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Harmonic Mitigation in Microgrids to Improve Power Quality

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Abstract— **Microgrids are a technology that is developing quite rapidly and is attracting world attention in facing the energy and pollution crisis. There are three types of microgrid structures: AC, DC, and AC-DC hybrid microgrid. Because it consists of an AC bus and a DC bus, AC-DC hybrid microgrids can connect more types of Distributed Generation (DG) and have smaller converter losses, making it more economical and reliable than other types of microgrids. Due to the use of nonlinear devices, harmonic distortion in microgrids is a problem that needs to be solved. In this research, the AC-DC hybrid microgrid system is simulated using ETAP software. Then the characteristics of the distribution of harmonics in the system obtained from harmonic load flow simulations are also analyzed. Following the installation of the passive filter, Bus 1 and Bus 2 now suitable to the IEEE Std standards 519-1992 for harmonic values. After the application of the filter, Bus 1 refer a THD of 1.32%, while Bus 2 indicate a THD of 0.84%. In addition, the Individual Harmonic Distortion (IHD) for Bus 1 has dropped below 3% at the 5th harmonic and below 1.5% at the 13th harmonic. Besides that, Bus 2 IHD has decreased to less than 3% at the 11th harmonic and less than 1.5% at the 13th harmonic.**

***Keywords—Distortion, Harmonics, Microgrids, Passive Filter*.**

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I. Introduction

Saat ini sistem fotovoltaik memainkan peran penting dalam pembangkit listrik dibandingkan dengan sistem tradisional yang berdiri sendiri [1]. Denmark tercatat sebagai negara yang paling banyak menggunakan sistem PV dan teknologi angin [2]. Berdasarkan data Ember Climate, porsi listrik dari PLTB dan PLTS di Denmark mencapai 51,9% dari total listrik yang dihasilkan di negara tersebut pada 2021. Di posisi selanjutnya ada Uruguay dengan porsi PLTB dan PLTS sebesar 46,7%, diikuti Luksemburg 43,4%, Lithuania 36,9%, dan Spanyol 32,9%. Secara global, pembangkit listrik tenaga angin dan surya menghasilkan 10,3% pasokan listrik dunia pada tahun 2021 dan angka ini meningkat dari 9,3% pada tahun 2020 [3]. Sementara pemanfaatan energi surya di indonesia saat ini baru sekitar 150 MW atau 0,08% dari potensinya [4].

PV technology also plays a key role in the shift towards green growth, a low-carbon economy, and a greater share of renewable energy in the energy mix [5]. This creates new challenges in the management and operation of power systems due to the intermittentness and variability of PV power plants [6],[7]. This variability mandates that grid impact studies must be conducted and requires a comprehensive analysis prior to PV integration into the utility grid [8].

Successful integration and penetration of PV systems into the electricity grid requires accurate modeling [9], and the power conditioning system needs to be well understood to design and assess system performance [10]. Assessment failure in PV systems can cause grid instability thereby compromising power system reliability, security of supply and power quality of the utility grid [11]. There are several factors that influence the level of efficiency and performance of PV systems [12]. Apart from environmental temperature conditions and fluctuations in solar radiation, the characteristics of PV systems can also cause serious problems related to the efficiency response and power quality of the system as a whole [13]. Low solar radiation has a significant impact on PV system output and system power quality [14].

In general, current and voltage harmonics produced by power plants can reduce power quality and reduce the reliability and safety of electrical equipment [15]. Harmonic currents can also cause interference in telecommunications systems, errors in measuring instruments and excessive heat in power breaker equipment. As a result, the power breaker can disconnect itself, the control system locks itself, and many other problems arise [16]. This research will focus on discussing the impact of PV system penetration on power flow and harmonics on power stability of the electricity network at the microgrid distribution level using ETAP 16.0 software.

II. Related Resarch

Several studies have been carried out regarding improving power quality in microgrid networks. In 2018, Lavanya and Kumar reviewed several strategies for making arrangements to improve power quality in microgrid networks.

By integrating small-scale distributed energy resources, microgrids are introduced as an alternative approach in generating electric power at distribution voltage levels. The use of power electronic devices provides the necessary flexibility, safety and reliability of operation between microsources and distribution systems. The existence of nonlinear and unbalanced loads in the distribution system causes power quality problems in microgrid systems. The author tries to explore and review various control strategies developed through several literatures to improve power quality in microgrids. Several comparisons of different control methods are presented with suggestions for further future research [17].

Farooqi and the researchers who are part of it explained the use of filters to mitigate power quality problems related to harmonics produced by equipment in distribution networks with a microgrid pattern. By using a Dynamic Voltage Restorer (DVR) is a device in a harmonic filter that is used to protect sensitive loads from power quality problems such as voltage sags, swelling, harmonics, or interference. It is very possible that the use of filters can mitigate power quality disturbances at the load terminals. Harmonics are a major power quality problem that pollutes distribution networks causing end user equipment to fail to operate due to disturbances in voltage, current or frequency. This research discusses DVR as one of the devices in a filter which is used as a proposed technique to reduce voltage sags and swells in distribution networks connected to energy storage systems and microgrid [18].

Then Doyran and the researchers who joined him discussed the optimal allocation of passive filters and a combination of inverter-based DG with optimal feeder reconfiguration to improve power quality in microgrids which are indicated to contain large harmonic content. In his research, a Multi Objective Problem (MOP) is proposed for the optimal allocation of inverter-based renewable Distributed Generations (DGs), namely Fuel Cell (FC) and Photovoltaic (PV) cells, passive filters by considering optimal Distribution Feeder Reconfiguration (DFR), in a Microgrid (MG). The multi-objective function is solved by the Multi-Objective Covariance Matrix Adaption-Evolution Strategy (MOCMA-ES) algorithm considering MG operator revenue (MGO), unbalanced bus voltage, greenhouse gas emissions as objective functions and Total Harmonic Distortion (THD) and profitability of the proposed model as a constraint. The best solution is selected using the Mean Ideal Distance (MID) index among the set of Pareto solutions achieved by the proposed algorithm. The performance of the proposed method is assessed on a 33-bus MG, with three electrical load levels. The simulation results illustrate the efficiency of the proposed optimization method, and the improvement of power quality [19].

A. Solar Power Plant

Solar power plant is a plant that converts photon energy from the sun into electrical energy [20]. Solar power plant utilizes sunlight to produce DC (Direct Current) electricity and can be converted into AC (Alternating Current) electricity if needed [21]. Poly Cristallyne Sillicon is a semiconductor material commonly used in photovoltaic panels and its principle is the same as the p-n diode principle [22]. An illustration of the working principle of photovoltaics can be seen in Figure 1.

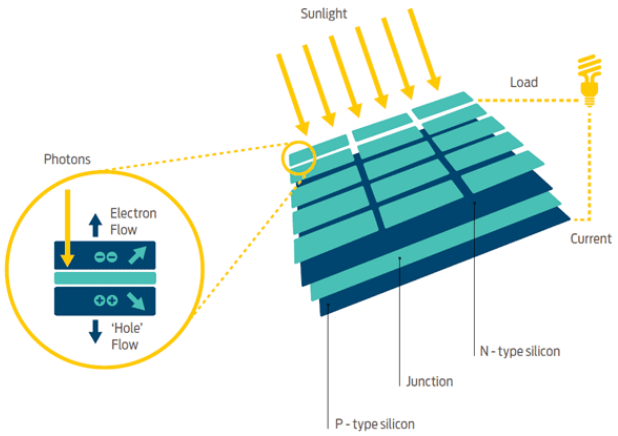

Figure 1. Working Principle of Solar Cells [22]

From the connection character, a photovoltaic solar power plant that produces electricity in the form of direct current (DC) electricity is connected via power electronics [23] as illustrated in Figure 2.

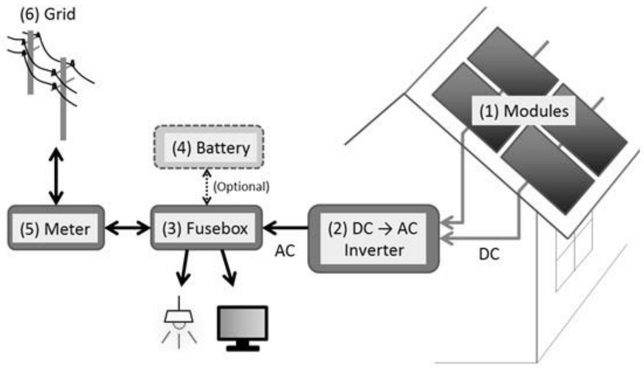

Figure 2. Direct current (DC) Power Plants are Connected to Alternating Voltage (AC) Electrical Networks via Power Electronic Devices [23]

B. Harmonics

Harmonics is the phenomenon of distortion in electrical network waves resulting from the operation of non-linear electrical loads [24]. The frequency of the distortion wave is formed at a multiple of the fundamental wave frequency value, where this wave will ride on the fundamental wave, resulting in the formation of a defective wave which is the sum of the fundamental wave and the distortion wave (harmonic wave) [25] as illustrated in Figure 4.

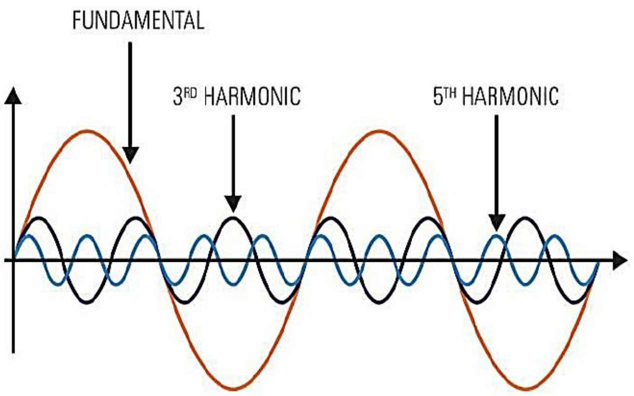

Figure 4. Fundamental Waves and Harmonic Waves

The ratio of the harmonic frequency to the fundamental frequency is the order of harmonics, expressed in the following equation.

$$H = \frac{fH}{f} \tag{1}$$

Harmonic parameters include:
Individual Harmonic Distortion (IHD).

$$IHD_i = \sqrt{\frac{Ish^2}{{I_1}^2}} \tag{2}$$

$$IHD_v = \sqrt{\frac{Vsh^2}{{V_1}^2}} \tag{3}$$

Total Harmonic Distortion (THD).

$$THD_i = \sqrt{\frac{\sum_{h>1}^{hmax} {I_h}^2}{I_1}} \times 100\% \tag{4}$$

$$THD_v = \sqrt{\frac{\sum_{h>1}^{hmax} {I_h}^2}{V_1}} \times 100\% \tag{5}$$

Root Mean Square

$$I_{rms} = \sqrt{\sum_{h>1}^{hmax} {I_h}^2} \tag{6}$$

$$I_{rms} = \sqrt{\sum_{h>1}^{hmax} {V_h}^2} \tag{7}$$

C. Microgrids

Microgrids are an example of a distributed generation pattern [26]. According to the EU research projects, microgrids include small-scale distribution systems, consisting of distributed energy sources, including microturbines, fuel cells, PV and so on, with energy storage media (flywheels, energy capacitors and batteries) and flexible loads [27]. Microgrids are located at low voltage and can work in normal conditions (gridconnected) and emergency operating conditions (islanded), thereby increasing reliability. Apart from increasing reliability, microgrids are also environmentally friendly [28].

D. Passive Filter

Passive filters are composed of a combination of inductors, capacitors and resistors. The value of the inductor and capacitor is determined in such a way that inductive reactance and capacitive reactance resonance occurs at certain harmonic frequencies. In series circuit resonance, capacitive reactance and inductive reactance have the same value so they cancel each other out. The impedance of the RLC circuit becomes minimal. So that harmonic currents at this frequency flow through this filter circuit and do not flow into the system. Several types of passive filters include low pass filters, high pass filters, band pass filters and stop band filters. Apart from that, passive filters can also be designed to reduce certain order harmonics in the form of single-tuned filters.

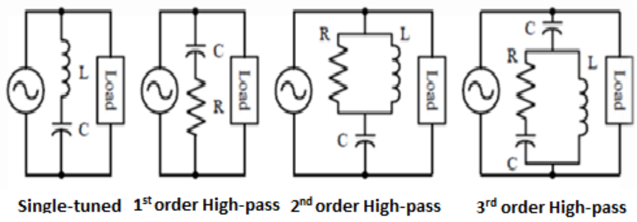

Figure 5. Types of Passive Filter

In designing a harmonic filter, apart from the values of capacitors, inductors and resistors, the Q factor also needs to be considered. The Q factor determines the sharpness of the harmonic damping area. The Q factor is defined as the ratio of inductive (or capacitive) reactance to resistance at the resonant frequency. Generally the Q factor is between 30 and 60.

III. Research Methodology

The type of research used in this research is quantitative research. The quantitative aspect of this research is determining how much voltage, current, active power and reactive power flows in the grid before and after penetration of the photovoltaic system. The method used to analyze these quantities is the Newton-Rhapson method which is integrated in the ETAP 16.0 program. In this research, a literature study was carried out by studying the theories and methods that will be used to achieve the research objectives [29]. Research data was obtained from the research object, namely the 20 kV distribution system. The data taken in this research is transformer data, load, single line diagram, and line length to the load. Furthermore, the single line microgrid diagram in Figure 6.

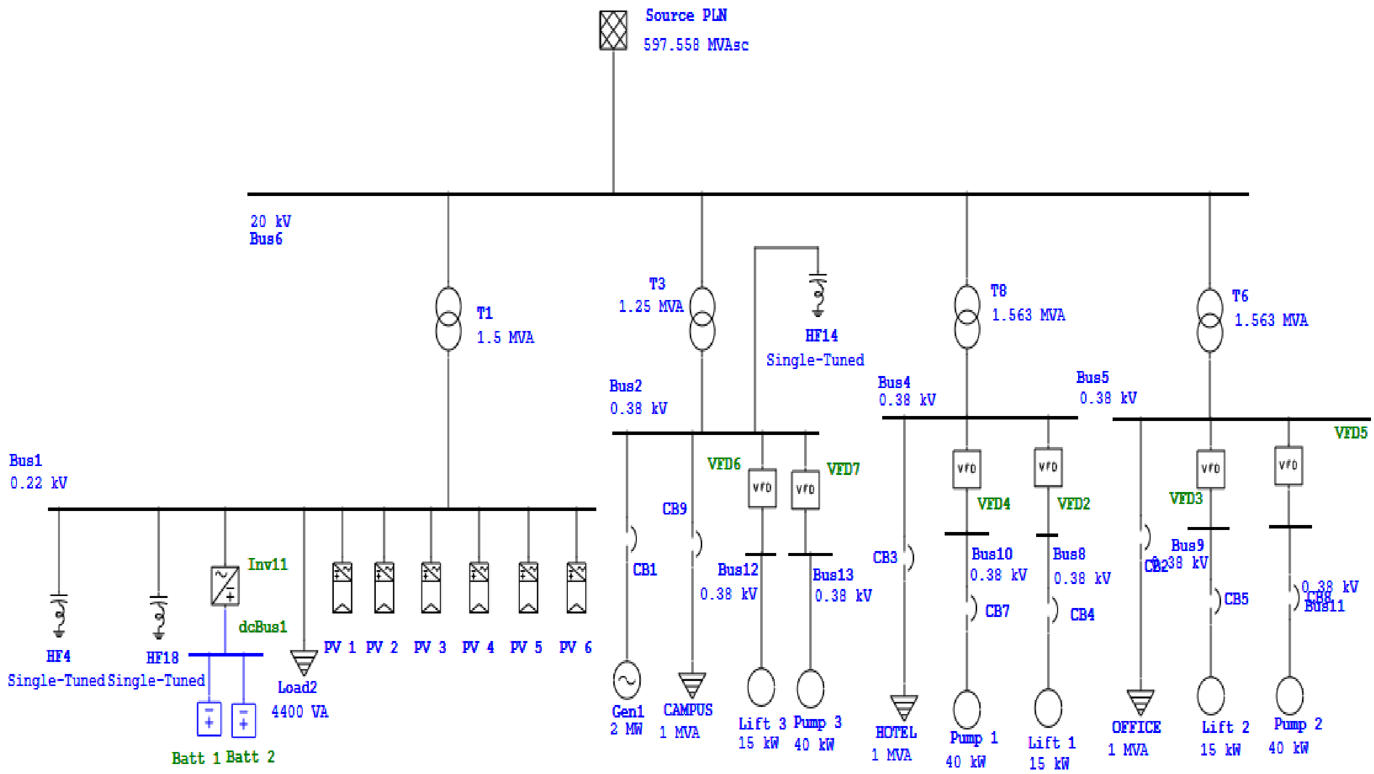

Figure 6. Single Line Diagram of Microgrid

A. Harmonic Flow Simulation

The AC-DC Hybrid Microgrid system from reference [30] which has been designed in ETAP 12.6.0 is simulated with harmonic load flow. From this simulation, IHD and THD values will be obtained from the voltage harmonics on each bus as well as current harmonic values. This data will be analyzed and used to design filters that suit system conditions.

B. Harmonic Filter Design

The type of harmonic filter designed in this final project is a single-tuned filter. A single-tuned filter is a passive filter consisting of an inductor, capacitor and resistor. Determining the value of these three components depends on the order of harmonics that will be suppressed and the amount of increase in power factor that will be achieved. Apart from that, the filter needs to be installed in an area close to the source of harmonics so that harmonic reduction is optimal. The following is a calculation of the capacitor, inductor and resistor values of a single-tuned filter to reduce nth order harmonics. The filter planning uses the single tuned type:

a. Determine the required reactive power compensation value.
b. Determines the initial tuning of the filter

$$Q = P \times (\tan \varphi\, initial - \tan \varphi\, target) \tag{8}$$

c. Determine the value of X_{eff} (capacitor reactance at fundamental frequency)

$$\mathrm{Xc} = \frac{\mathrm{VLL}^2}{\mathrm{Q}} \tag{9}$$

d. Determine the C value

$$X_L = X_C \tag{10}$$

$$\omega \,.\, \mathrm{L} = \frac{1}{\omega.\mathrm{C}} \tag{11}$$

e. Determining the L value

$$\mathrm{L} = \frac{1}{\omega^2.\mathrm{C}} \tag{12}$$

f. Determining the Q value (tuning quality factor).
For this filter, Q = 15 was chosen because this type of passive filter is single tuned, so Q = 15 was chosen.

g. Determine the R Value

$$\mathrm{R} = \frac{X_L}{\mathrm{Q}} \tag{13}$$

C. Load Data and DG Installation Scenarios

Determining the installation location of DG (PV integration) is used using the Voltage Stability Index method. This method is a method used to determine priority placement locations, by determining the lowest voltage performance index value of each bus as the priority location [31].

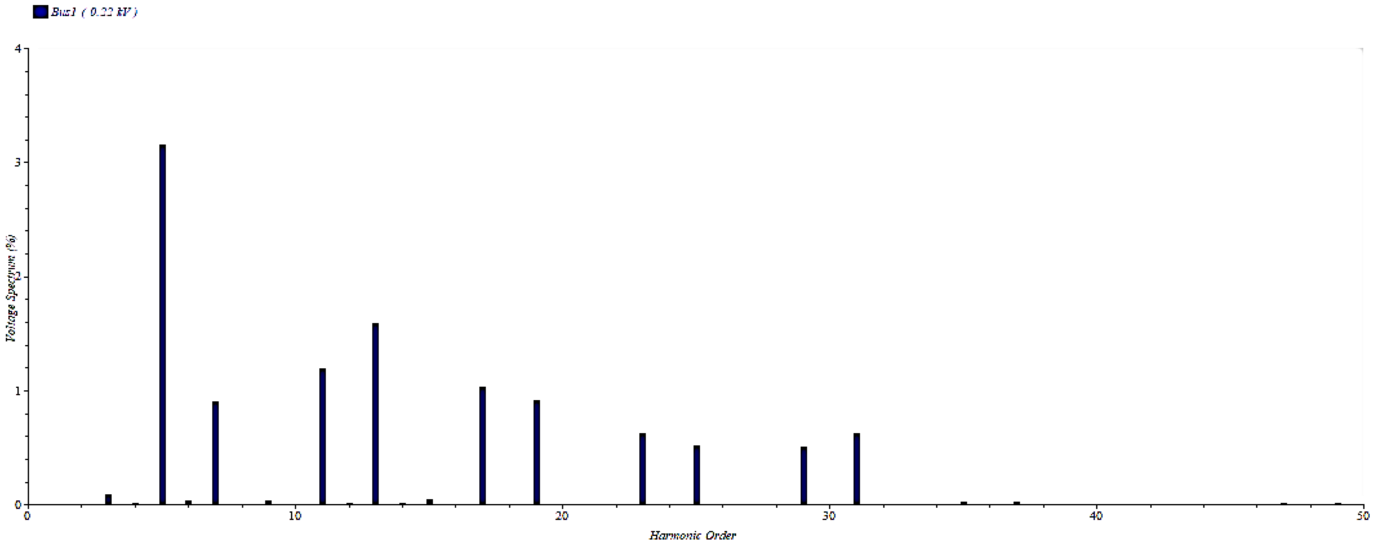

Figure 7. Harmonic Spectrum on Bus 1

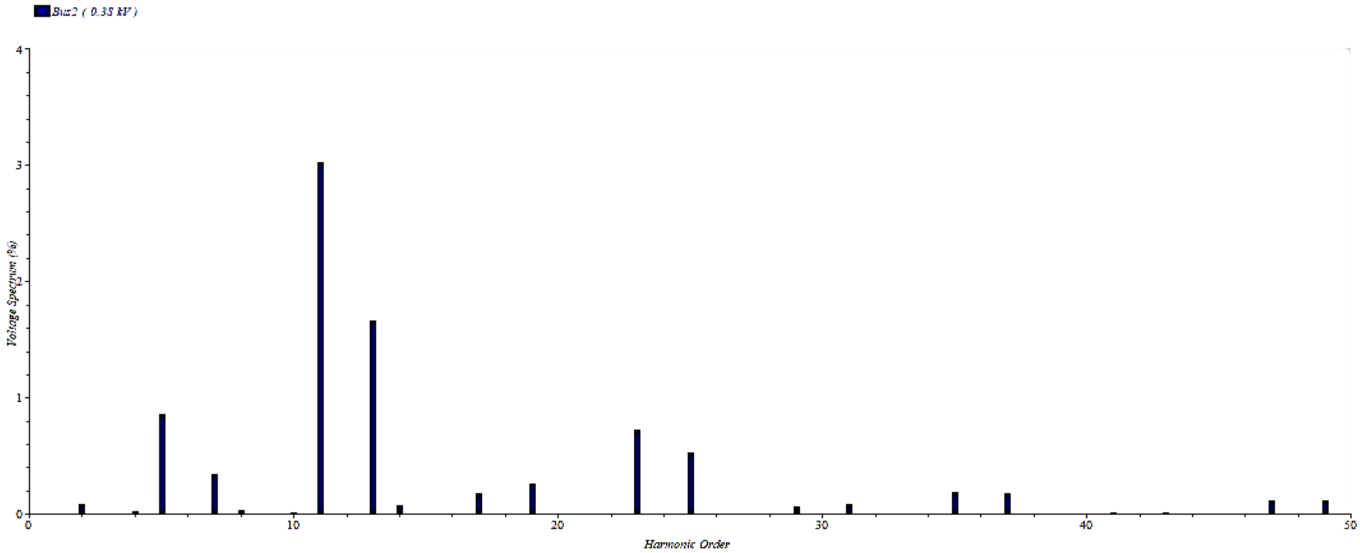

Figure 8. Harmonic Spectrum on Bus 2

Table 1. Load Data

Load Type	Total Load
Pump	120 kW
Lift	45 kW
Inverter	380 kW

Table 2. DG Installation Scenario

Location	Bus 2
Type of DG	Photovoltaics
Capacity of DG	1290 kW
Number of Photovoltaics	54 Cell

The type of load can be seen in Table 1, while the DG installation scenario is explained in Table 2. The simulation review is carried out when the system is running in normal conditions with the load running at maximum.

IV. Result dan Analysis

Harmonics simulations are carried out to determine the orde of harmonics and the distortion of waveform on each bus [32]. It needs to be understood that harmonic problems are closely related to the system power flow because of the consequences such as excessive losses [33]. The Harmonics simulation results for existing conditions can be seen in Figure 7 and Figure 8. Bus 1 and Bus 2 exceed the specified limits. For this reason, passive filter planning is needed to reduce harmonics. The magnitude of the harmonics on bus 1 and bus 2 is explained in full in Table 3. This table explains the maximum limits and existing conditions for harmonics produced due to inverter penetration in the DG. Total Harmonics Distortion produced on bus 1 and bus 2 is 4.24 and 3.71.

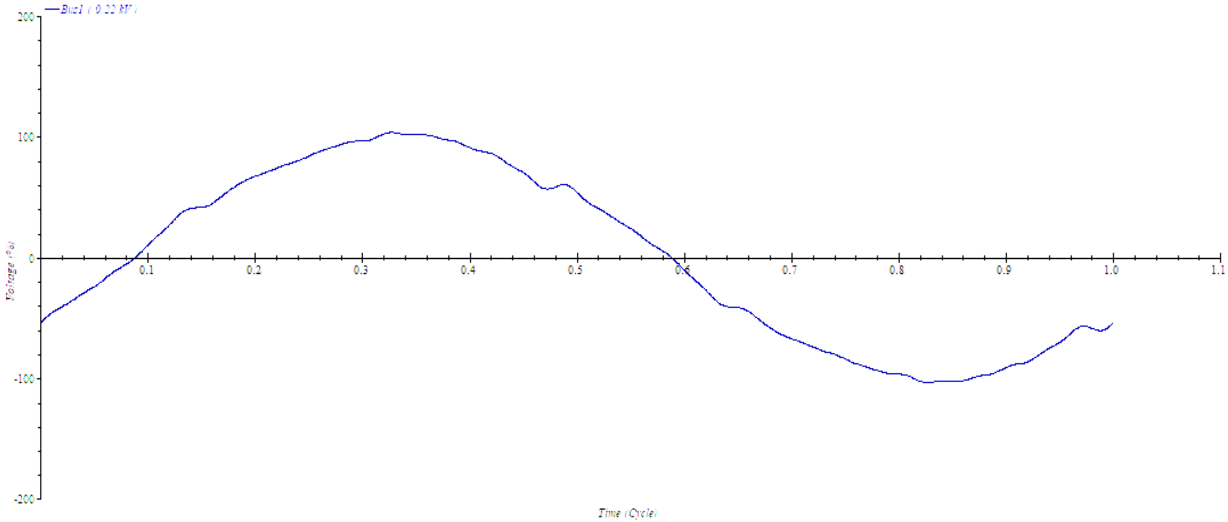

Figure 9. Sinusoidal Waveform Distortion on Bus 1

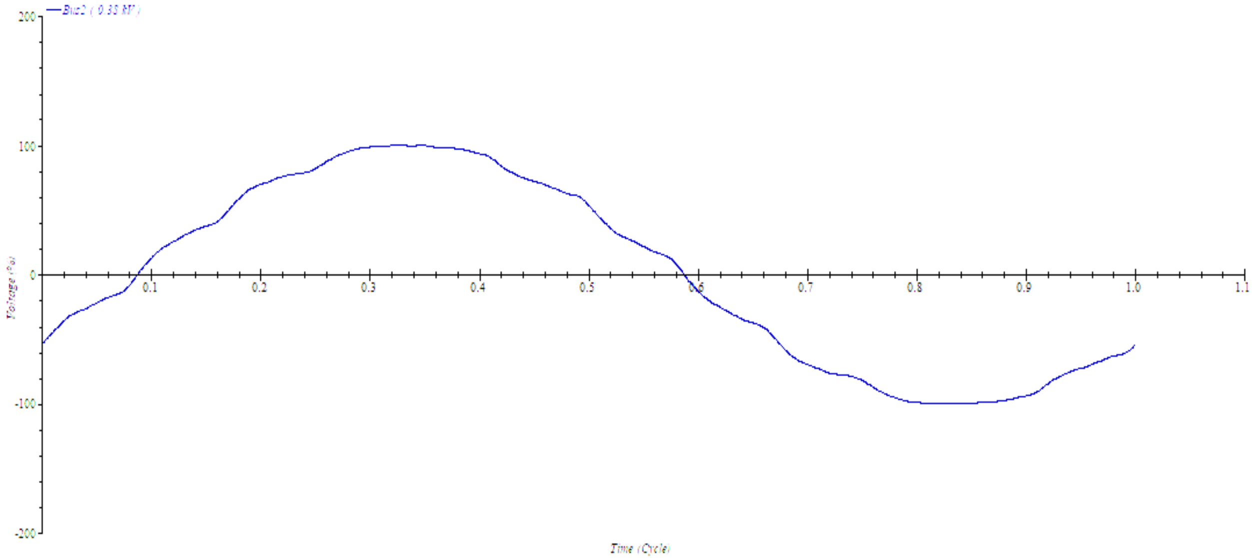

Figure 10. Sinusoidal Waveform Distortion on Bus 2

Table 3. Harmonics Value on Bus 1 and Bus 2

Device ID	**Type**	**Condition**	**Limit**	**Operating**	**Harmonics**
Bus 1	Bus IHD	Exceeds Limit	3	3,16	5
Bus 2	Bus IHD	Exceeds Limit	3	3,02	11
Bus 2	Bus IHD	Exceeds Limit	1,5	1,66	13
Bus 2	Bus THD	Exceeds Limit	2,5	3,71	Total
Bus 1	Bus IHD	Exceeds Limit	1,5	1,56	13
Bus 1	Bus THD	Exceeds Limit	2,5	4,24	Total

The influence of harmonics in microgrid systems can have several important impacts in electrical power systems and electronic equipment. From the simulation that have been carried out, the influence of harmonics on the microgrid can cause wave distortion as in Figure 9 and Figure 10. This can result in a waveform that is not sinusoidal, which can interfere with the performance of equipment that requires pure sinusoidal. It is important to properly manage harmonics in electrical systems to maintain electrical power quality, and protect equipment. The planning of a single tuned type passive filter is carried out, with the parameters of the resistor (R), reactor (R) and capacitor (C) values according to Table 4.

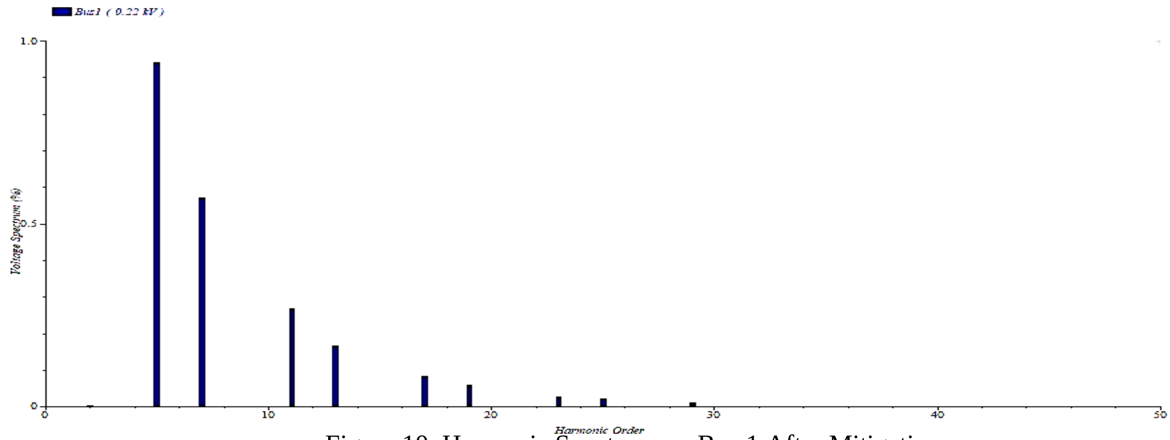

Figure 10. Harmonic Spectrum on Bus 1 After Mitigation

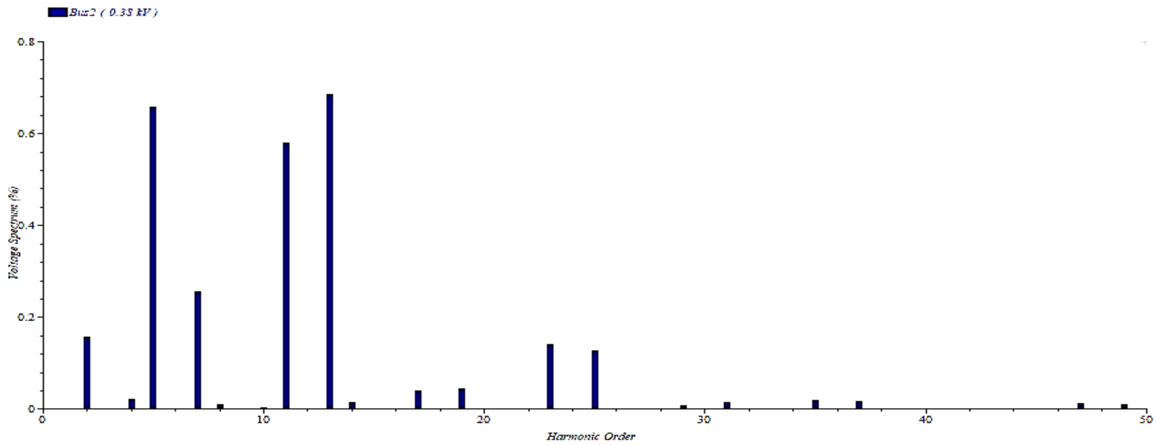

Figure 11. Harmonic Spectrum on Bus 2 After Mitigation

Table 4. RLC Value on Single Tuned Passive Filter

Bus 1	**Resistor (R)**	0,013 Ω
	Reaktor (L)	0.0001 H
	Capasitor (C)	0,09 F
Bus 2	**Resistor (R)**	0,013 Ω
	Reaktor (L)	0,0001 H
	Capasitor (C)	0,08 F

Tabel 5. Harmonic Value After Installing a Passive Filter

Device ID	**Type**	**Condition**	**Limit**	**Operating**	**Harmonics**
Bus 1	Bus IHD	Normal	3	< 3	5
Bus 2	Bus IHD	Normal	3	< 3	11
Bus 2	Bus IHD	Normal	1,5	< 1,5	13
Bus 2	Bus THD	Normal	2,5	0,844	Total
Bus 1	Bus IHD	Normal	1,5	< 1,5	13
Bus 1	Bus THD	Normal	2,5	1,32	Total

From the harmonic simulation results in Table 5, it is known that the Total Harmonics Distortion (THD) and Individual Harmonics Distrortion (IHD) values have decreased. The Total Harmonics Distortion (THD) and Individual Harmonics Distrortion (IHD) values for Bus on microgrid with harmonics 5^{th} , 11^{th}, and 13^{th} which were previously outside the standard, are now below standard or can be said to be within safe category. The single tuned filter has been proven to be successful in reducing harmonics due to penetration of the converter equipment installed on the DG.

V. Conclusion

The harmonic filter design has the ability to reduce harmonics on the harmonic source bus. After installing the passive filter, Bus 1 and Bus 2 have harmonic values that meet IEEE Std standards. 519-1992. After filtering, the THD on Bus 1 becomes 1.32%, and the THD on bus 1 becomes 0.84%. Meanwhile, IHD value for Bus 1 at the 5th harmonic decreased below 3% and at the 13th harmonic it decreased below 1.5%. The IHD value of Bus 2 at the 11th harmonic decreases below 3% and at the 13th harmonic it decreases below 1.5%.

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