Numerical Analysis of Filtering Circuit for Partial Discharges

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Abstract. Partial Discharge (PD) is a small electrical spark that happens within the insulation of medium and high voltage electrical assets. It is important to note that the discharge will erode the insulation and eventually result in disastrous insulation failure. Thus, PD detection is a crucial issue in high voltage insulation area. However, the on-site field PD tests, the high frequency PD signals detected by sensors, are vulnerable to interferences and background noises. This has a negative effect on high voltage apparatus fault diagnosis and localization accuracy. For that reason, noise suppression has become an urgent and vital issue for field high frequency PD signal testing. Thus, this research aims to model a filtering circuit to suppress the noise along with PD in high frequency measurement. A filtering circuit was analysed by using Proteus software to filter out the noise along with PD with decent accuracy and efficiency. Then, performance investigation of active high pass and passive high pass was conducted and studies to filter out PD noise suppression in high frequency were successfully developed. The active filter was focusing on the first order stage until fourth order stage. The passive filter only concentrated on two types of order stage; first order stage and second order stage. The result demonstrated that active high pass filter presented the best performance with low decibel frequency response (-20 dB), and was suitable for this research purpose compared to passive high pass filter. Besides, 700 Vrms has been selected to check the response at high voltages and the frequency values set at 50 Hz for low frequency and 8 kHz for high frequency. This specification design values have been selected because it is suitable for situations in high-tension power line. This type of filtering circuit is suitable to be used for academic and lab experimentation.

1. Introduction
Partial discharge (PD) is a phenomenon that happens in insulation breakdown in high-voltage equipment that has high risk in power transmission system. It is responsible for many power transformer failures and appears when the insulating materials remain continuously under high voltage stress [1]. The pulses are small electrical sparks which occur within the insulation of medium and high voltage electrical assets [2]. Since this problem can damage insulation materials in power transformer equipment and windings, it will cause failure in process and costly outages [3]. PD monitoring and surveillance are very critical to avoid major power transmission network losses [4-5]. The main focus of this research is to develop a filtering circuit for suppressing noise along with PD. A filtering circuit is one of the techniques to detect a PD system. An active filter and passive high pass filter circuit will be constructed to ensure which is better for PDs in transformer. From the active high pass filter, the circuit will be developed in the first order stage, second order stage, third order stage, and fourth order stage to observe the precise and high roll off in the result of frequency. Passive high pass filter circuit is only constructed for first order stage and second order stage as it is not suitable for the PD system. Many researchers suggest that PD noise is very important to detect as it has many adverse effects on high voltage system. The small leakage of...
output will affect inside a transformer that leads to further aging, degradation, and ultimate catastrophic failures [6-7]. A filter circuit is a simple technique to detect and filter unwanted frequency and PD noise.

An interference of qualitative and quantitative analysis on site using a Fast Fourier Transform (FFT) technique has been reported [8]. There have been various periodic interferences investigated, emanated from the carrier communication, thyristor switching, and high frequency protection signals of power system as well as radio broadcasting signals [8]. The FET method has been improved for the purpose of suppressing a continuous periodic interference.

It is suggested that low-pass filter circuit in PD detection system is able to filter undesired harmonic voltage and reduces background noises [9]. It is compatible with PD detection system for high voltage equipment [9]. The background noise of the commercial PD detection system and the total harmonic distortion (THDv) of the testing voltage are enhanced.

In is summarised that de-noising results of simulated and field detected UHF PD signals prove the feasibility and functionality of the proposed method [10]. When compared with four conventional de-noising methods, the results express that the proposed method can suppress background noise in the UHF PD signal effectively, with higher signal-to-noise ratio and less waveform distortion.

Therefore, this research will be focusing on developing a filtering circuit to suppress noise with PD in HF measurement system. In order to simulate the filter circuit operative, NI Multisim software was used to observe the result with decent accuracy and voltage response, and the Proteus software was used to observe the frequency response. An active and passive high pass (HP) filter circuit was constructed to ensure which was better for PDs in transformer. The 700 Volts of input voltage was considered as the purpose of this research was finding the significant output of high voltages into PD measurement. Active and passive filter circuits have been modelled and constructed with cut-off or critical frequency of 1 kHz, and the frequency response values were set to 50 Hz for low frequency and 8 kHz for high frequency.

2. Methodology
This research aims to implement methods of noise reduction and PDs and various circuit implementations that can be upgraded. The filtering circuit was constructed to filter out unwanted noise in certain set of frequency cut-off. The filter circuit was compared by type in active high pass and passive high pass. This research began by designing a filter circuit of active high pass filter and passive high pass filter using Proteus and Multisim software. The circuit of active high pass filter was constructed in four-order stages. Passive high pass filter was constructed in the first and second order stages.

Each circuit was simulated in the Proteus to observe the frequency response, while the Multisim software was used to generate output voltage response performance. Figure 1 shows the block diagram of filter circuit for suppressing the noise along PD. Based on Figure 1, the input signal passes through the first stage known as the voltage divider. Then, the signal is sent to high pass filter from the voltage divider to filter action noise. Next, the signal is received to the buffer part. Lastly, the high voltage (HV) amplifier processes the end stage of signal and sends it as the system output.

Figure 1. Block diagram of Partial Discharges system.
The purpose of existing voltage divider is to step down the voltage from the main source. This step-down voltage is used to avoid the overvoltage protection to the input of high pass filter. Then, the output of the voltage divider will go through high pass filter. In this section, the circuit filters the action of noise. The high pass filter allows passing through of high frequency signal and rejects the other or unwanted frequency signals. The high pass filter circuit includes the buffer circuit. The buffer circuit is used to provide isolation between high pass filter and high voltage amplifier for impedance matching and to avoid loading of the signal sources.

2.1. Active High Pass Filter
Active filters are filter circuits developed with combination transistors and op-amp as the fundamental components. In comparison, active filter circuits include resistors and condensers, but do not have inductors. In this section, the circuit of active filter will be designed from the first order stage until fourth order stage as in 50 Hz for low frequency and 8 kHz for high frequency. The filter shows the selectivity value of the frequency. Transistors and op-amps are used by active filter circuits to transfer a narrow frequency band, thus attenuating the majority of the signal. The concept illustration of an active filter circuit is as shown in Figure 2; the active high pass (HP) filter is built to have a cut-off frequency of 1 kHz and a gain of 1 by using Equation (1) to achieve voltage gain and simulate it in the Proteus software. \( A_v \) refers to voltage gain, and \( R_a \) and \( R_b \) refer to resistance. From this section, active high pass filter is presented from the first order stage until fourth order stage. Using the basic method shown in Equation (2), it is possible to find the cut-off frequency and corner frequency or -3 dB point of the high pass filter. Generally, because of higher operating rates, the high pass filter is less distorting than the comparable low pass filter. \( f_c \) corresponds to the cut-off frequency, \( R \) refers to resistance, and \( C \) refers to capacitance.

\[
A_v = \frac{R_a}{R_b} + 1 \quad (1)
\]

\[
f_c (Hz) = \frac{1}{2\pi RC} \quad (2)
\]

2.2. First Order Stage Active High Pass Filter
A first order (single-pole) stage active high pass filter, as its name implies, passes high frequency signals and attenuates low frequencies. It essentially consists of a passive portion of the filter accompanied by a non-inverting operational amplifier. Figure 2 indicates the active high pass filter by using op-amp circuit. The first order stage circuit has an input signal of 700 V and a fixed frequency of 50 Hz.
2.3. Second Order Stage Active High Pass Filter
The first order stage high pass active filter can be transformed into a second order stage high pass filter along with the passive filter simply by utilizing an additional RC network in the input direction. Therefore, the design measures needed by the active high pass filter of the second order are the same. Figure 3 indicates the second order stage active high pass filter with op-amp circuit. This circuit is in the second order stage and has a 700 V input signal and a 50 Hz frequency.

Figure 3. Second order stage active high pass filter circuit.
2.4. Third-Order Stage Active High Pass Filter

An additional block of an RC network is connected to the second order stage high pass filter at the input direction of the third order stage high pass filter to filter a signal by blocking certain frequencies and passing others. The active high pass filter using an op-amp is as shown in Figure 4. The circuit is in the third order stage and has a 700 V input signal and a 50 Hz frequency.

![Figure 4. Third order active high pass filter circuit.](image)

2.5. Fourth Order Stage Active High Pass Filter

An additional block of an RC network is connected to the first order stage high pass filter at the input direction of the fourth order stage high pass filter. Figure 5 illustrates the active stage high pass filter using op-amp. The circuit is in fourth order stage and has an input signal of 700 V with the frequency of 50 Hz.

![Figure 5. Fourth order stage active high pass filter circuit.](image)

2.6. First Order Stage Passive High Pass Filter

In comparison, the active filter, along with the resistors and capacitors, but not the inductors, uses active components such as op-amps. The high pass filter activates higher frequencies than the cut-off frequency, 'fc', and prevents lower frequency signals. On the basis of the figure, the first order stage circuit is only one reactive part with resistor. The passive high pass is as seen in Figure 6. The circuit has an input signal of 700 V and a frequency of 50 Hz and is of the first order stage.
2.7. Second Order Stage Passive High Pass Filter
It can produce the second order stage high pass filter by cascading the two first order high pass filters. Since it consists of two reactive elements, the two condensers shape the second order stage of the circuit. The efficiency of this two-stage filter is equivalent to the single-stage filter, except at -40 dB/decade where the filter slope is reached. The passive high pass filter occurs in Figure 7. The second order stage circuit has a 700 V input signal and a 50 Hz frequency. Table 3.1 shows a summary of types of filter, number of order, and types of frequency.

3. Results and Discussion
In this research, all the circuits have been simulated in the Proteus and Multisim. The active high pass filter or passive high pass filter is set at low frequency of 50 Hz and high frequency of 8 kHz. This research showed the performance result from active high pass filter in first order stage until fourth order stage and passive high pass filter for first and second order stages. Overall, frequency response result of active and passive high pass filters was compared from all circuits of each order stage and each voltage response and data was collected and tabulated.

3.1. Comparison result for Active High Pass Filter and Passive High Pass Filter
To suppress noise along the PD, the Active HP filter is the best option because it did not need any attenuation at output to provide signal gain. In active HP filter, high quality factor or Q-factor was suitable for PD situations. The higher the Q-factor, the narrower and the more selective the filter is. It increased the Q-factor by increasing the filter order. In order to design a filter circuit that adjusts output accordingly to any slight changes in frequency, the active filter is more effective for suppressing PD
noise because it is more sensitive. The overall value of the shift or gain function can be greater than the unit relative to the active filter and the passive filter. Table 1 display the result of voltage response output and frequency response. Lastly, precision decreases, as the distance between the true stopband response and the theoretical stopband response expands as the filter order increases. This is why the most effective protection area is to use the fourth order filter. The larger the frequency of the filter, the narrower the transfer band and the rate roll is the highest.

**Table 1.** Overall result of active high pass filter and passive high pass filter voltage response output and frequency response.

| Types of filter         | Number of order stage | Low frequency (50 Hz) | High frequency (8 kHz) |
|-------------------------|-----------------------|-----------------------|------------------------|
|                         |                       | Output voltage         | Decibel (dB)           | Output voltage         | Decibel (dB)           |
| Active high pass filter | First order           | 11.137 V              | -47                    | 965.897 V              | -47                    |
|                         | Second order          | 13.157 V              | -32                    | 965.901 V              | -32                    |
|                         | Third order           | 29.637 V              | -27                    | 989.798 V              | -27                    |
|                         | Fourth order          | 63.814 mV             | -12.5                  | 965.895 V              | -12.5                  |
| Passive high pass filter| First order           | 13.146 V              | -40                    | 975.536 V              | -40                    |
|                         | Second order          | 9.272 V               | -40                    | 970.956 V              | -40                    |

4. Conclusion
The main purpose of this research is to suppress the HV low frequency signal and only pass the HV low frequency signal. An electrical filter comes in many types, and controlling all of them with a single circuit is plausible, but requires a lot of components, especially considering the available HV voltages. The circuit constructed in this research is made specifically for suppressing the low frequency noise with good quality factor, high roll of rate, and lesser transition band. Modelling a filter for operating HV depends on the component selection. In conclusion, an electrical filter has many variables that need to be calculated and observed before designing. The most important factors are what voltage is applied to filter, and frequency range or bandwidth. After those two factors are figured out, some design parameters need to be considered including cost, space, precision, and temperature. The overall result shows that when the number of each order is increasing in low frequency of 50 Hz, the active high pass filter and passive high pass filter output voltage keep on reducing. At high frequency of 8 kHz, the output voltage of different number of order achieves almost the same value for both types of filtering circuit. The overall output voltage filtering circuit is higher in frequency compared to low frequency of PD measurement. Finally, it is concluded that the frequency response of active filter is better than passive filter. Active filter is almost suitable for partial discharge system. Besides, the result of frequency response shows that higher number of order has a faster roll rate. At the same time, an active filter output voltage is the same as input voltage at higher frequency. From this research, analysis result demonstrates that fourth order stage in active high pass filter has better performance in PD system as it has the highest roll and is more precise among others.

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Acknowledgements

The authors would like to acknowledge University Malaysia Perlis and the Malaysian Ministry of Higher Education for providing the Exploratory Research Grant Scheme (ERGS Grant No: 9010-00028), which made this study possible to be conducted and successfully published.