COMPARISON OF DIFFERENT IMPULSE CURRENT MEASUREMENT METHOD DURING LONG AIR GAP BREAKDOWN

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Abstract: Current is an important characteristic parameter to reveal the whole progression of long air gap discharge. It is difficult to measure the transient current at the high voltage side during breakdown because of high potential of instrument, large current amplitude, and the electromagnetic interference. In this paper, the advantages and disadvantages of instrument based on Rogowski coil, Current shunt, Electro-Optic Modulator were introduced and the properties of different methods were compared by experiment. Electromagnetic interference protection circuits for each instrument were applied during tests. Frequency spectrum characteristic of Partial Discharge, linearity and response time were measured and these characteristics can reveal the performance of different methods during measuring the breakdown current at the high voltage side. The waveform of current impulse that was measured at the high voltage side was performed and the effect of electromagnetic interference protection circuit was discussed. Current shunts and modulators can measure the DC component but coil can't. Comparing to modulators, current shunts can acquire the current of pre-discharge and the current of breakdown in one discharge. Current shunt would be the most appropriate device for the observation of current in long air gap discharge.

1 INTRODUCTION

Observing the process of long air gap discharge is an important method to study the characteristics of streamer and leader. In order to study this process, measuring the current is necessary. However, the most difficult task is measuring the current at the high voltage side because of the high electromagnetic interference level when the process of breakdown is completed. Although many methods, such as Rogowski coil[1][2], Current shunt[3], Electro-Optic Modulator and etc., can be used in electrical current measurements at high voltage side nowadays, comparison of these methods is seldom performed before.

Rogowski coil and current shunt are the most popular tools to measure the current at the high voltage side. For the observation of lightning, Rogowski coils are preferred because of the outstanding high frequency response.For the waveform produced by the current of lightning, it is enough to capture although the amplitude of the waveform has been changed because DC component can't be detected by coil.

For theory, Rogowski coil and electro-optic modulator have the advantages in the electromagnetic interference protection because none of them has the direct electro connection with the main circuit but Rogowski coil can't be used to measure the direct current component and electro-optic is sensible for the temperature. The disadvantage of current shunt is better electromagnetic interference protection is needed and the advantage is DC component can be measured. Influence caused by temperature is little compares to the electro-optic modulator.

In this paper, Rogowski coil (Current range: 1A-10kA, Frequency range: 30Hz-25MHz), Current shunt (Current range: 10mA-3kA, Frequency range: DC-50MHz), Electro-Optic Modulator (Current range: 20A-1000A, Frequency range: DC-25MHz) are used to measure the current at the high voltage side. The results (frequency response, linearity and sensitivity) will be compared and analysis

2 STRUCTURE OF THE ACQUISITION UNIT

EMI protection circuit is necessary for measuring the current produced by high voltage impulse. The scheme of the structure has been showed in Figure 1.

Metal box is made of iron with copper plated. Semi-sphere electrode can be replaced by different shape electrode. Current shunt resistor of 0.1Ω with a bandwidth of DC to 10MHz can be replaced by Rogowski coil with a bandwidth of 30Hz to 25MHz. Acquisition unit is consist of NI digitizer, trigger unit and optical fibber transmission system. It can be replaced by electro-optic modulator. Protection unit consist of 33nF capacitors and bidirectional TVS diodes.

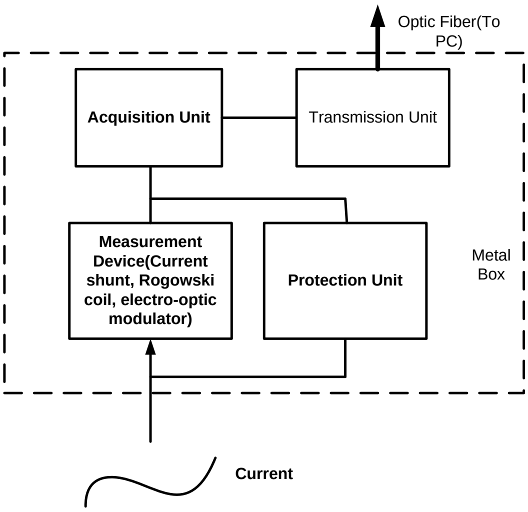

Figure 1: The scheme of the structure of EMI protection circuit

3 CHARACTERISTICS OF MEASURE INSTRUMENT

In this part, characteristics of instruments based on current shunt, electro-optic modulator and Rogowski coil will be discussed. For the process of pre-discharge measureing in air gap, the time is about several hundred nanoseconds [4][5] and the current is about several hundred micro amperes. When the gap is breakdown, the maximum current is about 2000A to 3000A. Therefore, measuring instrument requires the frequency response of at least DC-1MHz and the measuring current range of 100mA to 3000A. In this transient process, linearity, sensitivity and frequency are standard to compare the performance.

3.1 Linearity

Linearity shows the relationship between the amplitude of injected current waveform and the signal. In order to acquire the linearity of measurement instrument, a test circuit shown in Figure 2 is used. The injected current is measured by a standard current sensor.

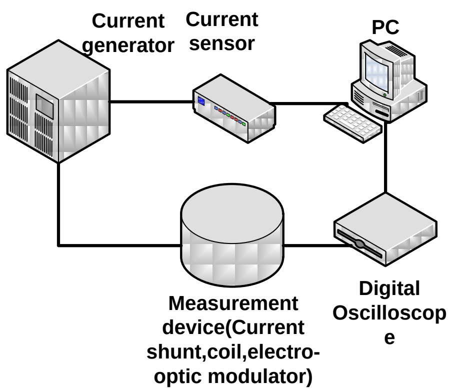

Figure 2: The scheme of the test circuit that use to measure the linearity

The linearity of Rogowski coil, current shunt and electro optic modulator is shown in Figure 3-5

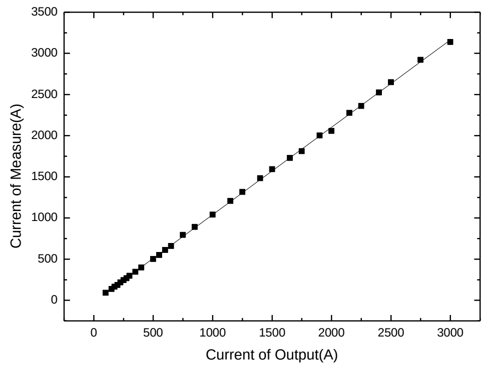

Figure 3: Relationship between the injected current and the measure result of current shunt

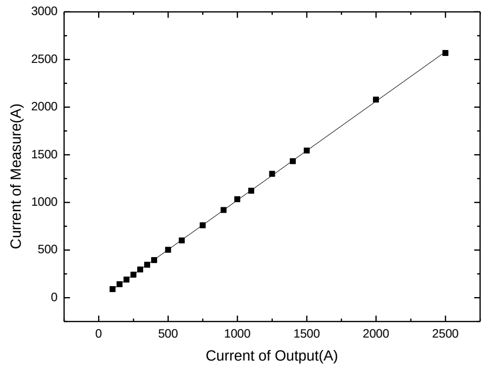

Figure 4: Relationship between the injected currentand the measure result of Rogowski coil

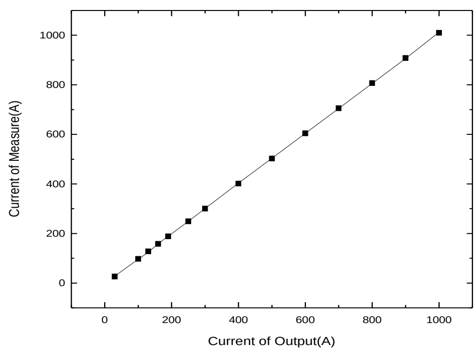

Figure 5: Relationship between the injected currentand the measure result of electro-optic modulator

From Figure 3-5, when the amplitude of measuring current is in the range of 20A to 1000A, the linearity of current shunt, Rogowski coil and electro-optic modulator is smaller than 0.5%. When the amplitude of current goes beyond the range (for example, 200mA or 3000A), current shunt and Rogowski coil can keep this linearity but the linear relationship between the output signal and the measuring signal of electro-optic modulator will wrap.

3.2 Response Time

Response time shows the reaction time after the triggered signal has been released. In order to acquire the sensitivity of measurement device, the circuit has been shown in Figure 6 is used.
The following directions serve the purpose of obtaining a uniform layout.

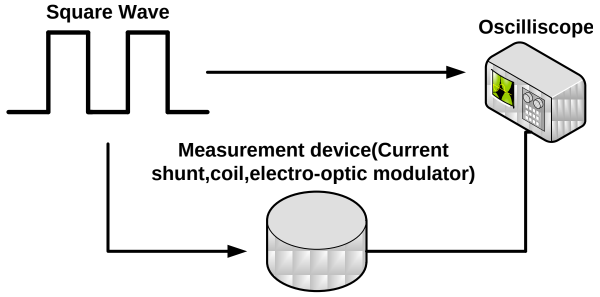

Figure 6: The scheme of the test circuit that use to measure the sensitivity

The Sensitivity of Rogowski coil, current shunt and electro optic modulator has been shown in Table I

Table 1: Reaction time of measurement device

Measurement Device	Reaction time
Current shunt	<20ns
Rogowski coil	<20ns
Electro-optic modulator	<20ns

Because the rising time of waveform that we concerned is about one hundred nano seconds, the reaction time of current shunt, coil and electro-optic modulator can satisfy the propose

3.3 Frequency Response

Frequency response is the measure of any system's output spectrum in response to an input signal. In order to acquire the frequency response of measurement device, the circuit shown in Figure 7 is used

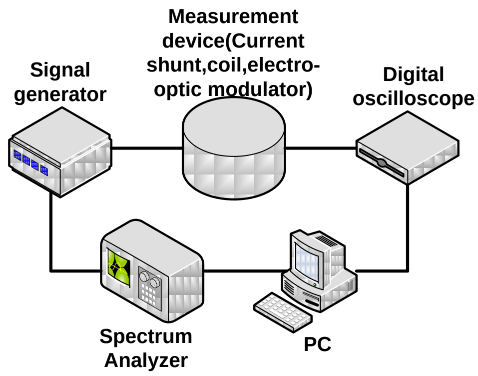

Figure 7: The scheme of the test circuit that use to measure the frequency response

The frequency response of Rogowski coil, current shunt and electro optic modulator has been shown in Figure 8-10

From Figure 8-10, current shunt has the best frequency response. The 3db attenuation bandwidth of is over 50MHz and also can measure the direct current. When the frequency of signal is below 30Hz, the frequency response of Rogowski coil is attenuate because coil can't detect the DC component of signal theoretically. Electro-optic modulator has monotonic decreasing frequency response and can measure the DC component. The 3db attenuation bandwidth of coil and modulator is about 25MHz.

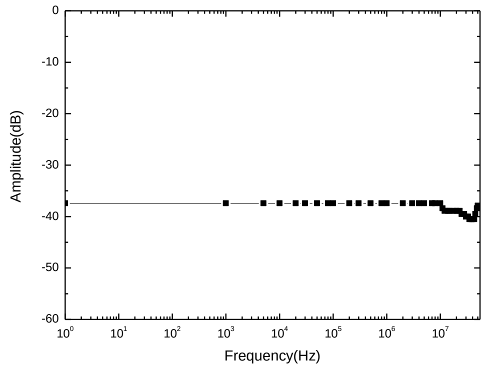

Figure 8: Frequency response of current shunt

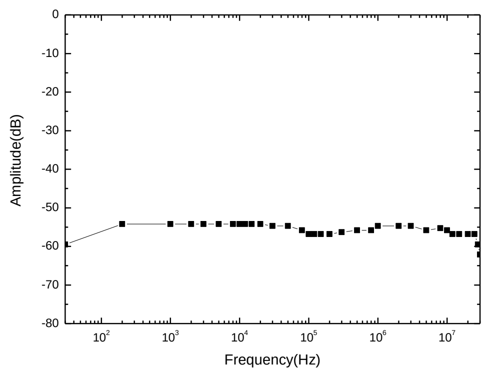

Figure 9: Frequency response of Rogowski

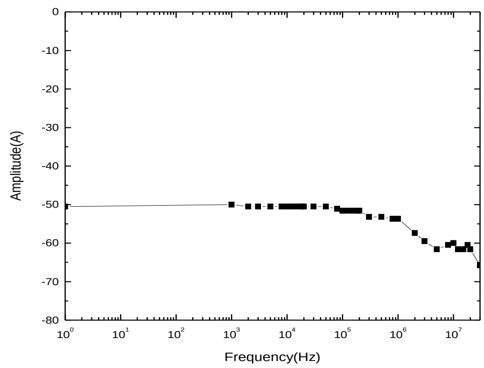

Figure 10: Frequency response of electro-optic modulator

4 EXPERIMENT

This section will compare the waveform measure by different current measuring device through measuring the signal that we know. The signal was generated by a large current generator and the waveform is a lightning impulse of 1.2/50us shape. The max amplitude of the impulse is about 500A. In order to measure the current at the same time, the circuit has been shown in Figure 11 is used.

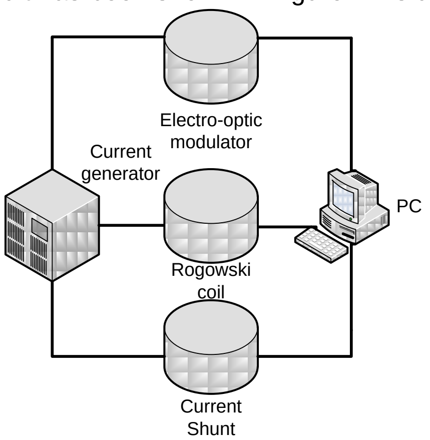

Figure 11: Frequency response of electro-optic modulator

The result has shown in Figure 12.From the figure, the peak of waveform measured by current shunt, coil and electro-optic modulator has a about 3% different. It may be cause by different connection method that we use because the mechanical structure of different measurement device is different. From the result, the half-ware time is about 25us, it is well consistent with the lightning impulse that current generator produced and the results that measurement device (current shunt, Rogowski coil and electro-optic modulator) measured are good in agreement with each other.

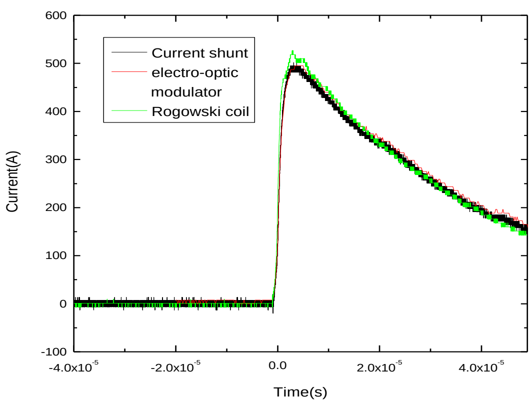

Figure 12: The waveform of 1.2/50us lightning impulse

5 CONCLUSION

In this paper the performances of different measuring device (current shunt, Rogowski coil and electro-optic modulator) are compared. The specifications are as follow: Rogowski coil (Current range: 1A-10kA, Frequency range: 30Hz-25MHz), Current shunt (Current range: 10mA-3kA, Frequency range: DC-50MHz), Electro-Optic Modulator (Current range: 20A-1000A, Frequency range: DC-25MHz). The 3db attenuation bandwidth of all these measuring devices can satisfy the demand of measuring the current during the long air gap discharge . Current shunt and modulator can measure the DC component but coil can't. This may influence the amplitude of peak of waveform that measured. Compare to current shunt and coil, the amplitude dynamic range of modulator is too small. The current shunt can acquire the current of pre-discharge and the current of breakdown in one discharge. In summary, current shunt would be the most appropriate device for the observation of current in long air gap discharge.

6 ACKNOWLEDGMENTS

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