE, Aug. 2023, doi: 10.1109/ichveps58902.2023.10257461.

[35] L. Cai, Y. Hou, Y. Zhao, and J. Wang, "Application research and improvement of particle swarm optimization algorithm," *2020 IEEE International Conference on Power, Intelligent Computing and Systems (ICPICS)*. IEEE, Jul. 2020, doi: 10.1109/icpics50287.2020.9202023.

[36] W. Chuanjun, W. Ling, and R. Xuejing, "General particle swarm optimization algorithm," *2023 IEEE 2nd International Conference on Electrical Engineering, Big Data and Algorithms (EEBDA)*. IEEE, Feb. 2023, doi: 10.1109/eebda56825.2023.10090725.

BIOGRAPHIES OF AUTHORS

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), power distribution and transmission system. He can be contacted at email: muhiradzarfaraby@poliupg.ac.id.

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 form 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.

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, Sofyan 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 things. She can be contacted at email: musfirahputrilukman@poliupg.ac.id.

Asma Amaliah received bachelor degree (S.T.) in 2012 from Department of Electrical Engineering, Hasanuddin University, Indonesia. Master degree (M.T.) in 2016 from Department of Electrical Engineering, Hasanuddin University. Currently, she is a lecturer in Department of Electrical Engineering, Ujung Pandang State of Polytechnic, Indonesia. Her research interest in digital signal processing and embedded system. She can be contacted at email: asmaamaliah@poliupg.ac.id.

Mustika received a bachelor of computer degree from the Department of Computer Science from the STIMIK Palcomtech, Palembang in 2004, while the master of computer degree from the Department of Computer Science, Bina Dharma University, Palembang, in 2013. Now, she's a lecturer in Department of Computer Engineering, University Muhammadiyah of Metro. Her research interest includes multimedia and networking, optimization with artificial intelligence, big data, and information system. She can be contacted at email: mustika@ummetro.ac.id.

Mochammad Apriyadi Hadi Sirad received a bachelor of engineering degree from the Department of Electrical Engineering from the Muslim University of Indonesia Makassar in 2006, While the master of engineering degree from the Department of Electrical Power Engineering, Hasanuddin University, Makassar, in 2014. He is lecture now in Department of Electrical Power Engineering, Faculty of Engineering, Khairun University, Ternate, Indonesia. Researching about being in power system analysis, optimization and distributed energy resources. He can be contacted at email: apriyadisirat@unkhair.ac.id.

Anisya Sonita received the S.Kom. degree in 2011 from the Department of Informatic Engineering in Muhammadiyah University of Bengkulu Indonesia and the M.Kom. degree in 2013 at UPI YPTK Padang Indonesia. Currently, she is a lecturer and head of department human resources in Muhammadiyah University of Bengkulu. Her research interest includes mobile application, optimization program, artificial intelligent and big data. She can be contacted at email: anisyasonita@umb.ac.id.