A STUDY ON THE PERFORMANCE OF IMPEDANCE MATCHING CIRCUIT IN PARTIAL DISCHARGE MEASURING SYSTEM

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ABSTRACT. *Partial discharge (PD) phenomena often result in serious faults in insulation. They may lead to electrical breakdown and cause loss of revenue to repair and replace the damaged part of the electrical equipment due to lack of precise and early detection of PD occurrence. PD measurements are important diagnostic tools to monitor the insulation condition of a device. Filtration in a PD measuring system is essential to eliminate or reduce noise pulses from affecting the measurement value. The device that is widely used nowadays is a high pass filter (HPF). In this project, an alternative filter device is established and studied, which is an impedance matching circuit (IMC). The aim of this project is to build an IMC in a PD measuring system for filtration purposes. The IMC is then measured to observe its characteristics and performance as a filter device in a PD measuring system. By measuring the number of PD occurrences and magnitude of PD on an insulation sample, the outcomes of PD obtained in the measurement system of impedance matching circuit are compared with those in high pass filter. From the tests, it was observed that IMC shows a smaller number of false PD occurrences and higher individual PD magnitude of each occurrence compared to HPF. Thus, the PD can be observed clearly even at smaller supply voltages by using IMC and breakdown of insulation can be avoided.*

KEYWORDS. Partial Discharge (PD), Impedance Matching Circuit (IMC), High Pass Filter (HPF).

INTRODUCTION

Partial discharge (PD) is often the primary cause of serious faults in cable insulations. A partial discharge is a localized electrical discharge that does not completely bridge the insulation between the conductors (BS 60270: 2001). It can occur in gaseous, solid, or liquid insulating media and usually begins with voids or cracks at some point in the insulation system where the electric field strength exceeds the breakdown strength of the insulating material. The electric field strength is the field's ability to accelerate an electron to the point that if it impacts another molecule, more electrons are knocked loose than are absorbed. In order for a PD to occur, a free electron must be present within a voltage dependant volume to accelerate within the field. Current can flow across the void and return the voltage across the void to zero (Lazarevich, 2003).

Although the magnitude is usually small, it can lead to problems such as current floating and insulation breakdown, and affect the device connected to it, which causes loss of revenue to repair and replace the damage part of the equipment due to lack of precise and early detection of PD occurrence. It is therefore vital to detect PD existence before it damages the electrical system and leads to a disaster. The PD measuring system can be used to detect weaknesses of insulation structure. Hence, the PD measuring system was developed and improved over time, to monitor the condition of electrical devices (Lazarevich, 2003).

There are several methods and techniques that are widely used so that fast and accurate action can be taken whenever a PD takes place, e.g. acoustic emission measurement, capacitive coupler, or impulse current measurement, However, noise has been a major problem in PD measurement, limiting its effectiveness as an instrument in assessing insulation condition and detecting faults in power plant insulation (Zhou *et al*., 2009) The main form of noise is Radio Frequency (RF) and pulse shaped noise.

As the PD signal from the detector is a very feeble high frequency signal (at micro-volt level) superimposed with 50 Hz alternating current signal, the 50 Hz alternating current must be filtered.

Several methods of filtration are used in measuring the PD signal, such as high pass filter (HPF) and impedance matching circuit (IMC). The objectives of this research are to build an IMC in a PDC measuring system and to compare the results obtained using IMC to HPF. An HPF lets through high frequency signals, but reduces or stops low-frequency signals. Thus, at low frequency, the capacitor in the HPF acts like an open circuit and does not let the signal go from the input to the output. Figure 1 shows a simplified HPF configuration made up of capacitor and resistor.

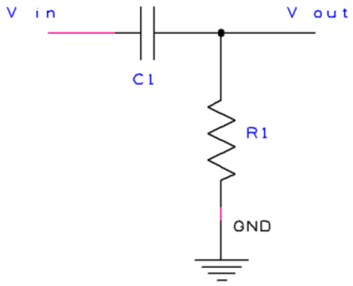


Figure 1. A simplified High Pass Filter configuration.

Impedance Matching Circuit

Impedance matching networks are not only used to match load and source for maximum power transfer as in the field of electronics, but also to transform impedances for other purposes. As an example, impedance transformation is the optimisation of an amplifier for optimum noise performance (Abrie, 1985). The required source impedance (as viewed from the transistor terminals) is not the conjugate of the transistor input impedance. Therefore, it is used for transforming impedances to certain required values, which may or may not be the conjugate of the source impedance. For this reason, the design of matching networks shares much in common with filters, in that filters are used for noise attenuation (Maharudin, 2010). It is designed for the purpose of signal enhancement within the proper frequency band of the detector (Chang *et al.*, 2000).

The impedance matching circuit (IMC) in this project has a very steep waveform in nano-second order (Arief, 2006). The IMC converts the current detected by the electrode of the test cell into the voltage by resistance, and converts characteristic impedance into 50 Ω. The design of IMC in this project can detect PD signal up to 800MHz. As PD are detected by means of electromagnetic waves radiated by the discharge source with a frequency range which can go up to 3 GHz, while the high pass filter can detect only up to 80 MHz, the IMC design is selected. The schematic of IMC used in this project is shown in Figure 2. Figure 3 shows the fabricated IMC prepared by the authors.

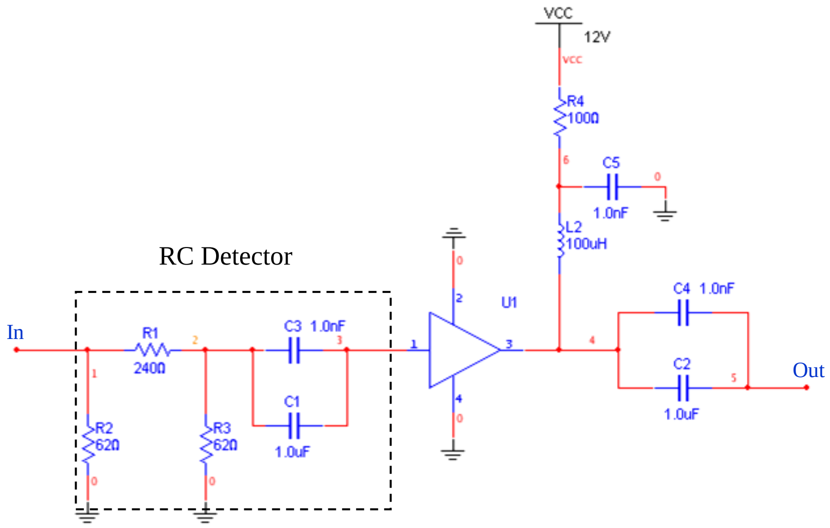


Figure 2. Schematic circuit of impedance matching circuit with RC detector.

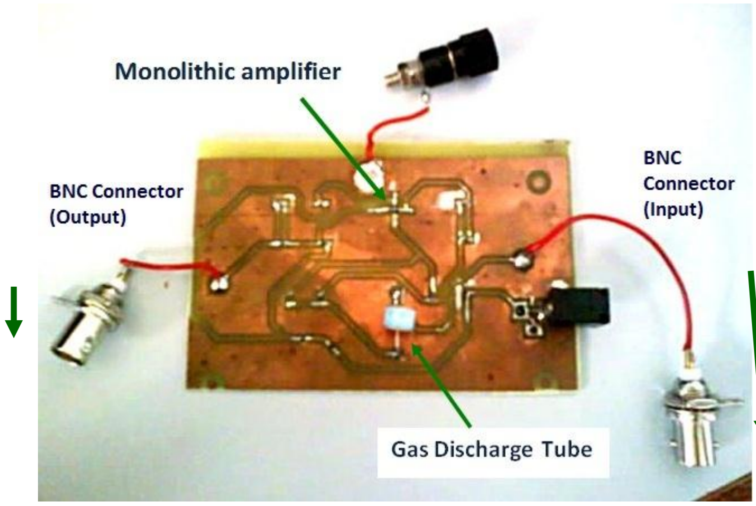


Figure 3. The printed circuit board of Impedance Matching Circuit (IMC).

The IMC consists of RC detector, monolithic amplifier, and gas discharge tube as main components, powered by 12V voltage source. The signal from Input port will be detected by RC detector, consisting of resistors and capacitors, which function to detect PD pulse. It is essential to smooth the output of power supply and eliminates noises, especially in filter networks. The monolithic amplifier will amplify the signal transmitted from RC detector, detecting a greater number of PD pulses. The Output port of the IMC will connect the signal to an A/D Converter.

EXPERIMENTS

Assess Performance of Devices

The performance of the IMC is evaluated to see if it can work properly in a certain bandwidth. In high frequency networks, scattering parameter (S-parameter) is probably the simplest to work with and to measure. S-parameters do not require the input and output of a network be short circuited or open circuited. Instead, they use matched loads. The scattering effect can be observed when a plane electromagnetic wave is incident on an obstruction or passes across dissimilar dielectric modes (Kaiser, 2006).

A linear 2-port electrical network can be depicted as in Figure 4; where a_1 is the incident signal that transmits into the network from port 1 (the input port), b_1 is the reflected signal from the network at port 1, a_2 is the incident signal that transmits into the network at port 2 (the output port), and b_2 is the reflected signal from the network at port 2.

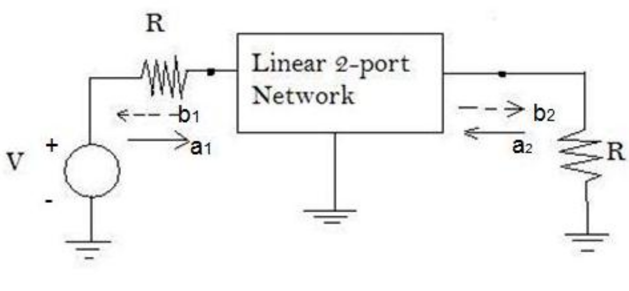


Figure 4. Schematic diagram of transmission and reflection of a linear 2-port network (Kaiser, 2006).

Generally, each 2-port S-parameter has the following generic descriptions:

i. S_{11} is the input port voltage reflection coefficient
ii. S_{12} is the reverse transmission coefficient
iii. S_{21} is the forward transmission coefficient
iv. S_{22} is the output port voltage reflection coefficient

If one considers an incident signal at port 1 (a_1), there may result from it signals exiting from either port 1 itself (b_1) or port 2 (b_2). However if, according to the definition of S-parameters, port 2 is terminated in a load identical to the system impedance (Z_O) then, by the maximum power transfer theorem, b_2 will be totally absorbed making a_2 equal to zero. Therefore,

$S_{11} = \frac{b_1}{a_1}$ and $S_{21} = \frac{b_2}{a_1}$.

Similarly, if port 1 is terminated in the system impedance then a_1 becomes zero, giving

$S_{12} = \frac{b_1}{a_2}$ and $S_{22} = \frac{b_2}{a_2}$.

In this test, the parameter measured is the S_{21} parameter, to compare the forward transmission coefficient from the input of the circuit which is indicated as port 1, to the output of the circuit which indicated as port 2, for both IMC and HPF. The circuit was measured using Agilent Vector Network Analyzer (VNA) E5071C (300 kHz – 20 GHz). Data for both IMC and HPF was saved in S2P File which comprises magnitude and phase of S-parameters; S_{11}, S_{12}, S_{21} and S_{22}.

PD Measurement

PD measuring system consists of a coupling device, a transmission system, and a measuring instrument. It is an important diagnostic tool to monitor the insulation condition of a device. The PD measuring system utilized in this study is shown in schematic diagram Figure 5. The setup during the experiment is depicted in Figure 6.

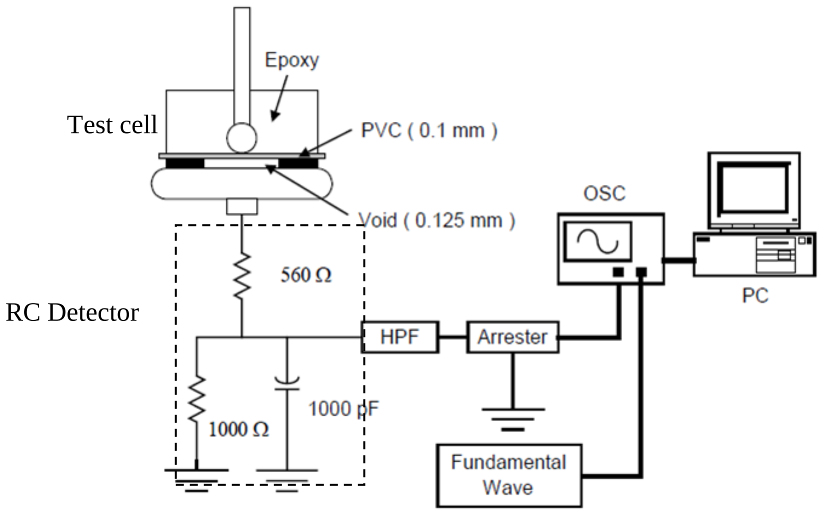


Figure 5. Schematic diagram of partial discharge measuring system (Makmud, 2009).

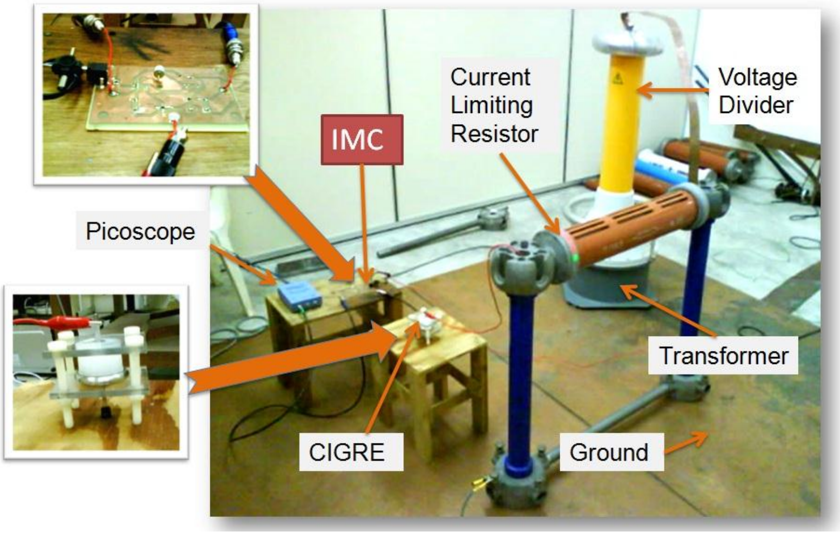
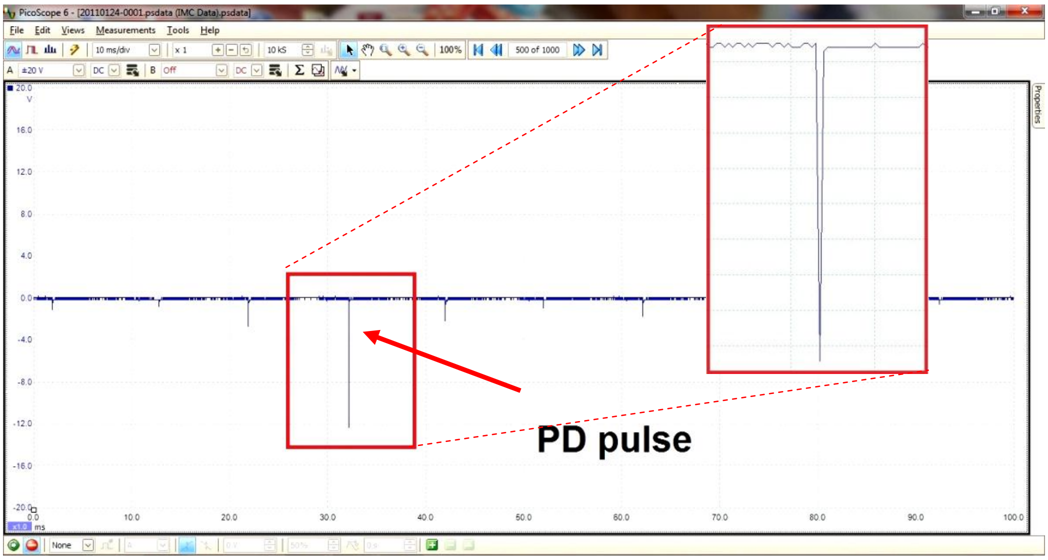
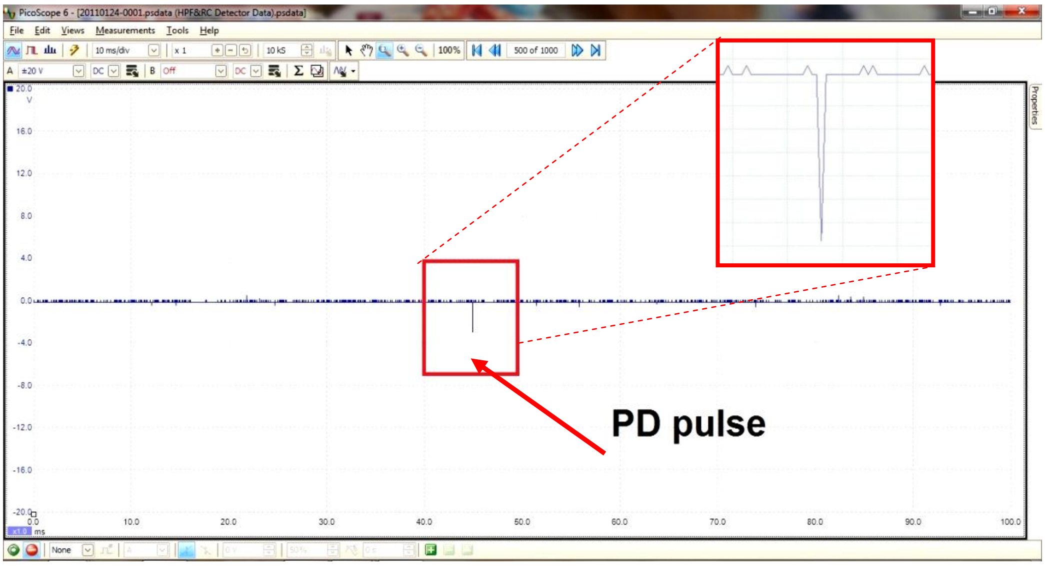


Figure 6. Experimental setup of PD measurement test.

In this project, the test sample of a polymeric material was tested at the test cell with applied voltage of 10 kVrms. The test cell used was the CIGRE Method II electrode consisting of sphere-plane electrode configuration. PD current induced in the test sample was detected by RC detector. The detected signal was then transmitted to the High Pass Filter (HPF) for filtration. Using Picoscope 3000 series as an A/D converter, the PD signal was converted and stored in a PC for further analysis. The Picoscope 3000 series has high performance as it is equipped with specifications of 2 channels, 10 GS/s sampling rate, 200 MHz bandwidth, 1 MS buffer memory, and high-speed USB 2.0 interface. Then, the experiment was repeated using the IMC instead of HPF. During test, PD pulses were measured from the PSDATA file saved through PicoScope 6 ™ software which can be opened in Microsoft Excel ™ to view the accurate measurement. The examples of PicoScope 6 ™ capturing the PD pulses are shown in Figure 7 for IMC and HPF labelled as (a) and (b), respectively.



(a)



(b)

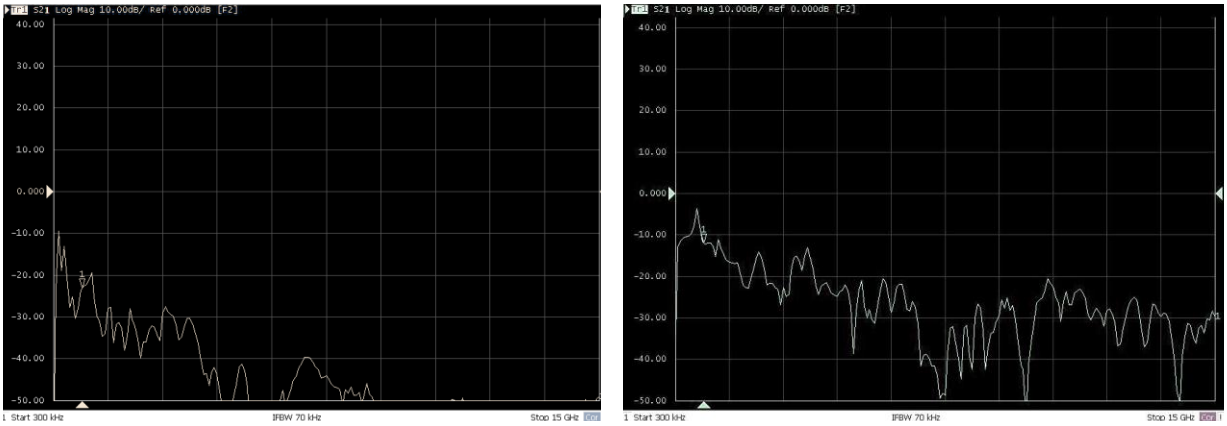
Figure 7. PD pulses captured during the PD test for (a) IMC and (b) HPF.

Both views of pulses were taken from frame 500 of PSDATA file. The y-axis represents the voltage magnitude up to 20 V, while the x-axis represents the time of 100 ms/div, where there are 10 divisions in a frame. The pulse in the rectangular box is magnified to show the shape of the PD pulse. From the PSDATA file, the PD pulses were analyzed and counted at each frame from 1 to 1000. This makes the test run 16.67 minutes for each device used. The analyzed data were then tabulated and converted to graphical presentation for comparison. The analyzed characteristics are the PD number of occurrences in each frame and maximum magnitude in each minute.

RESULTS AND DISCUSSION

Assess Performance of the Devices

The reason for taking the S_{21} parameter is to measure the coefficient of the transmitted wave from the input port and the reflected wave from the output port. In other words, it tells whether the circuit is matched. The VNA sends in the wave (power) and measures how the wave is reflected back to the source. The graphs of S_{21} parameter in log magnitude versus frequency were captured as in Figure 8 for IMC and HPF, labelled as (a) and (b), respectively.



(a) **(b)**

Figure 8. Graph of log magnitude (dB) versus frequency (Hz) of S_{21}-parameter captured from Agilent VNA E5071C for (a) IMC and (b) HPF.

The S_{21} measurements show that the signal is attenuated across the frequency below 0 dB for both IMC and HPF. The IMC is considered to have the characteristic of a filtering instrument, like the HPF.

However, there are drawbacks from the results of this measurement. The graph for IMC shows that the waveform is attenuated to as low as 0 dB at frequency above 7 GHz. Besides, a large spike is observed in the graph of HPF. These might be due to limitations such as disturbance or noise from the surroundings while measuring the devices, bending of the devices' cables or the 2-port VNA cables, mismatch in the circuits' transmission lines or cables or adaptors or break in the ground on the PCB. In fact, there is no protection from noise for IMC as it is not protected in a case.

PD Measurement

The results that need to be analysed are PD number occurrence and PD voltage magnitude, which are presented in graphs in Figure 9 and Figure 10, respectively.

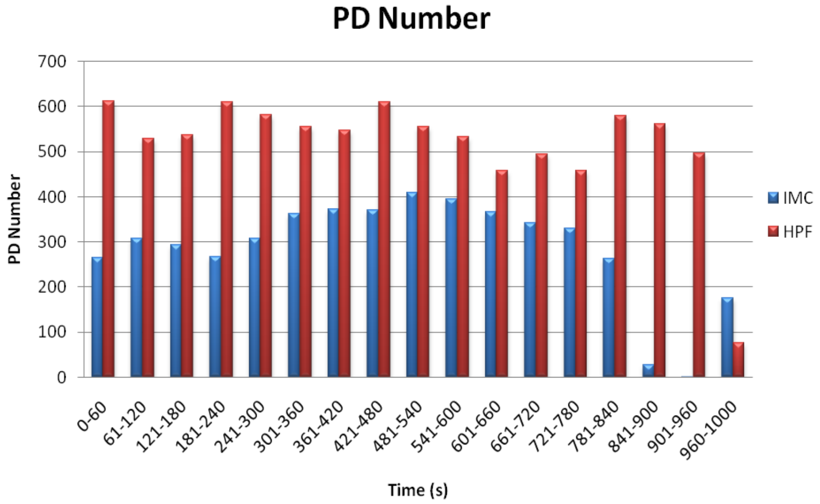


Figure 9. Graph of PD number occurrence versus time (second) in 1000 second for IMC and HPF.

From the graph of PD number occurrence, it is observed that the HPF has higher number of PD occurrence compared to the IMC. This is because the HPF not only captures PD signals, but also other signals from the surrounding and equipments used in the experiment itself, as it can detect in high range of frequency. As for the IMC, it captures almost all real PD. Hence, it is proven that utilization of IMC for filtration purpose is better than that of HPF in terms of PD occurrence detection.

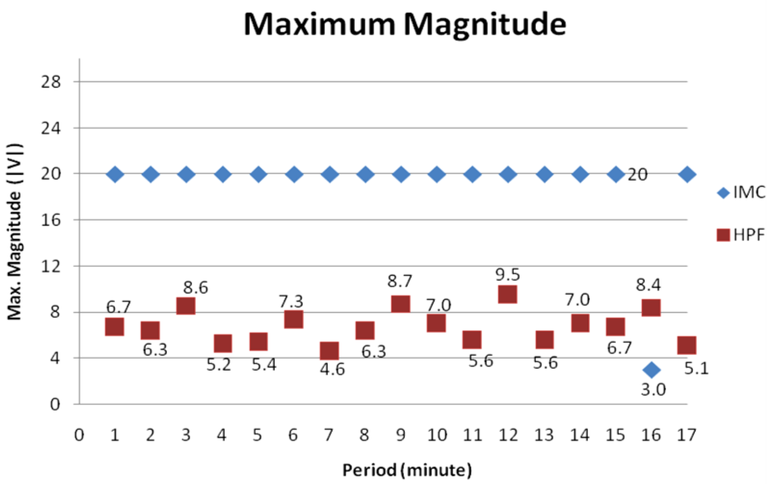


Figure 10. Graph of PD maximum magnitude versus period (minute) in 16.67 minutes (1000 second) for IMC and HPF.

Observably, IMC has higher PD magnitude than HPF, as shown in Figure 9. This is because the IMC has an amplifier in its circuit, making the IMC a compact device that can amplify the signals detected by it. Furthermore, normally PD already occurs at 6 kVrms to 7 kVrms in the polymeric insulation sample, but the voltage applied is 10 kVrms. Thus, the PD can be observed clearly even at smaller supply voltage by using IMC and breakdown of insulation can be avoided. The saturation at maximum magnitude of 20 V at almost every period by the IMC means that the PD magnitude is actually higher than 20 V. This saturation is due to the setting on PicoScope 6 ™, where it was set to a maximum of 20 V during the test.

CONCLUSION

From the measurement and PD test throughout this project, there are some characteristics that can be concluded, which are:

1. The IMC is considered to have the characteristic of a filtering instrument, like the HPF. This can be observed from the S_{21} measurement of both devices where the signals from the input port to the output port were attenuating throughout the frequencies.
2. The IMC detects a smaller number of PD occurrences compared to HPF as it captures almost only real PD.
3. IMC is a compact device that has higher PD magnitude than HPF, due to the amplifier used in the circuit of IMC. Thus, the PD can be observed clearly even at smaller supply voltage using IMC and breakdown of insulation can be avoided.

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