Determination of location and capacity of distributed generations with reconfiguration in distribution systems for power quality improvement

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ABSTRACT

The use of non-linear loads and the integration of renewable energy in electricity network can cause power quality problems, especially harmonic distortion. It is a challenge in the operation and design of the radial distribution system. This can happen because harmonics that exceed the limit can cause interference to equipment and systems. This study will discuss the determination of the optimal location and capacity of distributed generation (DG) and network reconfiguration in the radial distribution system to improve the quality of electric power, especially the suppression of harmonic distribution. This study combines the optimal location and capacity of DG and network reconfiguration using the particle swarm optimization method. In addition, this research method is implemented in the distribution system of Bandar Lampung City by considering the effect of using nonlinear loads to improve power quality, especially harmonic distortion. The inverter-based DG type used considers the value of harmonic source when placed. The combination of the proposed methods provides an optimal solution. Increased efficiency in reducing power losses up to 81.17% and %total harmonic distortion voltage (THDv) is below the allowable limit.

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NOMENCLATURE

ACO	= Ant colony optimization	$[V_0]$	= The initial vector of the bus voltage
DG	= Distributed generation	I_i^{k+1}	= The current of bus I in iteration k+1
DHA	= Direct harmony analysis	ε	= The tolerance specified
FBS	= Forward backward sweep method	P_{Loss}	= Total active power losses
GA	= Genetic algorithm	${P_{Loss_i}}^{(1)}$	= Fundamental active power losses
HLF	= Harmonic load flow	h	= Harmonic order
ITLO	= Improved teaching learning optimization	$[V^{(h)}]$	= The voltage of harmonic
PSO	= Particle swarm optimization	${P_{Loss_i}}^{(h)}$	= Harmonic component active power losses

h_{max}	= The maximum harmonic orders	V_{min}	= The minimum standard voltage bus
h_0	= The minimum harmonic orders$V_{d,i}$	V_{rms_i}	= The rms voltage in bus i
$V_{d,i}$	= Absolute voltage on fundamental frequency	V_{max}	= The maximum standard voltage bus
$V_{THD,i}$	= Total harmonic distortion voltage	P_{DG}	= Active power output of DG
ΔV	= Voltage deviation	Q_{DG}	= Reactive power output of DG
$V_1 V_1$	= Swing bus voltage	P_{Load}	= Active power output of load
$V_i V_i$	= Voltage bus on each bus	Q_{Load}	= Reactive power output of load
SFLA	= Shuffle frog leaping algorithm	HSA	= Harmony search algorithm
THDv	= Total harmonic distortion voltage	ULP	= *Unit layanan pelaksana* (technical implementation unit)

1. INTRODUCTION

The development of technology to support life and the increase in the human population has led to an increase in the consumption of electrical energy. This force changes to the electrical grid system. The transition from fossil fuel power plants to renewable energy will occur along with technological developments and human concerns about environmental damage caused by the use of conventional power plants [1]. The integration of renewable energy generation in the distribution network system called DG is experiencing very rapid development at this time [2]. Challenges in the integration process in distribution systems with renewable energy plants are power quality problems that can cause voltage fluctuations and harmonics caused by the use of nonlinear loads and power electronics devices in renewable energy plants [3]. The spread of harmonics in the system can result in increased frequency and system voltage, equipment damage, heat losses, and resonance in the capacitor bank [4]–[6]. The use of the FBS method and HLF method reviews and analyzes the distribution of harmonics due to the use of nonlinear loads on a radial distribution system both at the fundamental frequency to the harmonic orders of the frequency [7]–[13].

In the distribution system, the implementation of DG is one of the breakthroughs that is able to maintain and improve the quality of electrical power in the radial distribution system [14], [15]. However, if the DG installation is carried out with a size and location that is not optimal, it can cause increased power losses, decreased quality of electrical power, and stability problems in the system [16], [17]. Network reconfiguration consists of changing the distribution network topology by operating tie switches and sectional switches to achieve a more optimal configuration while maintaining the radial topology after the reconfiguration process. This optimization technique aims to reduce power losses and improve the quality of electrical power in the distribution network [18]–[23].

The distribution system should control good power quality to the system with complex demanding conditions must be maintained according to the increase in the existing load. Moreover, the use of semiconductor equipment or switching processes is increasing rapidly due to high efficiency and ease of operation and control [24]. The combination of several optimization techniques is considered capable of providing better results in improving power quality. The combination of simultaneous placement of DG and capacitors optimized using the GA, PSO and ITLO methods [25], [26], the placement of capacitors with simultaneous net reconfiguration optimized using the ACO, HSA, PSO, refined-GA and DHA methods [27], [28]. The combination of placing DG and capacitors with network reconfiguration on IEEE 33-bus and IEEE 69-bus radial distribution systems optimized using GA, PSO and H-PSO method gives better results in suppressing the spread of harmonics, but the harmonic sources of the placement DG is not considered [14], [29]–[32].

Optimization methods based on artificial intelligence in solving combinatoric problems provide the best solution with faster computation time. Optimization techniques such as DG placement, capacitor placement dan network reconfiguration is still being studied in this decade in improving the performance of radial distribution systems. The combination of these optimization techniques contributes in finding the objective function to be achieved using artificial intelligence-based methods [1]–[32]. PSO is one of the optimization methods based on artificial intelligence which is considered capable of providing solutions in solving problems from the search for proposed optimization technique [33], [34]. This research will combine the design of DG based on renewable energy with network reconfiguration in finding multi objective function are minimum total active power losses, minimum %THDv and minimum voltage deviation validated using the Bandar Lampung City radial distribution system by considering the use of nonlinear load and harmonic source from renewable energy-based DG in improving power quality related to the spread of harmonic distortion. This paper is organized as: section 2 is research method that is divided into four parts: first is n modelling ULP. Way Halim distribution system of Bandar Lampung City, second is harmonic source, third is optimal with PSO, fourth is integration DG in distribution system, fifth is objective function, sixth is constrain and last is study case. In section 3 presents the simulations result and discussion. In section 4 shows the conclusion.

2. RESEARCH METHOD

2.1. Modelling ULP Way Halim 20 kV distribution system of Bandar Lampung City

The distribution system of Bandar Lampung City ULP Way Halim uses 4 feeders from 2 substations. The feeders are the Rolex feeder (purple), the Bonia feeder (green) and the Bulova feeder (blue) at the Sukarame substation and Perunggu feeder (brown) at the Sutami substation on Figure 1. The selection of the feeder was chosen because it has a close distance, there is a tie switch or it is possible to install a tie switch and connect to each other.

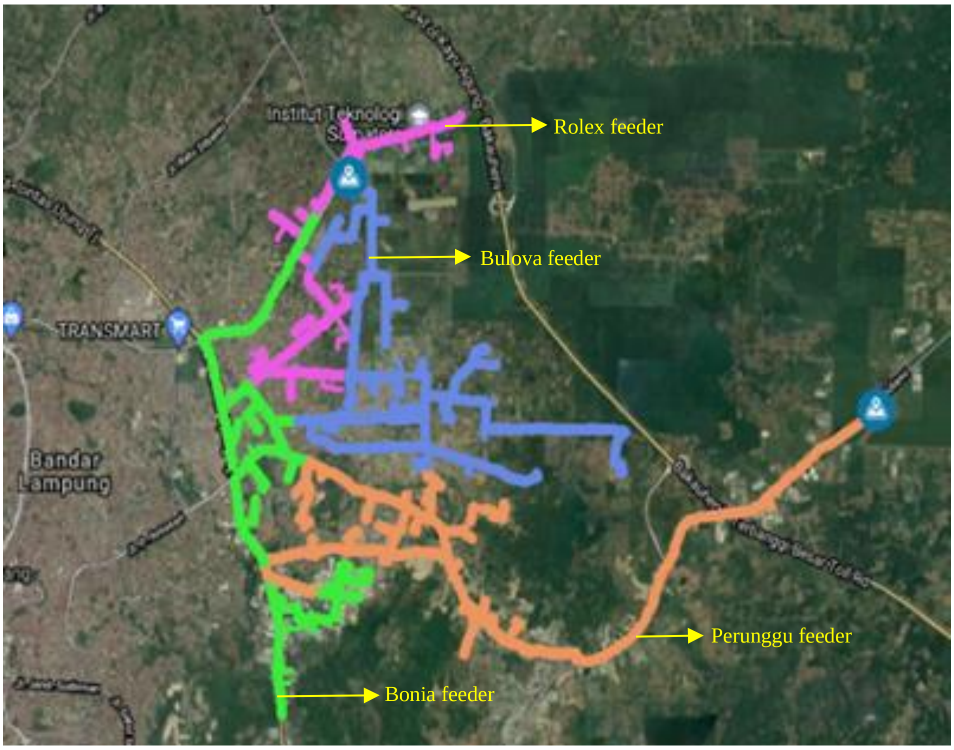

Figure 1. Electricity maps of 4 feeders ULP Way Halim [35]

The ULP Way Halim system has 88 buses and 4 feeders in Figure 2 with a total electrical power requirement of $17400.35\ kWatt + j10783.73\ kVAr$. The characteristics of the feeders in this system are scattered and complex, so modelling is needed to determine the number of dimensions in the search space when the simulation is carried out. In centralized load modelling, ramdomly distributed loads can be considered as scattered mass point. The modelling of load does not take into account the randomness of the loads location and the irregularity of the load capacity [36]. Centralized load modelling aims to simplify systems with multiple nodes. Centralized load modelling can make it easier to solve problems in the distribution system [37].

2.2. Network reconfiguration technique modelling

In ULP Way Halim Bandar Lampung City system, there are seven search loops based on the determination of tie switches to be reconfigured. The combination of existing switches is used to determine the search space in the optimization process. From the search of PSO the loop that has been determined, the channel will open on the selected the sectional switch so that a new channel can be connected through a closed the tie switches. The loop data on the system is shown in Table 1.

2.3. Harmonic source

This study uses two types of harmonic source, namely nonlinear load of variable frequency drive (VFD) and inverter-based DG. VFD will be injected into bus 2, 5, 12, 15, 17, 18, 19, 26, 27, 31, 32, 37, 42, 44, 51, 53, 54, 57, 60, 61, 62, 66, 69, 70, 73, 80, 83, 86, 87, and 88 and inverter-based DG which will be injected into bus 3, 8, 23, 25, 38, 43, 68, 77 and 84 each with a size of 45 kWatt. The value of the injection of harmonic currents from the two types of harmonic sources is shown in Table 2.

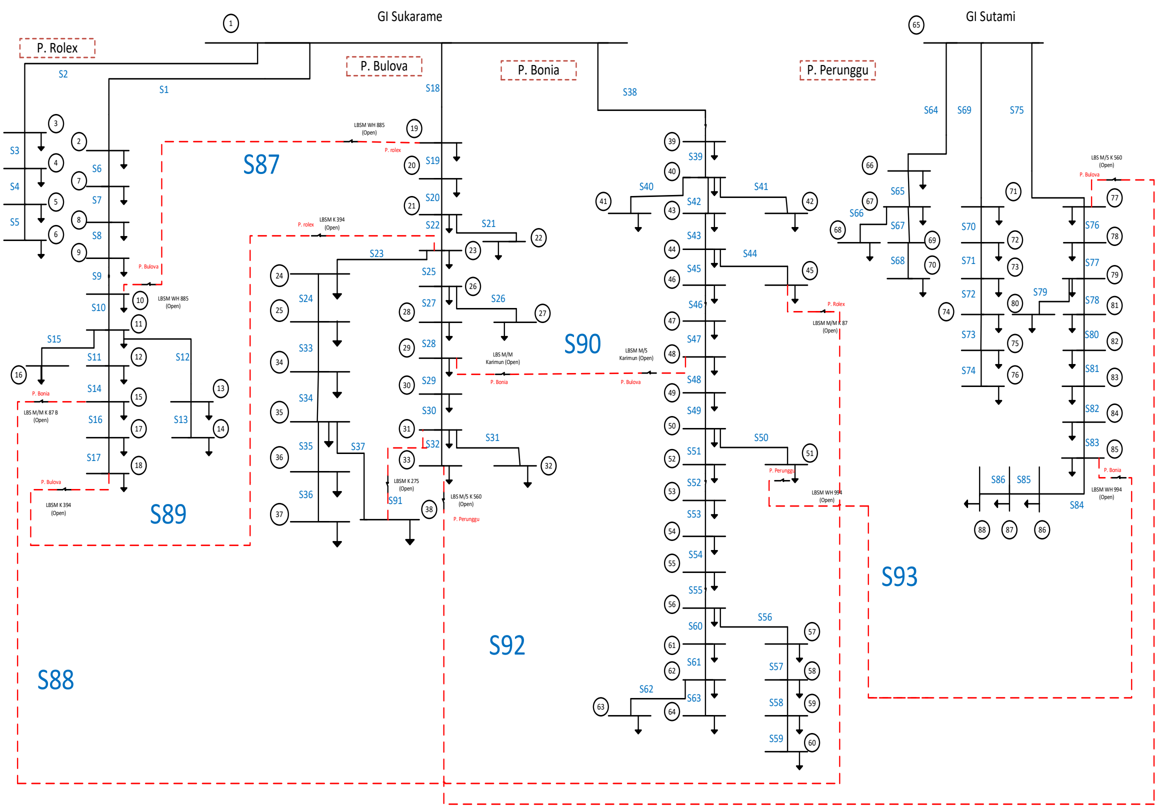

Figure 2. Single line diagram ULP Way Halim Bandar Lampung City

Table 1. Loop data of reconfiguration network

Loop Reconfiguration	Sectional Switch	Tie Switch
1	S1, S6, S7, S8, S9	S87
2	S16, S17, S19, S20, S22	S88
3	S25, S27, S28, S45, S46, S47	S89
4	S23, S24, S33, S34, S37, S29, S30	S90
5	S10, S11, S14, S42, S43, S44	S91
6	S32, S75	S92
7	S48, S49, S50, S80, S81, S82, S83	S93

Table 2. The value of harmonic source [38], [39]

Types of Harmonic Load	VFD		Inverter-based DG	
Orde	Magnitude (%)	Angle	Magnitude (%)	Angle
5^{th}	98	140	15	-20.74
7^{th}	39.86	113	10	-30.85
11^{th}	18.95	-158	5	65.54
13^{th}	8.79	-178	3	42.62
17^{th}	2.5	-94	0	0

2.4. Optimal with particle swarm optimization

The steps for implementing the PSO algorithm are: i) initiating a population of particles with random position and velocity in a search dimension space; ii) evaluating the value of fitness function in the variable d for each particle; iii) comparing the value of the fitness function of particle with P_{best}. If the existing value is better than P_{best}, $P_{best} = P_i$; iv) identify the particle with the best result and update the velocity and position of the particle; and v) the searching for the fitness value will stop when the best value is obtained at the maximum iteration. Parameter of PSO used is the *population=100*, *iteration=100*, *a=1*, *b=1*, *c=1*, $c_1=1$ and c_2=1. In this study, the sizing a, b, and c is made equivalent in finding multi objective function on the constrain determined. The flowchat of the optimization process using PSO method can be seen in Figure 3.

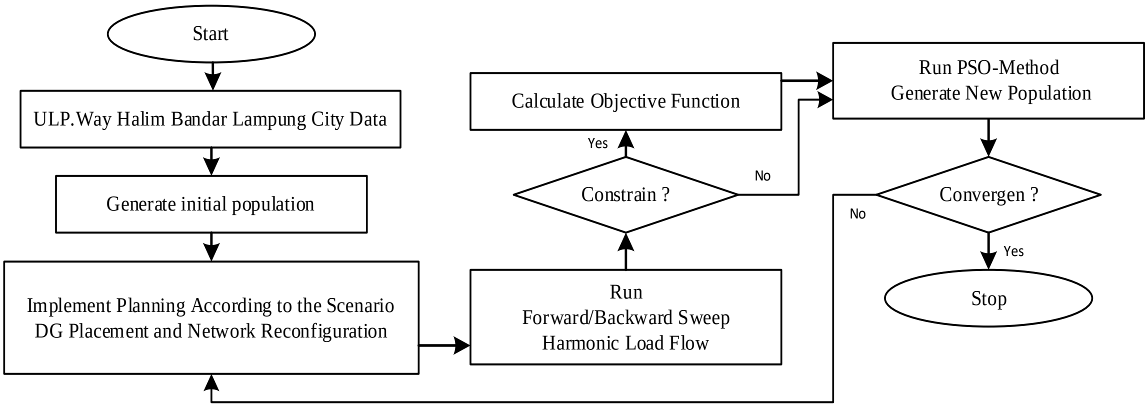

Figure 3. Flowchart of PSO method

The stages of the optimization process using the PSO method in all scenarios are line impedance data, load data, single line diagram from ULP. Way Halim Bandar Lampung City was entered which then the initial population from the PSO search was generated for the optimization process. The planning implementation of the proposed optimization technique in all scenarios is continuing by reanalyzing the harmonic distribution use the FBS and HLF methods. If the predetermined limits are met, then the stage is continuing with the search for PSOs and generating a new generation. if not, then the step is continuing by calculating or searching for the predetermined objective function and proceeding to the PSO search process then generating a new generation. If the system has converged, the process is complete. if the system has not converged, then return to the implementation stage of the optimization technique that has been proposed for all scenarios.

2.5. Integration of distributed generation in distribution system

The use of DG can improve the performance in the distribution system, such as a better voltage profile and reduced electrical power losses [40]. In this research, DG is modelled as a negative PQ load in Figure 4. In a radial distribution system, power flows from the source bus to the load bus. The direction of the load current flow is direct because the load can absorb both active and reactive power. However, if the generator or the power injection on distribution side, the flow direction is opposite to the load. The DG connection will be expressed as a negative load. The DG equation as a negative load can be expressed as (1).

$$P + jQ = (P_{Load} - P_{DG}) + j(Q_{Load} - Q_{DG}) \quad (1)$$

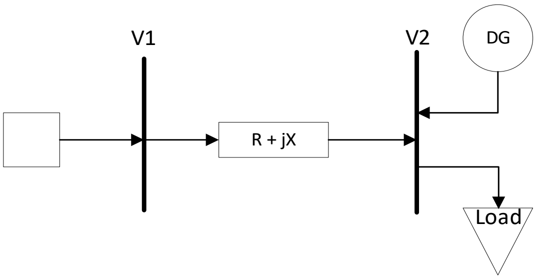

Figure 4. Illustration of DG integration in distribution system

2.6. Objective function

The multi objective function in the form of optimal value is minimum to be achieved in this research are:

– Minimum total active power losses ($\sum \quad P_{loss}$)

$$f(x)_1 = min \sum \quad P_{Loss} = \sum_{i=1}^{nb} \quad {P_{Loss_i}}^{(1)} + \sum_{i=1}^{nb} \quad \sum_{h=h_0}^{h_{max}} \quad {P_{Loss_i}}^{(h)} \quad (2)$$

– Minimum total harmonic distortion voltage ($\%THD_v$)

$$f(x)_2 = \%V_{THDv,i} = \frac{V_{d,i}}{V_{rms,i}} * 100\% \tag{3}$$

– Minimum voltage deviation (ΔV)

$$f(x)_3 = \Delta V = \left|\frac{V_i - V_1}{V_1}\right| \tag{4}$$

– The multi objective function is

$$f(x) = af(x)_1 + bf(x)_2 + cf(x)_3 \tag{5}$$

2.7. Constrain

The constraints must be met to make the optimization process more selective are:

– Bus voltage limit: the amount of voltage bus that must be kept within operating limit is

$$V_{min}(0.95\ pu) \leq V_{rms_i} \leq V_{max}(1.05\ pu) \tag{6}$$

– Total harmonic distortion limit: THD on each bus must be kept less than or equal to the level of harmonic distortion allowed on the system. THD value limits refer to IEEE std 95 standards 9 [41].

$$THD_i(\%) \leq THD_{max} \tag{7}$$

– The number and capacity of DG: determination of DG capacity the amount of active and reactive power injected must not exceed the need for active power on the load side. The active power supplied by DG is in a steady state without intermittent condition from the side of DG or the side of the load.

$$0\ kWatt \leq P_{DG} \leq 45\ kWatt \tag{8}$$

– Network topology: the network topology after the network reconfiguration optimization process remains in a radial condition.

2.8. Study case

To obtain effective result in the search for the objective function on the use of the proposed optimization techniques, several case scenarios were carried out, namely:

– Scenario 1. Initial condition
– Scenario 2. Network reconfiguration after injection of harmonic source on load bus.
– Scenario 3. Network reconfiguration after injection of harmonic source on load bus and integration of inverter-based DG.
– Scenario 4. Optimal DG placement after injection of harmonic source on load bus.
– Scenario 5. Optimal DG placement and network reconfiguration simultaneously after injection of harmonic source on load bus.

3. RESULTS AND DISCUSSION

The injection of a harmonic source from a nonlinear load and an inverter-based DG generates a harmonic spread lowering the power quality values tested on the ULP. Way Halim City of Bandar Lampung radial distribution system. The search result from the use of the Particle Swarm Optimization method on the optimization techniques proposed in several scenarios are given an effective solution in finding the multi objective function with the specified limits. The search results of optimization techniques are shown in Table 3, Figure 5, Figure 6, dan Figure 7.

Table 3 shown the comparison simulation results before and after optimization. In scenario 1, Increasing in the total value of active power losses after injection of harmonic loads in the form of VFD on several load buses is 19.89 kW or 32.33% and injection of harmonic source in the form of VFD and inverter-based DG on several load buses is 23.57 kW or 38.31%. In addition, decreasing in the value of the bus voltage level, increasing in the value of the voltage deviation bus and the occurrence of harmonic spread that exceeds the permissible standard with the value of %THDv >5% on several bus loads. In scenario 2 and scenario 3, it is shown the effect of network reconfiguration on the injection of harmonic sources from VFD and inverter-based DG. Efficiency of the system increases with a decrease in total active power losses to 67.69 kWatt or 79.52% in scenario 2 and 67.46 kWatt or 79.22% in scenario 3. In scenario 4, optimizing the placement of inverter-based DG using the PSO method at 24 load bus points with a total size of 658 kWatt, the result is an increase in system efficiency by reducing the total active power losses by 8.7 kW or 10.22%. However, there are some points where the load bus has a %THDv value that exceeds the allowable limit. Scenario 5 gives the most optimal results compared to other optimization scenarios. The placement of inverter-based DG at 25 load bus points with a total size of 555 kWatt with simultaneous network reconfiguration is able to increase system efficiency by reducing total active power losses by 69.34 kWatt or 81.46%, increasing bus voltage level, reducing voltage deviation value and decreasing the value of %THDv.

Table 3. The results before and after optimization

Parameter	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Tie Open	-	S1, S16, S25, S24, S10, S32, dan S49	S1, S16, S25, S24, S10, S32, dan S49	-	S1, S16, S25, S24, S10, S32, dan S49
Total Sizing DG (kWatt)	-	-	360	658	555
Total P_{Loss} (kWatt)	85.12	17.43	17.66	76.42	15.78
Total Q_{Loss} (kVAr)	378.76	81.15	86.51	341.48	73.71
Min Voltage (p.u)	0.98611	0.99557	0.99558	0.9866	0.99581
Max Voltage Deviation (p.u)	0.01389	0.00443	0.00442	0.01351	0.00419
THD max (%)	5.82272	1.87319	1.60967	5.44959	1.72048

The comparison of voltage level bus before and after optimization shown in Figure 5 improved by increasing the average voltage level bus. Increasing the average of voltage level bus by 0.33% for scenario 2, 0.34% for scenario 3, 0.009% for scenario 4 and 0.34% for scenario 5. Network reconfiguration technique provides optimal results from the proposed optimization technique in improving power quality in suppressing harmonic distortion. It can be seen from increasing the efficiency in reducing the amount of active and reactive power losses and increasing in voltage levels on each bus in scenarios 2, 3 and 5.

The comparison of %THDv values before and after optimization shown in Figure 6 improved by decreasing the average %THDv value according to one of the objective functions of the proposed optimization technique. Decreasing the average value of %THDv by 83.31% for scenario 2, 84.61% for scenario 3, 4.08% for scenario 4 and 84.42% for scenario 5. The optimization results in scenario 4 in the form of inverter-based DG placement and size do not show maximum results. Even though there was a decrease in the value of $\%THDv$ on all buses, there were still some buses that had $\%THDv$ values outside the allowed limits. This is also because the inverter-based DG is placed to supply a harmonic source which can increase the harmonic distortion value in the system. The comparison of voltage deviation bus before and after optimization shown in Figure 7 improved by decreasing the average voltage deviation bus according to one of the objective functions of the proposed optimization technique. Decreasing the average voltage deviation bus by 79.69% for scenario 2, 79.92% for scenario 3, 2.15% for scenario 4 and 80.34% for scenario 5.

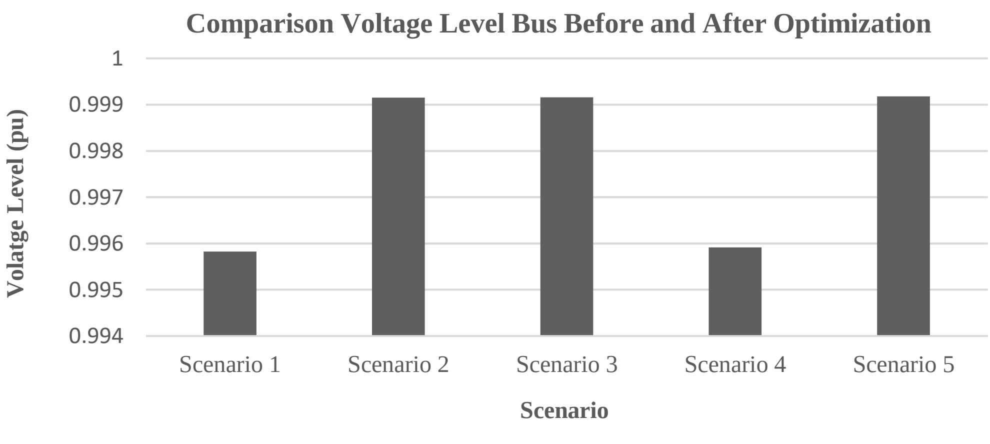

Figure 5. Comparison voltage level bus before and after optimization in each scenario

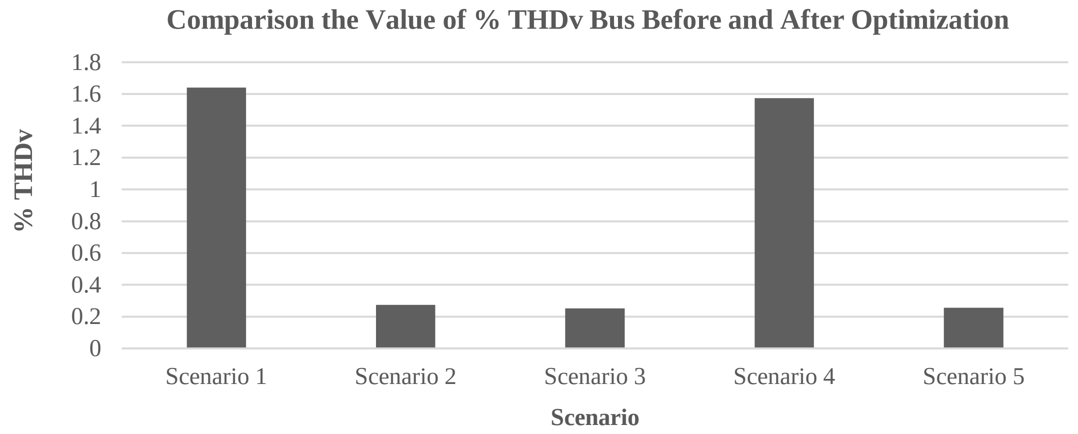

Figure 6. Comparison the value of %THDv before and after optimization in each scenario

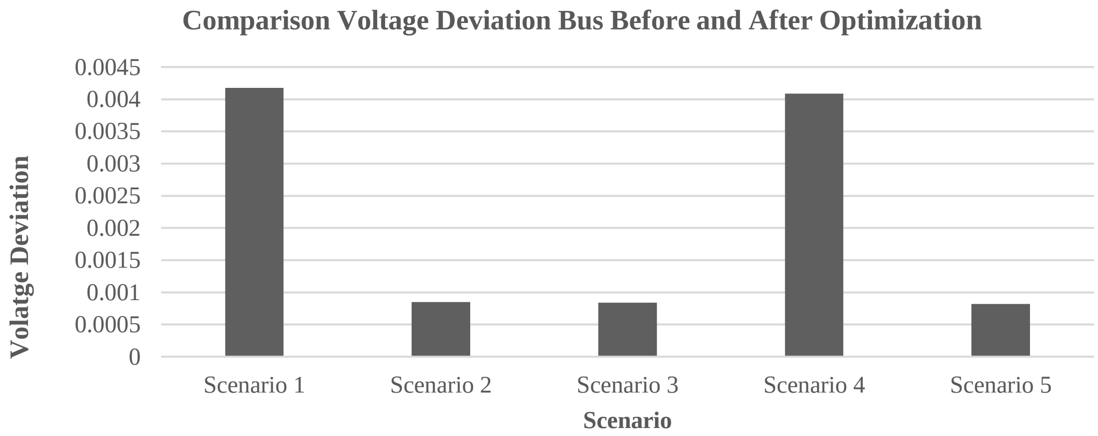

Figure 7. Comparison voltage deviation bus before and after optimization in each scenario

4. CONCLUSION

The source of harmonics from nonlinear loads is injected into the load bus and the placement of inverter-based DG is not optimal in 4 ULP feeders. Way Halim Bandar Lampung City generates harmonics, increases the THD value, losses, lowers the voltage profile and increases the voltage deviation. The use of particle swarm optimization method is able to provide optimal solutions in determining the location and capacity of DG and network reconfiguration which has been tested in several scenarios. There is a decrease in power loss of 81.17% or 273.12 kW, improve the voltage level of each bus, reduce the value of %THDv and voltage deviation by activating all tie switches in network reconfiguration techniques and placing DG in 22 locations with a total size of 496.94 kW on scenario 5 shows better result than other scenarios in finding the objective function with a predetermined limit. It is necessary to develop the use of forward backward sweep and harmonic load flow methods to analyze the distribution of harmonics in a radial distribution system so that it can be used in a closed (loop/mesh) distribution system. Further research will add consideration of other technical aspects of short circuit, protection coordination, the effect of changes in the shape of electric power flow, and islanding phenomena in finding the objective function of using the proposed optimization technique.

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