Optimal inverter-based distributed generation in ULP Way Halim considering harmonic distortion

Sofyan[1], Muhira Dzar Faraby[1], Satriani Said Akhmad[1], Ahmad Gaffar[1], Andi Fitriati[2], Yoan Elviralita[2], Akhyar Muchtar[3]
[1]Department of Electrical Engineering, Politeknik Negeri Ujung Pandang, Makassar, Indonesia
[2]Department of Mechatronic Engineering, Politeknik Bosowa, Makassar, Indonesia
[3]Department Education of Electrical Engineering, Universitas Negeri Makassar, Makassar, Indonesia

Article Info

Article history:

Received Jun 19, 2023
Revised Jul 12, 2023
Accepted Jul 17, 2023

Keywords:

%THDv
Harmonic distortion
Inverter-based distributed generation
Losses
Multi objective particle swarm optimization

ABSTRACT

Integration of distributed generation (DG) based on the use of new renewable energy is considered to be able to increase the capability of the electric power distribution system. However, the use of inverter-based DG is not optimal, it can worsen the condition of the system, especially in terms of the spread of harmonic distortion which can damage the equipment. This is due to the inverter-based DG technology, apart from supplying electrical energy, DG also injects harmonic currents from existing semiconductor components. This research discusses optimization placement of inverter-based DG using the multi objective particle swarm optimization (MOPSO) method which was tested on the *Unit Layanan Pelaksana* (ULP) Way Halim 88-bus radial distribution system based on MALTAB 2020b to increase the efficiency of the electrical system by reducing losses and %THDv. The inverter-based DG placed on 24 bus points with a capacity of 690 kW can reduce losses by up to 12.74 kW or 14.96% and all %THDv values for each bus are below 5%.

Corresponding Author:

Sofyan
Department of Electrical Engineering, Politeknik Negeri Ujung Pandang
Perintis Kemerdekaan street, Km. 10, Makassar-90245, Indonesia
Email: sofyantato@poliupg.ac.id

NOMENCLATURE

THDv	=	Total harmonic distortion voltage	h_{max} h_0	=	The harmonic max and min orders
$[V_0]$	=	The initial vector of voltage bus	$V_{d,i}$	=	Voltage on fundamental frequency
I_i^{k+1}	=	The bus current 1 in iteration k+1	$V_{THD,i}$	=	Total harmonic distortion current
ε	=	The tolerance specified	V_1	=	Slack bus voltage
P_{Loss}	=	Total losses of active power	V_i	=	Voltage bus on each bus
${P_{Loss_i}}^{(1)}$	=	Fundamental losses of active power	V_{min} V_{max}	=	The standard min and max voltage bus
h	=	Orde of harmonic	V_{rms_i}	=	The rms voltage in bus i
$[V^{(h)}]$	=	The voltage of harmonic	P_{DG} P_{Load}	=	Active power of DG and load
${P_{Loss_i}}^{(h)}$	=	Active power losses harmonic	Q_{DG} Q_{Load}	=	Reactive power of DG and load
V_{rms_i}	=	Total rms voltage			

1. INTRODUCTION

Distributed energy resources (DER) and load of electricity are growing rapidly in response to concerns about sustainability of electricity and the growing energy demand in electrical systems. However, since a large quantity of power electronic devices are used to realize power conversion, harmonic distortion in power distribution systems becomes a serious problem [1], [2]. Electric energy consumption is increasing due to the development of life support technology and population growth [3]. The limited availability of conventional primary energy in the form of fossil energy used to generate electrical energy has been predicted to run out. This makes researchers and engineers switch to utilizing the availability of primary energy which is very abundant in nature which is non-conventional in nature such as water, air, geothermal, sunlight and others [4], [5]. The advantage of this energy is that it is very friendly to the environment and the operational costs of converting it into electrical energy are very economical [6]–[9].

The use of renewable energy generation into the grid system, known as distributed generation (DG), is currently developing very rapidly [10], [11]. A challenge in the process of integrating power distribution systems with renewable energy power generation is power quality (PQ) issues. It can lead to voltage fluctuations and harmonic distortions caused by nonlinear loads in the power electronic devices of renewable energy power plants [12]–[14]. This is also exacerbated by nonlinear loads by necessity of customers, both industrial and household, so that the effect of spreading harmonic distortion in a distribution electricity system is wider. The effect of harmonic distortion is caused by an odd order in the form of acceleration of the aging process of the insulating material, an increase in the temperature of the equipment until the equipment is damaged [15]–[17]. To analyze the magnitude and spreading effect of harmonic distortion due to the presence of nonlinear loads, a combination of forward backward sweep method (FBS) and harmonic load flow method (HLF) methods can be used [18]–[20]. The FBS method is used to obtain bus voltage values, currents for each channel and total losses at the basic frequency conditions. Furthermore, the HLF method is used to obtain the value of current distortion, voltage distortion and power losses in each order of harmonics [21], [22].

In Indonesia, the type of distribution system is a radial type with passive conditions. This is because the energy source comes from just one point. this makes the system less reliable [23]. Distribution system type transformation from passive to active type by integrating distributed power plant types called DG [24], [25]. However, the presence of DG that is not optimal can make the system worse due to the level of penetration of the power supplied to the system [26], [27]. It can cause improved power losses, decreased PQ, and stability problems in the radial distribution system (RDS) [28]. However, if the DG based inverter is not placed optimally, it can increase the spread of harmonic distortion due to harmonic sources originating from the inverter [29].

Power distribution systems must control good PQ in the system while maintaining complex requirements as the existing load increases. In addition, the use of devices from semiconductor and switching processes is rapidly increasing due to their high efficiency, easy control and operation [30]. In carrying out a plan, the objective function to be achieved with the specified constraints makes optimization problems can be solved effectively and efficiently. The use of artificial intelligence-based optimization methods has been widely used and is growing rapidly in solving complex and combinatoric optimization problems with faster computation time [31], [32]. Optimizing the placement and size of the DG on the IEEE 14-bus RDS [33] and IEEE 18-bus RDS [34] using the genetic algorithm (GA) method can remain network protection scheme without changes, also harmonic distortions stay in allowable limitation [35]. The number of DG locations and sizes optimized using particle swarm optimization (PSO) [10], [36]–[38], fireflies algorithm (FA) and simulated annealing (SA) affect the spread of harmonic distortion to be better tested on IEEE 33-bus RDS [39]. DG placement is able to provide increased efficiency to PQ using ant colony optimization (ACO) [40].

This study tries to examine and discuss the effect of the placement of the size and location of DG based on an optimized inverter considering the injection of harmonic currents from nonlinear loads using multi objective particle swarm optimization (MOPSO). Minimizing total losses and the value of %THDv becomes a multi objective function in determining the location and size of the DG based inverter with specified limits. Implementing service unit or *Unit Layanan Pelaksana* (ULP) Way Halim or executive unit service way Halim 88-bus RDS electrical system is used to determine the effectiveness of the proposed method of increasing PQ in reducing the spread of harmonic distortion. This paper is organized as follow: section 2 is method that is divided into four parts: first is n modelling ULP Way Halim distribution system and study case, second is objective function and constrain, third is optimal using MOPSO and fourth integrating DG into distribution system. In section 3 presents the simulations result. Last section 4 is conclusion.

2. METHOD

2.1. Modelling ULP Way Halim and study case

The ULP Way Halim 88-bus RDS electrical system is located in Bandar Lampung City. Figure 1 shows a map of the location of the system. At ULP Way Halim 88-bus RDS, there are 4 feeders supported by 2 substations. The Rolex feeder (purple), The Bulova feeder (blue) and The Bonia feeder (green) are provided by Sukarame Substation and the Bronze feeder (brown) is provided by Sutami Substation.

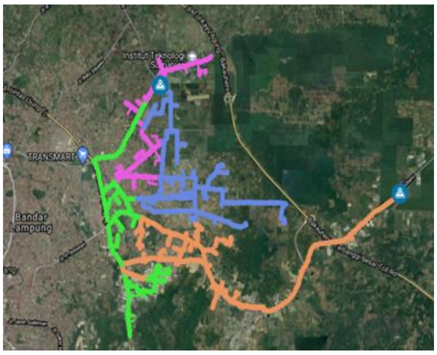

Figure 1. Maps of ULP Way Halim 88-bus RDS [41]

The ULP Way Halim 88-bus RDS with 4 feeders have an electrical power requirement of 17.4 MWatt+j10.783 MVAr. Due to the distributed and complex properties of the feeders in this system, modeling is required to determine the dimensionality of the search space when performing simulations. In central load modeling, irregularly distributed loads can be viewed as scattered mass points. Spatial spread of load locations and irregularities in load capacity are not considered in load modeling [42]. Centralization of all loads modeling aims to simplify multi-node systems. Centralization of all loads modeling facilitates problem solving in distribution systems [43]. Single line diagram of ULP Way Halim 88-bus RDS can be seen in Figure 2.

Several case scenarios were performed to obtain effective results when searching for the objective function using the proposed optimization technique: i) normal condition after injection harmonic load from variable speed drive (VFD) (S-1), ii) placement DG based inverter in (S-1) without optimization (S-2), and iii) optimal placement DG based inverter in (S-1) using MOPSO (S-3). Table 1 shows the types and values of harmonic sources based on references [44], [45] which will be implemented on the ULP Way Halim 88-bus RDS, namely VSD and inverter-based DG.

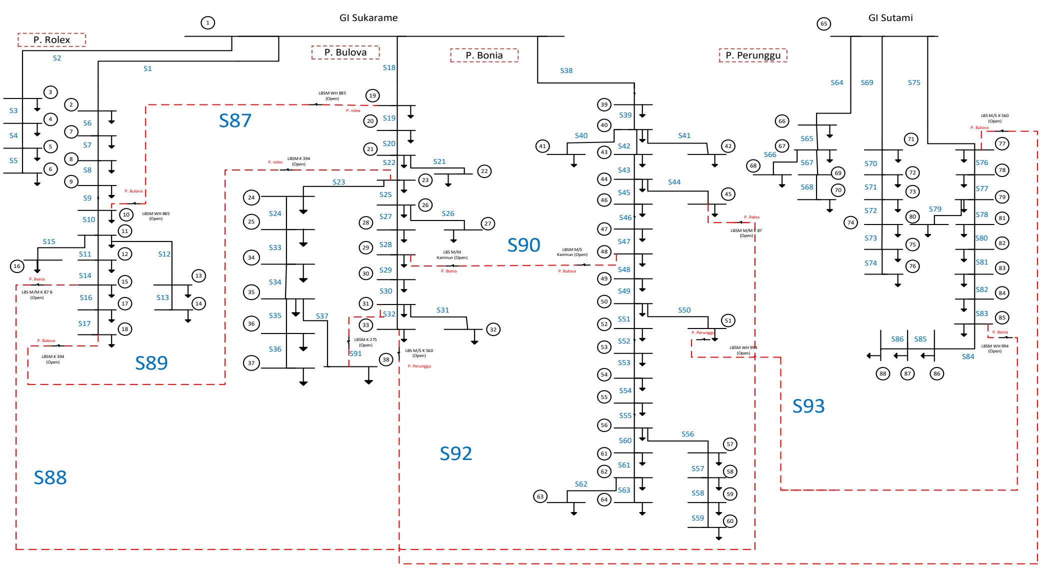

Figure 2. Single line diagram of ULP Way Halim 88-bus RDS

On load buses 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 will be injected with VFD on (S-1) and on bus loads 3, 8, 23, 25, 38, 43, 68 and 77 with a capacity of 45 kW will be injected with inverter based DG with the aim of generating the spread of harmonic distortion in the ULP Way Halim 88-bus RDS.

Table 1. The harmonic sources value

Harmonic load types Orde	VFD	Inverter-based DG
5th	98∠140º	15.00∠0º
7th	39.86∠113º	10.00∠0º
11th	18.95∠-158º	5.00∠0º
13th	8.79∠-178º	3.00∠0º
17th	2.5∠-94º	0.00∠0º

2.2. Objective function and constrain

Multi-objective functions in the form of optimal values are the bare minimum achieved in this study is:

- Minimum total losses (min $\sum P_{loss}$)

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

- Minimum %THD_v

$$f(x)_2 = \min \%V_{THDv} = \frac{V_{d,i}}{V_{rms,i}} * 100\% \tag{2}$$

The multi objective function is

$$f(x) = af(x)_1 + bf(x)_2 \tag{3}$$

Boundary conditions must be satisfied to make the optimization process more selective.

- Bus voltage limit

  The value of bus voltage that must be maintained within operating limits is

$$V_{min}(0.95\ pu) \leq\ V_{rms_i} \leq\ V_{max}(1.05\ pu) \tag{4}$$

- Total harmonic distortion limit (THD)

  The THD of all load bus should be less than the harmonic distortion level allowed by the system. THD value limits refer to IEEE std 95 standards 9 [40].

$$THD_i(\%) \leq THD_{max} \tag{5}$$

- The number and value of DG

  The injection value by DG must not exceed the active power requirement at the load bus.

$$P_{,minDG} \leq P_{DG} \leq P_{maxDG} \tag{6}$$

2.3. Optimal with PSO

The steps for using the MOPSO algorithm are [46], [47]:

- Starting with initiating a new population of particles with random location and velocity in a search of dimension area.
- Evaluate fitness function value in the variable d for all particle.
- Comparing the fitness function value of particle with P_{best}. If the value of existing is better than P_{best}, $P_{best} =\ P_i$.
- Identify the particle that give the best result than update the velocity and location of the all particles.
- The searching for the fitness function values will ends when the best value is reached in the maximum number of iterations.

The value of, a=1, b=1, *population*=100, *liter*=100, c_1=1 and c_2=1 is used in parameter of MOPSO. In this study, the value of a and b is set equivalent in getting all objective function on the constrain determined. Figure 3 shows the flow of the optimization process with the MOPSO method. By considering the harmonic injection value given by the penetration of the active power of the DG which is placed through the optimization stages using MOPSO in finding the objective function with predetermined constraints.

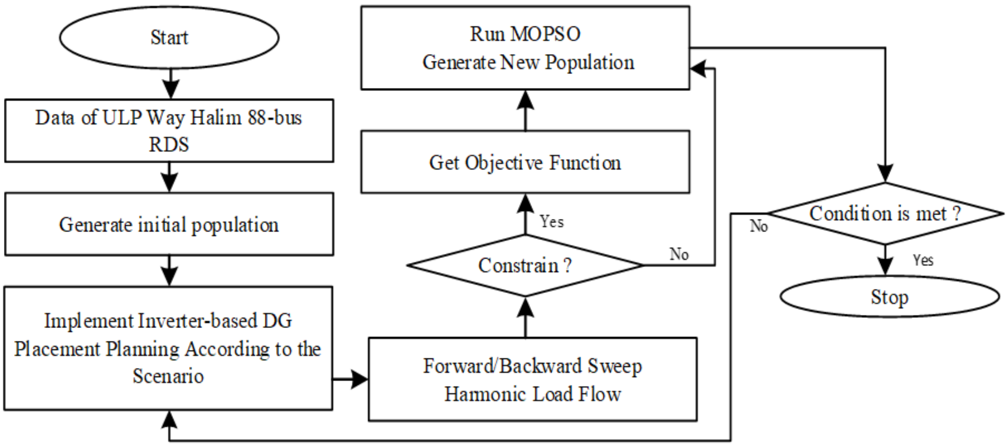

Figure 3. Flowchart step of MOPSO method optimization

2.4. Integrating DG into RDS

The utilize of DG can bring a better condition in the RDS, such as a improve profile of voltage bus and losses are lowered [48]. In this study, PQ is negative for DG integration modeling in the system which can be illustrated in Figure 4. In RDS, the electrical energy flows from the slack bus to the all of load bus. Since the load can absorb real power, flow direction of load current is direct. But, if the DG or power sources injection is on the distribution system, the direction of flow will be foreign to the load. A connection of DG is represented as a negative value in load bus. The equation of DG can be written as in (7).

$$P = (P_{Load} - P_{DG}) \quad (7)$$

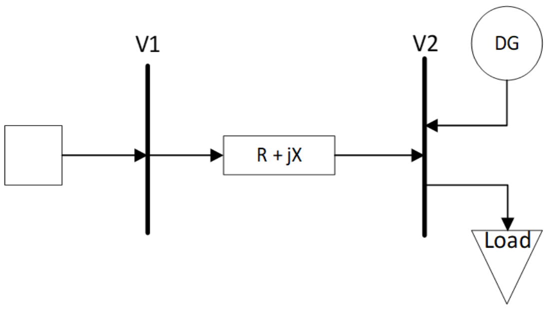

Figure 4. DG Integration to distribution system

3. RESULTS

The harmonic currents injection originating from a nonlinear VFD load at several load bus points in scenario 1 (S-1) generates the spread of harmonic distortion which makes the system performance in maintaining PQ worse. this can be seen by the presence of several load buses that have %THDv values >5%. In scenario 2 (S-2), the placement of several inverter-based DG as many as 8 points with a capacity of 45 kW each shows a worsening effect on PQ performance. In scenario 3 (S-3), placement of an inverter-based DG using the MOPSO method provides an increase in PQ performance. The simulation results for each scenario in Table 2, Figures 5 and 6.

Table 2 shows a comparison of several parameters from all existing scenarios on changes in PQ performance on the ULP Way Halim 88-bus RDS. In S-1, harmonic current injection due to the use of a nonlinear load in the form of a VFD makes PQ decrease. This can be seen by the presence of several buses that have a value of %THDv >5% and a total loss value of 85.12 kW. In S-2, the addition of a random inverter-based DG placement with a total capacity of 360 kW can reduce losses by up to 2.54 kW or 2.98%. In S-3, optimizing the placement and size of the inverter-based DG with a total capacity of 630 kW using MOPSO was able to reduce losses by up to 12.74 kW or 14.96%. The location and size of the inverter-based DG were optimized using MOPSO can be seen in Table 3. The existence of an active power supply from the DG placement can increase efficiency by reducing total losses in the ULP Way Halim 88-bus RDS.

Table 2. The results of simulation for all scenario

Parameter	Scenario 1	Scenario 2	Scenario 3
Total sizing DG (kW)	-	360	690
Total P_{Loss} (kW)	85.12	82.58	72.38
Total Q_{Loss} (kVAr)	378.76	360.16	288.74
Min voltage (p.u)	0.98611	0.9845	0.98599
THD max (%)	5.3313	5.4992	4.5109

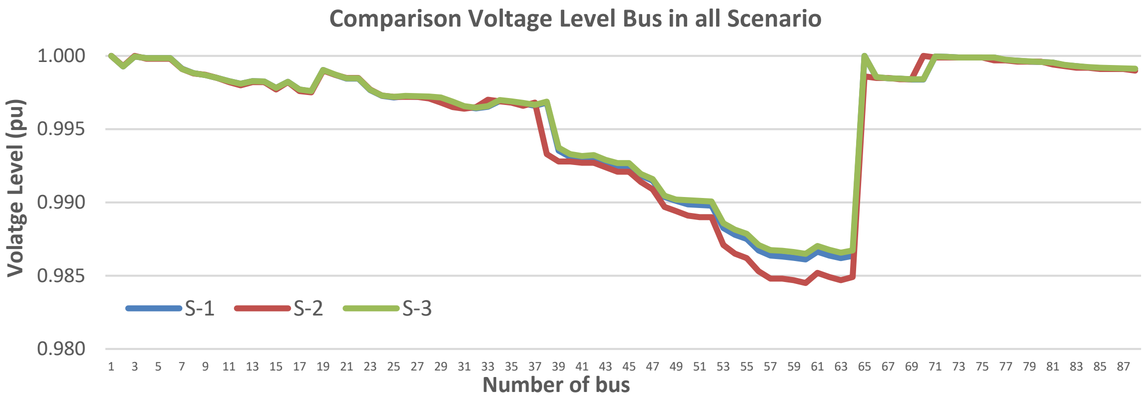

Figure 5. Value of voltage level bus in all scenario

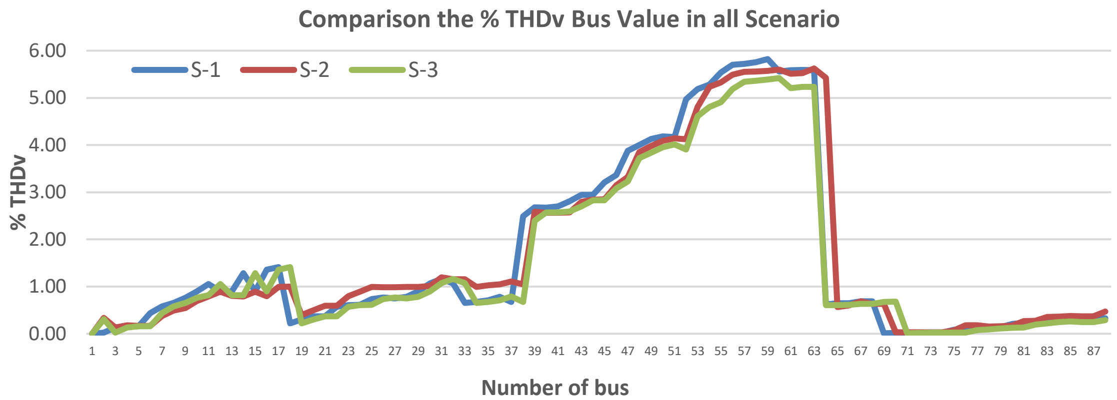

Figure 6. Value of %THDv all scenario

Table 3. Optimization result of placement inverter-based DG

Sizing of DG	Location
10 kW	28, 30, 33, 41, 44, 61, 69, 71, 75, 78 and 88
40 kW	55
45 kW	23, 25, 34, 48, 49, 51, 57, 59, 62, 63 and 87

Figure 5 shows a comparison of the bus voltage level values at the ULP Way Halim 88-bus RDS. Changes in the value of the voltage level varies on S-2. The average decrease in the value of the voltage level is up to 0.034%. This is also seen by the increase and decrease in the value of the voltage level at several buses. In contrast to S-3, there was an enhancement in the value of the voltage level across all buses with an average of 0.009%.

Different changes compared to the decrease in the value of losses in S-2, the %THDv value increases in all ULP Way Halim 88-bus RDS buses with an average of 1.24%. this is because the injection of harmonic currents from the inverter-based DG which is placed makes the spread of harmonic distortion increase and worsens PQ has been seen in Figure 6. However, in S-3, the placement of an inverter-based DG optimized with MOPSO was able to reduce the %THDv value by an average of 7.74%.

The spread of harmonics occurring in a RDS is strongly influenced by the location and type of nonlinear load placed on the system as shown in S-1. Primary energy in the form of sunlight which is converted to generate electrical energy in inverter-based DG is growing rapidly. However, the location and size of inverter-based DG should not be placed casually. This is because the inverter-based DG also contributes harmonic currents which can increase the value of the spread of harmonics as seen in S-2. The positive impact in increasing the PQ of the location and size of the inverter-based DG will be optimal if the planning is carried out using an AI-based optimization method that has a predetermined objective function and constraints as shown in S-3.

4. CONCLUSION

The harmonic current injection originating from nonlinear loads in the form of VFD is able to exacerbate PQ due to the spread of harmonics on the ULP Way Halim 88-bus RDS. Placement of inverter-based DG that is not optimal can reduce total losses but increase the spread of harmonic distortion. The use of MOPSO with the objective function of minimizing total losses and %THDv with specified limits is able to determine the location and size of the inverter-based DG by considering the injection of harmonic currents originating from the DG type. Placement of 24 inverter-based DG points with a total capacity of 690 kW is able to reduce the total losses by 12.74 kW or 14.96%, reduce %THDv by an average of 7.74% to the allowable limit (%THDv<5%) and increase all level values bus voltage with an average increase of 0.009%. Subsequent research will examine the optimization of the combination of inverter-based DG and harmonic filters in industrial electrical systems that use inductive loads optimized with artificial intelligence-based methods.

ACKNOWLEDGEMENTS

This research is supported financially from the Innovation Research Program for Advanced Indonesia III (RIIM 3-BRIN) and LPDP Indonesia.

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BIOGRAPHIES OF AUTHORS

Sofyan finished the S.T. and M.T. degree in 2002 and 2010 from Department of Electrical Engineering, Hasanuddin University (UNHAS), Indonesia. Now he is a student in Doctoral Program Department of Electrical Engineering, UTM, Malaysia. Currently he is a lecturer in Department of Electrical Engineering Polytechnic State of Ujung Pandang (PNUP), Indonesia. His research interests are operation and optimization in power system, demand energy in smart grid system and renewable energy technology. He can be contacted at email: Sofyantato@poliupg.ac.id.

Muhira Dzar Faraby finished the S.T. and M.T. degree in 2012 and 2014 from Department of Electrical Engineering UNHAS, Indonesia and the Dr degree in 2021 from Department of Electrical Engineering, ITS Surabaya, Indonesia. Currently he is a lecturer in Department of Electrical Engineering, PNUP, Indonesia. His research interests are PQ, optimization of power system, and stability of power systems. He can be contacted at email: muhiradzarfaraby@poliupg.ac.id.

Satriani Said Akhmad finished the Ir. And M.T. degree in 1992 and 2005 from Department of Electrical Engineering UNHAS, Indonesia and the Dr degree in 2019 from Department of Civil Engineering, UNHAS, Indonesia. Now, she is a lecturer in Department of Electrical Engineering, PNUP, Makassar, Indonesia. Her research interests are power system simulation, smartgrid, power system optimization, and market of power quality. She can be contacted at email: Satriani_said@poliupg.ac.id.

Ahmad Gaffar finished the Ir. and M.T. degree in 1986 and 2002 from Department of Electrical Engineering, UNHAS, Indonesia. Now, he is a lecturer in Department Electrical Engineering, PNUP, Indonesia. His research interests are power distribution system, control of electric machine and power electronic devices. He can be contacted at email: ahmadgaffar@poliupg.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 is a lecturer of Mechatronic Engineering, Polytechnic of Bosowa (POLIBOS), Indonesia. Her research interests are optimization process using artificial intelligence, big data, and digital system. She can be contacted at email: andi.fitriati@bosowa.co.id.

Yoan Elviralita finished the S.ST degree in 2004 from the Department of Information Technology Polytechnic Electronic State of Surabaya and the M.T degree in 2012 from Department of Industrial Control, Indonesia University, Indonesia. Currently, she is a lecturer of Mechatronic Engineering, POLIBOS, Indonesia. Her research interests are pneumatic hidrotic control, big data, machine learning, and programming logic controller system. She can be contacted at email: yoan.elviralita@politeknikbosowa.ac.id.

Akhyar Muchtar finished S.Pd. degree in 2008 from Department of Electrical Engineering Education, University State of Makassar (UNM), Indonesia, the M.T. degree in 2012 from Department of Electrical Engineering, UNHAS. Currently, he is a lecturer in Department of Electrical Engineering Education, UNM, Indonesia. His research interests are renewable energy technology, power system control and optimization. He can be contacted at email: akhyarmuctar@unm.ac.id.