Reduction of Harmonics for Induction Generator with Simulator Mini Pelton Microhidro Turbine

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***Abstract* — Micro Hydro Power Plant as one of type of power generation that relies on water as the driving force for waterfalls or river flows. This generator produces harmonic waves where these waves are a distorted wave disturbance causing multiplication in the fundamental frequency. This study aims to find the best filter in reducing harmonics in an induction generator, two selected filter is chosen, i.e. Band Pass Filters and High Order Passive Filters as the harmonic damper. The Band pass 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 band pass filter has no effect while the system connected with the load. The high order passive filter is able to reduce the harmonic wave with THD 67 % becomes THDi 0.0003% and THDv 0.40% to 0.17%.**

Keywords* — *mini micro hydro simulator, harmonic reduction, induction generator, Total Harmonic Distortion

I. INTRODUCTION

Micro Hydro Power Plant (known also as Pembangkit Listrik Tenaga Micro Hidro - PLTMH) is a power generation that relies on water as the driving force for waterfalls or river flows. PLTMH is also a small-scale hydropower plant, especially because of the construction of the building and the produced power which is not as big as a hydropower plant.

One of the most important components of PLTMH is the generator that converts mechanical energy into electrical energy. This generator produces harmonic waves where these waves are a distorted wave disturbance causing multiplication in the fundamental frequency. As a result of these harmonics, they affect on any load such as an increase of heat which in turn causing damages. One of the solution for this problem is an addition of a harmonic filter to reduce the distorted wave. 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 previous realities, this study aims to find the best filter in reducing harmonics in an induction generator especially for the Micro Hydro Power Plant. It should be noted here that, a simulator Micro Hydro Power Plant is introduced and developed. In addition, the simulator can be used for the scientific and education purposes. Two selected filter is 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.

II. THEORY

Induction generator is 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. This type of induction generator works similar 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 produces harmonics. Harmonics are the multiplication of frequency from the fundamental frequency. The harmonics is usually in odd order, causing a distorted sine wave. The effect of this distorted wave causes overheat of electrical equipment, which later may damage if it was left unmonitored.

To reduce the harmonics that occur in the system, harmonic filters can be applied. 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. To determine the value of the component, the following equation is used. [1]. The capacitor values are determined using Eq. 1, 2 and 3, while the inductor values are from Eq. 4 and 5.

$$P = \sqrt{3x}\ V \text{ x } I \text{ X } \cos\varphi$$

$$S = \sqrt{3x} V \text{x } I$$

$$Q = \sqrt{S^2 - P^2} \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$Q\text{per-phase} = \frac{Q}{phase}$$

$$Xc = \frac{V^2}{Qper-phase} \quad (2)$$

$$C = \frac{1}{2x\pi xfxXc} \quad (3)$$

$$X_L = \frac{Xc}{n^2} \quad (4)$$

$$L = \frac{Xl}{2\pi f} \quad (5)$$

The amount of Total Harmonic Distortion (THD) is given in Eq. 6. [2]

$$\text{Distortion (total dB)} = 10\log(10^{dB1/10}+10^{dB2/10}+10^{dB3/10}+...+10^{dBn/10}) \quad (6)$$

$$\text{THD (\%)} = 100 \times 10^{\text{total dB}/10} \quad (7)$$

III. Methodology

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

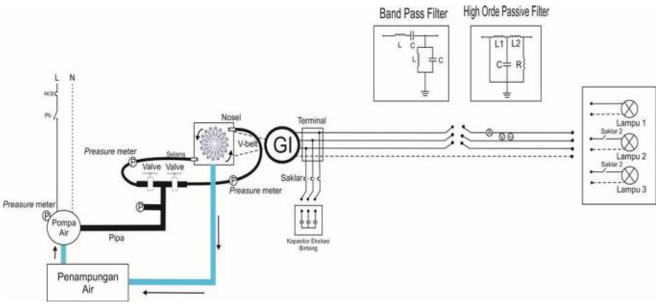

Fig. 1. The custom made simulator of micro hydro generation

Fig. 2. The final product of micro hydro generation simulator

Fig. 1 and 2 show an induction generator coupled with a Pelton Turbine as the driver using the v-belt. The excitation of 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. Testing is done to determine the characteristics of the parameters of the main simulator.

TABLE I. THE DEVELOPED TURBINE PARAMETERS

Parameter	Value
Type of Turbine	Pelton
Blade Width	5.5 cm
Turbine Diameter	25 cm
Number of Blade	6 blade
Rotation Speed	646 rpm
Tuebine Output Power	2.4 watt

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

IV. Result and Discussion

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

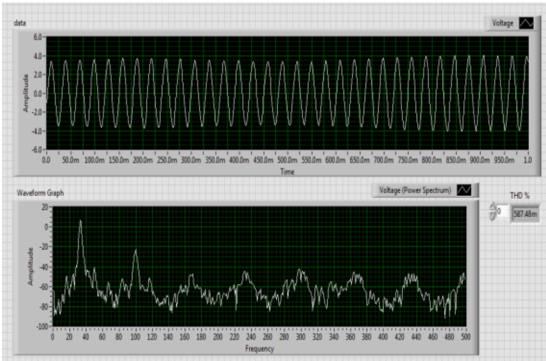

Fig. 3. The voltage and frequency waveforms with a 3 Watt 220 V load before filtering

Fig. 3 shows that the sine wave voltage has a period of 0.03 seconds with a fundamental frequency at around 33 Hz with 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, -45 dB, -42 dB, -45 dB and -46 dB respectively. By using Equation 6 and 7, 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.

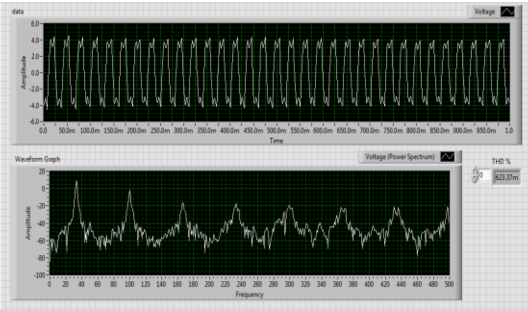

Fig. 4. The current and frequency waveforms with a 3 Watt 220 V load before filtering

It can be seen in Fig. 4 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. 4, 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 current is relatively easier to be identified than the voltage.

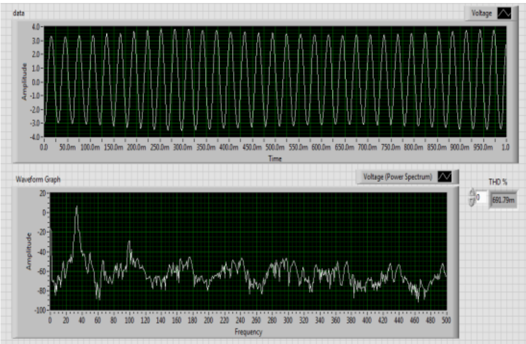

Fig. 5. The voltage and frequency waveforms with a 3 Watt 220 V load after filtering

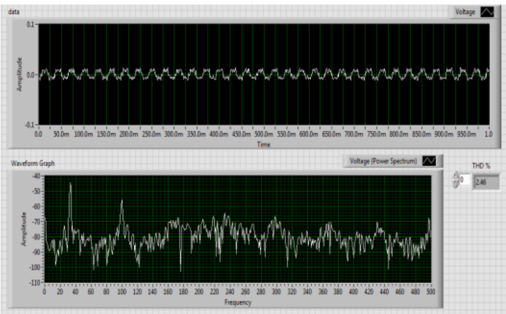

Fig. 6. The current and frequency waveforms with a 3 Watt 220 V load after filtering

Fig. 5 shows the results of high order passive filter application to reduce any harmonics. Figure indicates that sine waveform voltage has a period of 0.03 seconds with a fundamental frequency of 33 Hz with 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, -45 dB, -50 dB and -51 dB. It can be demonstrated that appears that the 3rd order can be suppressed significantly by adding filters. The other order 9th 11th and 13th are also reduced compare 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 recognize in current measurements. Fig. 6 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 of voltage and current before and after filtering using a simple load. The summary relationship of the voltage and current can be presented in the following paragraph.

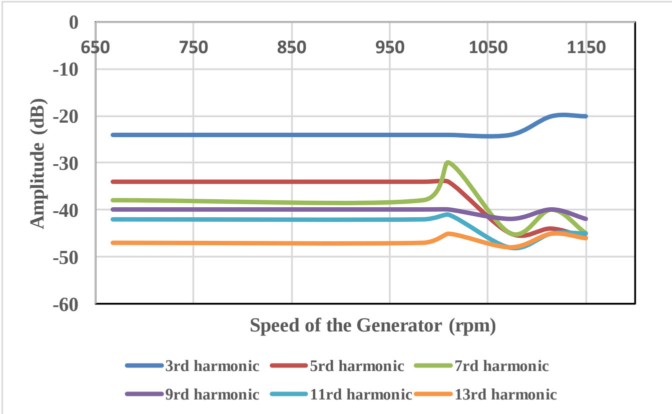

Fig. 7. Voltage harmonics with various speed before filtering

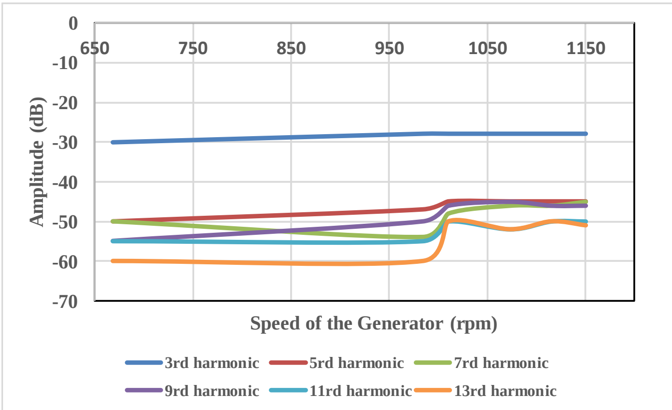

Fig. 8. Voltage harmonics with various speed after filtering

Based on the two voltage harmonic graphs in Fig. 7 (before filtering) and the 8 (after filtering), it is indicated that after filtering the harmonic waveform peak decreases. The value capacitors and inductors as the harmonic dampers can be also 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 magnetic field of the induction motor itself which are much better at high speed producing less harmonics.

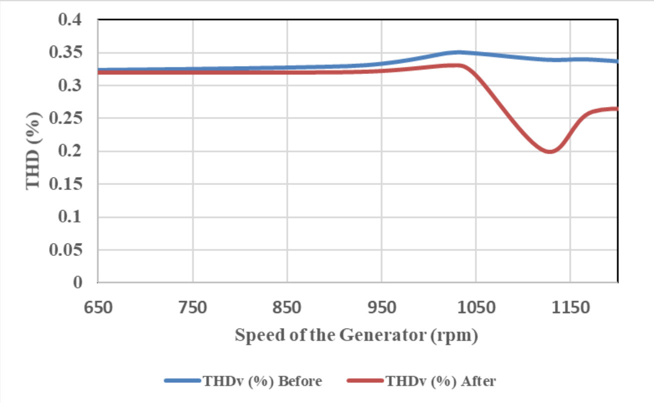

Fig. 9. Summary of the total harmonic distortion before and after the filtering

Fig. 9 demonstrates the THD according to the variation of the generator speed. The THD decreased after filtering especially above 1000 rpm even though 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.

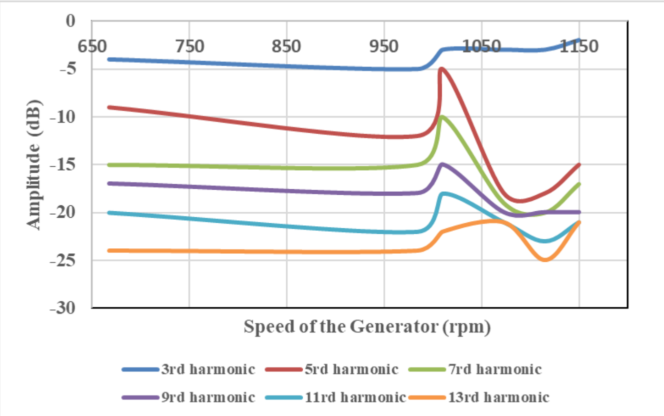

Fig. 10. Current harmonics with various speed before filtering

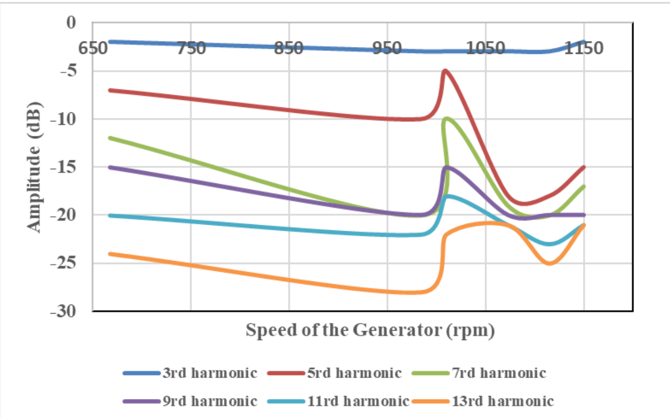

Fig. 11. Current harmonics with various speed after filtering

Fig. 9 and 10 show the relationship of various harmonics amplitude under various speed of the induction generator before and after the filtering. The current measurements also employ similar filter as given by voltage measurements. In case of voltage harmonic wave graph, after filtering the peak of harmonic wave decreases by the band pass 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 nay indicate the signature characteristic of the induction generator. In other words, from the rpm 1010 to 1150 clearly shows that the band pass 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 type of filter. The high order passive filter type was applied further to understand how the harmonic reduction can be realized. The results is given in Fig 12.

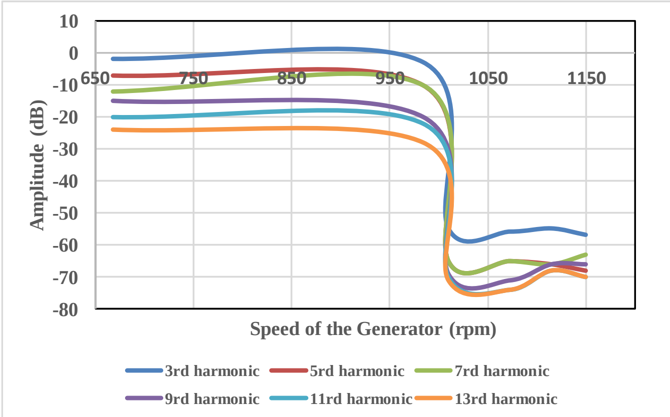

Fig. 12. Current harmonics with various speed after filtering

Fig 12 indicate the applicability and functionality of the high pass order filter as one of the solutions to reduce the harmonics. This filter seems showing better performance at high speed generator. At the low speed the higher harmonics can be reduced significantly similar with the band pass filter, but it is not for the 3rd harmonics. In addition, the high order filter also effective at the high speeds of the induction generator. This filter must be also applied carefully to avoid the reduction of fundamental current as well.

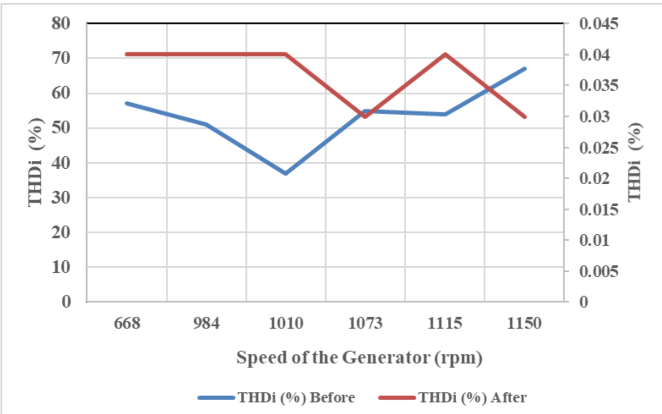

Fig. 13. THDi before and after filtering

Figure 13 shows that the THDi graph shows the comparison of the harmonic reductions between the Band Pass Filter and High Order Passive Filter. Using the bandpass filter the harmonics are up to around 64%, compare with the high order passive filter, i.e. maximum for about 0.38%. This harmonic reduction provide practical solution to reduce harmonics which are produced by the generator.

V. CONCLUSIONS

The Band pass 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 band pass filter has no effect while the system connected with the load. The high order passive filter is able to reduce the harmonic wave with THD 67 % becomes THDi 0.0003% and THDv 0.40% to 0.17%.

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