Practical Reduction of Harmonics for Induction Generator with Simulator Mini Micro Hydro for Educational Purposes

Syaiful Bakhri, Seflahir Dinata, M Toriqul Amien, Yanwar Saputra
Electrical engineering, Pamulang University, Jl. Raya Puspiptek, Pamulang, Kota Tangerang Selatan, Banten, Indonesia, 15310
syaful20201@gmail.com; dosen01138@unpam.ac.id; dosen01794@unpam.ac.id; yanwarsaputra15@yahoo.com

Abstract. Micro Hydro Power Plant as one of the power generation that relies on waterfalls or river flows as the driving force. The generator produces harmonic voltage and current waves where these waves are a distorted wave disturbance causing multiplication in the fundamental frequency. This study aims to demonstrate practical and straightforward approaches to implement the appropriate filters in reducing harmonics in an induction generator for the micro hydropower. This approach could be useful for standalone rural/remote applications with a minimum competency of an electrical engineer to arranged the hydropower as well as for educational purposes at universities. Mini custom made micro-hydro simulator is employed. Two selected filters were chosen, i.e., Band Pass Filters and High Order Passive Filters as the harmonic dampers. The Bandpass filter able to reduce voltage harmonics without load, which is THDv 0.33% to 0.26% even though it is still far in the IEEE standard, i.e. 5%, and the bandpass filter does not affect while the system connected with the load. The high order passive filter can reduce the harmonic wave with THD 67% becomes THDi 0.003% and THDv 0.40% to 0.17%. It was demonstrated that the applicability of this filter at the simulator could be employed to adjust the harmonics for the generated output of micro-hydro.

1. Introduction
Pico and Micro Hydro Power Plant (P/MHPP) also known as Pembangkit Listrik Tenaga Micro/Pico Hydro (PLTM/PH) in Indonesia is a power generation that relies on water as the driving force for waterfalls or river flows with the capacity less 500 kW and 10 kW respectively [1]. PLTMH is also a small-scale hydropower plant, mainly because of the construction of the building and the produced power, which is not as big as a hydropower and mini-hydropower plant. This source of electricity generation in Indonesia is also promising in the future. The potency was around 143,845.30 kW, which is only 1.8% utilization[1]. In addition, considering the location of Pico and Micro-Hydro Power Plant both available in small and remote rivers, it can be very beneficial for standalone power sources[2]. These opportunities mean that a better understanding and acceptance of the public to implement this simple technology is needed. However, it is hardly found a simulator or trainer that demonstrates this technology even on a laboratory scale in Indonesia. This research uses this mini micro-hydro previously developed[3].

One of the essential components of PLTM/PH is the generator that converts mechanical energy into electrical energy. In the case of the type of generator, the induction generator draws more attention than the synchronous one, due to its lower price, better reliability, lesser maintenance, a wider range of
power selection and more straightforward starting and control [4-6]. This generator produces harmonics that are in the form of distorted disturbance waves causing multiplication for the fundamental frequency [7, 8]. As a result of these harmonics, they affect the loads, in the form of increasing the heat, which in turn causing damages. One of the simple solutions for this problem that might be applied easier in rural areas is an addition of a harmonic filter to reduce the distorted wave [7]. According to the Institute of Electrical and Electronics Engineers' IEEE, the allowable standard harmonics is around 5%. Therefore, the subject of discussion is which type of filter is the most appropriate in reducing harmonics.

Considering these realities, this study aims to demonstrate the filter approaches in reducing harmonics for an induction generator, especially for the Pico or Micro Hydro Power Plant. This practical and straightforward approach is expected to give a better understanding of the public with no particular expertise in electrical engineering to reduce the harmonics of the induction generator for their pico or micro hydropower plant arrangements. It should be noted here that a Simulator of Micro Hydro Power Plant is introduced and developed. The simulator was used both for scientific and educational purposes. Two selected filters are chosen, i.e., Band Pass Filters and High Order Passive Filters as the harmonic damper. This research analyzes the signal amplitude and the behavior of harmonics before and after filtering.

2. Theory

Induction generators are employed to convert rotary energy into electrical energy. In a self-powered induction generator, the excitation is obtained from a capacitor installed parallel to the generator output terminal [4, 5]. This type of induction generator works similarly like an induction machine in its saturation area except that there is a capacitor bank installed at the stator terminal. Because the source of the excitation of this generator comes from the capacitors mounted on the terminal, the induction machine with wound rotors or squirrel cages can be used as self-powered induction generators.

The induction generators or on all rotating machines usually produce harmonics. Harmonics are the multiplication of frequency from the fundamental frequency [4, 9]. The harmonics are usually in an odd order, causing a distorted sine wave. The effect of this distorted wave causes overheats of electrical equipment, which later may damage if it was left unmonitored.

Harmonic filters can be applied to reduce the harmonics that occur in the system. The harmonic filter functions to drain, hold, eliminate high frequencies in the system. In this study, two types of harmonic filters were used, namely. a. Band Pass Filter: a filter that passes frequencies with certain bands. b. High Order Passive Filter: a filter that absorbs frequencies at high order. The following equation is employed to determine the value of the components [10, 11]. The capacitor values are determined using Eq. 1, while the inductor values are from Eq. 2 and 3.

\[
C = \frac{1}{(2 \pi f \cdot X_C)} \quad (1)
\]

\[
X_L = \frac{X_C}{n^2} \quad (2)
\]

\[
L = \frac{X_L}{(2 \pi f)} \quad (3)
\]

Where C is the capacitance in Farads, L Inductance in Henry, f frequency in Hz, XC capacitive reactance, XL inductive reactance, and the n is the ratio of capacitive and inductive reactance. The amount of Total Harmonic Distortion (THD) is given in Eq. 5.

\[
\text{Distortion (total dB) = } 10 \log(10^{\text{dB}1/10} + 10^{\text{dB2}/10} + 10^{\text{dB3}/10} + \ldots + 10^{\text{dBn}/10}) \quad (4)
\]

\[
\text{THD (\%)} = 100 \times 10^{\text{total dB/10}} \quad (5)
\]
3. Methodology

This research developed a mini simulator for Micro/Pico Hydro Power Plant. The entire block diagram of the custom made simulator can be seen in Fig. 1[3].

**Figure 1.** The custom made simulator of micro-hydro generation

![Block diagram of the custom made simulator](image1.png)

**Figure 2.** The final product of micro-hydro generation simulator

![Final product of micro-hydro generation simulator](image2.png)

**Figure 3.** The applied filter, bandpass filter (left) and high order passive filter (right)

![Applied filters](image3.png)

Fig. 1 and Fig. 2 show an induction generator coupled with a Pelton Turbine [12] as the driver, using the v-belt. The excitation of the induction generator circuit is arranged with a star connection system. After the excitation system is installed, the micro-hydro system is coupled with various filters, as given in Fig. 3. Testing is done to determine the characteristics of the parameters of the main simulator before and after the filter was applied.
Table 1. The developed turbine parameters

| Parameter         | Value  |
|-------------------|--------|
| Type of Turbine   | Pelton |
| Blade Width       | 5.5 cm |
| Turbine Diameter  | 25 cm  |
| Number of Blades  | 6 blade|
| Rotation Speed    | 646 rpm|

For the measurement, NI-USB 6009, was employed. This data acquisition measures voltage, flow, and current. The harmonic detection and calculation are done on the computer using LabVIEW National Instrument.

4. Result and discussion

Following the testing parameters that have been previously determined, in this section, the results of the test are discussed. Tests have been carried out on Harmonics Filters with an LED load lamp of 220V 3 Watt using a bandpass filter. Here is the example of micro-hydro generation implementation, including the various filter applications. One of the examples was obtained at 43 volts, and 1150 RPM generator as the waveform is given in Fig. 4.

![Figure 4. The voltage and frequency waveforms with a 3 Watt 220 V load before filtering](image)

Fig. 4 shows that the sine wave voltage has a period of 0.03 seconds with a fundamental frequency at around 33 Hz with an amplitude of 8 dB. In this figure, the 3rd (100 Hz), 5th (170 Hz), 7th (233 Hz), 9th (298 Hz), 11th (366 Hz), and 13th (435 Hz) order of harmonic have amplitudes at around -24 dB, -45 dB, -42 dB, -45 dB and -46 dB respectively. By using Eq. 4 and 5, it was found that the THD is around 0.40 %. It clearly shows that various harmonics might produce by the induction generator and LED lights.
It can be seen in Fig. 5 the sine waveform voltage has a period of 0.03 seconds with a fundamental frequency of around 33 Hz at an amplitude of 10 dB. In Fig. 5, it can be seen that the harmonics on the 3rd (100 Hz), 5th (165 Hz), 7th (235 Hz), 9th (298 Hz), 11th (366 Hz), and 13th (435 Hz) order have amplitudes of around -2 dB, -15 dB, -17 dB, -20 dB, -21 dB, and -21 dB respectively. It can be seen that the amplitude of the current is relatively easier to be identified than the voltage.
Fig. 6 shows the results of high order passive filter applications to reduce any harmonics. The figure indicates that sine waveform voltage has a period of 0.03 seconds with a fundamental frequency of 33 Hz with an amplitude of 6 dB. The harmonics on the 3rd (100 Hz), 5th (170 Hz), 7th (234 Hz), 9th (298 Hz), 11th (366 Hz), and 13th (435 Hz) have amplitude around -28 dB, -45 dB, -45 dB, -50 dB and -51 dB. It can be demonstrated that it appears that the 3rd order can be suppressed significantly by adding filters. The other order 9th, 11th, and 13th are also reduced compared with without filter. The total amplitude is around -27.6 dB with the THDv (%) is around 0.17 %.

The implementation of the filter can also be recognized in current measurements. Fig. 7 demonstrates sine waveform current, which period 0.03 seconds with a frequency of 33 Hz (fundamental) at an amplitude of -44 dB. In this figure, The harmonics on the 3rd (100 Hz), 5th (165 Hz), 7th (235 Hz), 9th (298 Hz), 11th (366 Hz), and 13th (435 Hz) order have amplitudes of around -57 dB, -68 dB, -63 dB, -66 dB, -70 dB, and -70 dB respectively. The total of the amplitude is around -58.9 dB with THDi (%) around 0.0003 %. These results demonstrate that the effect of the filter also significantly suppressed the amplitudes.

The example above shows the relationship between voltage and current before and after filtering using a single load. The summary relationship of the voltage and current can be presented in the following paragraph.

Based on the two voltage harmonic graphs in Fig. 8 (before filtering) and Fig. 9 (after filtering), it is indicated that after filtering, the harmonic waveform peak decreases. The value capacitors and inductors as the harmonic dampers can also be investigated further to obtain better dampening. In addition, the magnitude of harmonics after filtering seems reasonably converge above 1000 rpm. It might be the characteristic of the magnetic field of the induction motor itself, which is much better at high speed, producing fewer harmonics.
Fig. 10 demonstrates the THD according to the variation of the generator speed. The THD decreased after filtering, especially above 1000 rpm, even though it is still below 5% as standardized. This graph also shows the practical application in reducing the harmonics of the voltage using simple filtering, especially for the application in the micro-hydro.
Fig. 10 and 11 show the relationship of various harmonics amplitude under the various speed of the induction generator before and after the filtering. The current measurements also employ similar filters as given by voltage measurements. In the case of voltage harmonic wave graph, after filtering, the peak of the harmonic wave decreases by the bandpass filter. However, for the current measurement, the filter can seem more effective at low speed. In addition, between 950 and 1050, a small bump or increase occurs, which indicates the signature characteristic of the induction generator. In other words, the rpm from 1010 to 1150 clearly shows that the bandpass filter cannot filter or reduce the current harmonic waves. Further effort was carried out to try reducing these harmonics at these specific areas by applying other types of filters. The high order passive filter type was applied further to understand how the harmonic reduction can be realized. The results are given in Fig 13.

![Figure 13. Current harmonics with various speed after filtering](image)

Fig 13 indicates the applicability and functionality of the high pass order filter as one of the solutions to reduce the harmonics. This filter seems to show better performance at the high-speed generator. At the low speed, the higher harmonics can be reduced significantly, similar to the bandpass filter, but it is not for the 3rd harmonics. In addition, the high order filter also useful at the high speeds of the induction generator. This filter must also be applied carefully to avoid the reduction of fundamental current as well.

![Figure 14. THDi before and after filtering](image)

Fig. 14 shows that the THDi graph shows the comparison of the harmonic reductions between the Band Pass Filter and High Order Passive Filter. The measured harmonics using the bandpass filter are up to around 64%, compared with the high order passive filter, i.e., maximum for about 0.38%. This
harmonic reduction provides a practical solution to reduce harmonics that are produced by the generator.

5. Conclusions

This paper demonstrates the application of filters performance for the mini pico or micro-hydro simulator applications. The paper presents the practical, low cost, and simple approaches of additional filters to the generator for better performance of the voltage and current output. This paper demonstrates the applicability of the simulator as well for the educational purposes. The Bandpass filter able to reduce voltage harmonics without load, which is THDv 0.33% to 0.26% even though it is still far in the IEEE standard i.e., 5%, and the bandpass filter has no effect while the system connected with the load. The high order passive filter can reduce the harmonic wave with THD 67 % becomes THDi 0.003% and THDv 0.40% to 0.17%. However, further investigations are still needed to ensure that the generated current is not excessively filtered. Style and spacing

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6. References

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