Characteristics analysis of sensors for on-line partial discharge measurement

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Abstract--As the demand of high power system reliability,condition based maintenance (CBM) becomes a better solution for maintaining equipment reliability. According to the diagnostics of CBM, one can estimate the condition of insulator, and find an optima strategy. Among them, on-line partial discharge measurement is one of the most important diagnostics assessing the condition of insulator. However, the majority problem of on-site measurement is the noise distinguishability. Therefore, different manufactories develop their own methods to overcome this difficulty. Unfortunately, different methods utility different sensor varying with bandwidths, and they are difficult to compare the measurement results with each other. Based on these problems, authors test different commercial sensors to assess their characteristics. Authors inject different calibrating signals into the test system including a voltage transformer, and measure the sensitivities, bandwidths, and waveforms of partial discharges. According to results, magnetic sensor has similar sensitivity with coupling capacitor, and UHF sensor has better signal to noise ratio. Based on this paper, one may compare different measurement results from different instruments to estimate the condition of insulator.

***Index Terms*--partial discharge, sensitivity, sensor**

I. INTRODUCTION

As the requirement of power system reliability increases,the condition based maintenance (CBM) shows an effective approach to maintain high reliability economically.According to the results of condition assessment, user replaces equipments with bad insulation before accident, or extends lifetime of equipments with good insulation as the designed lifetime elapsed. Based on conditions assessment, the system reliability can increase effectively and economically. Among the means of condition assessment, on-line partial discharge measurement (PDM) is a useful diagnosis used to assess insulation condition.

The difficulty of on-line PDM is to distinguish between partial charge signal and background noise. And there is much effort done in literatures and researches. Because the background noise usually spread in relatively lower frequency range (below 30 MHz in authors' experience), the majority method to overcome the difficulty is to increase the signal-to noise ratio (SNR) by increasing measuring frequency. Hence, manufacturers utilize varies measurement frequencies depending on themselves' experiences, and the instruments show different sensitivities and measured bandwidth.Unfortunately, the measurement results conducted by different manufacturers usually can't be compared with each other directly. Many researches focus on the high voltage/extra high voltage equipments, such as GIS, Oil-TR, EHV Cable.The used frequency bandwidth is usually in the range of UHF and VHF, and the background noise is also simply. The measured frequencies used for on-line PDM on medium voltage are more varies, and the sensors used for measurement are also different. Therefore, this paper compared the characteristics of common sensors used for medium voltage, including waveform, spectrum, and sensitivity.

Firstly, authors inject predefined charge into test circuit and measure the responses of tested sensors. In the calibration results, the sensitivities of coupling capacitor and transient magnetic field sensor have good sensitivity, and close bandwidth. Then, a disqualified voltage transformer is tested to compare the characteristics of these sensors under real partial discharge signal. Under conventional partial discharge diagnosis, coupling capacitor and transient magnetic field sensor also show good sensitivity, and close bandwidth. Besides, UHF and transient electromagnetic field sensor have large measured frequency, and could have good performance with good amplifier and filter in dirty electric environment.

II. SENSITIVITY CHECK

This section mainly compares the characteristics of mentioned sensors, including the difference of sensitivity and frequency bandwidth. A charge calibration generator is used as the partial discharge source, injecting varies quantities into test circuit. Figure 1 is the diagram of the test circuit and the test arrangement. A disqualified 24 kV potential transformer is taken as the test object. There are six sensors tested here, one for conventional PDM: coupling capacitor (CC), and five for on-line PDM: transient magnetic field sensor (TM), ultrahigh-frequency sensor (UHF), high frequency current transformer (HFCT), and transient electromagnetic field sensor (TEM). Among them, CC, TM, UHF, HFCT measure partial discharge currents in different frequency bandwidth. TEM sensor measure the change of transient electromagnetic field like antenna.

Figure 2 shows the sensitivity comparison of these sensors X-axis is the quantity of injected charge, and Y-axis is the magnitude measured by these sensors. As shown in figure 2, the voltages measured by coupling capacitor show the

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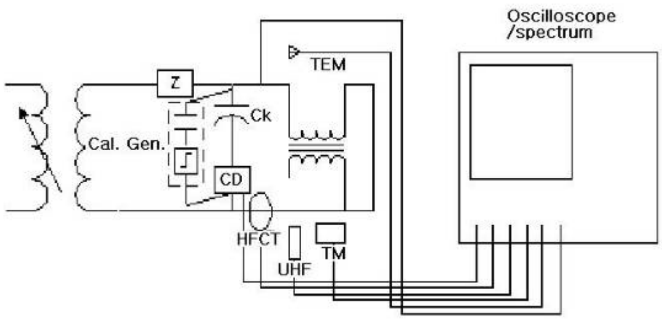
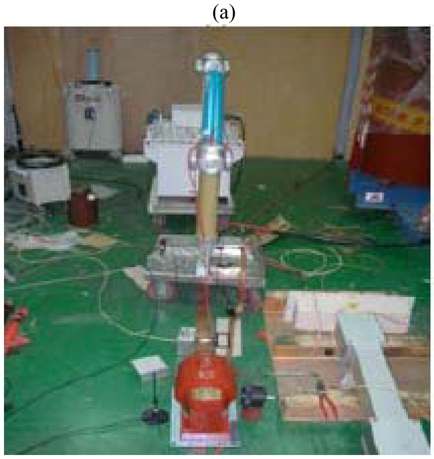


(a)



(b)

Fig. 1

strongrelationship with the injected charges, and TM sensor is second. UHF, TEM and HFCT sensors also show the positive relationship with the injected charges, but them can't sense any signal caused by the injected charges until the injected charge is larger than 20 pC.

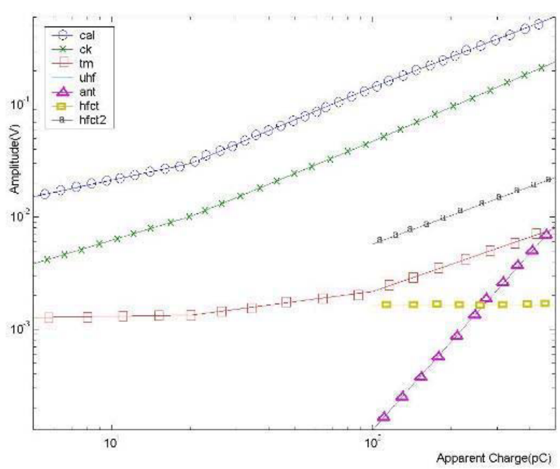
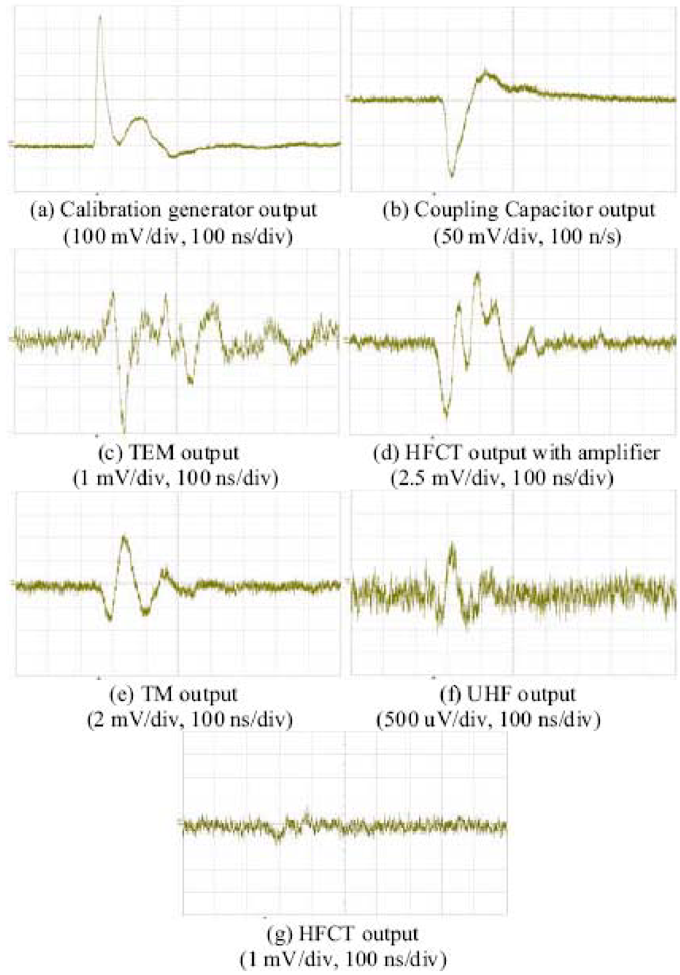


Figure 2

Figure 3 show the waveforms measured by oscilloscope with 500 pC injected charge. CC has well-damped waveform due to the relatively narrow bandwidth. The waveforms measured by TM, TEM, UHF, and HFCT oscillate inspired by thepartial discharge signal. Well-damped waveform can be used to calculate the quantity of partial discharge by integrating the waveform, as conventional PDM done, and oscillating waveform can't. Therefore, the better way representing the degree of partial discharge activity measured by on-line PDM is the amplitude of the waveform (uV, mV), instead of apparent charge.



(a) Calibration generator output (100 mV/div, 100 ns/div)

(b) Coupling Capacitor output (50 mV/div, 100 n/s)

(c) TEM output (1 mV/div, 100 ns/div)

(d) HFCT output with amplifier (2.5 mV/div, 100 ns/div)

(e) TM output (2 mV/div, 100 ns/div)

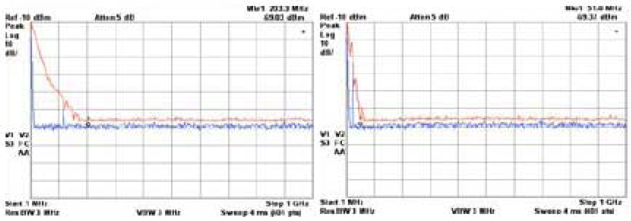
(f) UHF output (500 uV/div, 100 ns/div)

(g) HFCT output (1 mV/div, 100 ns/div)

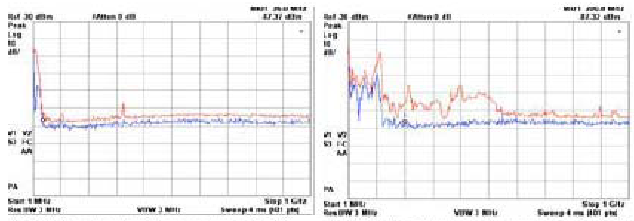
Figure 3 measured waveforms of different sensors at 500 pC apparent charge

Figure 4 is the frequency spectrums of these sensors with 500 pC injected charge. HFCT shows the narrowest measured bandwidth about 30 MHz. CC and TM have similar measured bandwidth about 50 MHz, and UHF and TEM have the widest measured bandwidth. Comparing figure 3 with figure 4, the higher the measured bandwidth is, the waveform oscillates more.

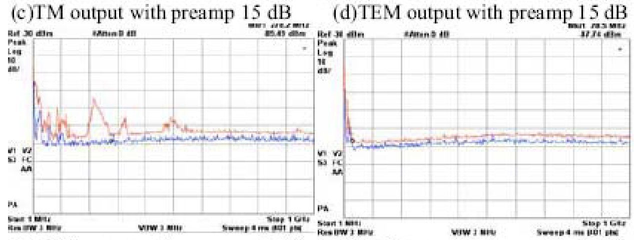
Among the sensors used herein, the characteristic of TM is similar to CC. UHF and TEM have lower sensitivities but wider measured bandwidths. HFCT has lowest sensitivity without amplifier and measured bandwidth. Therefore, TM will be a good choice for on-line PDM while the background noise is low. UHF and TEM will have better performance with proper amplifier to improve their sensitivity, and will be useful for dirty electric environment with filter to filter out noise.



(a) Calibration generator output (b) coupling capacitor output
without preamp without preamp



(c)TM output with preamp 15 dB (d)TEM output with preamp 15 dB



(e)UHF output with preamp 15 dB (f)HFCT output with preamp 15 dB

Figure 4

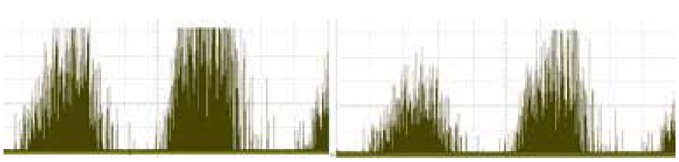
III. FIELD MEASUREMENT

Because the property of charge calibration generator and actual partial discharge source may be different, authors apply voltage to the disqualified voltage transformer, gradually increasing to rated voltage 24 kV. The wiring diagram is the same as figure 1 except the absence of charge calibration generator.

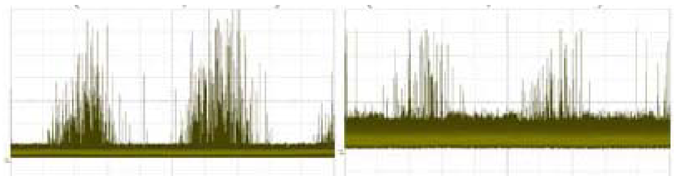
As the applied voltage reached 19 kV, there are partial discharge activities detected by conventional PDM, and the PD reading is 20 pC. At the same time, on-line PDM sensors do not detect any abnormal signal.

Continuing to increase voltage to 24 kV, partial discharge activities increase, and the reading of apparent charge is 2000 pC by conventional PDM. Figure 5 shows the phase-resolved pattern measured by different sensors, and they show the same property with conventional PDM.

(a) voltage reference (b) voltage reference
(10 V/div, 2 ms/div) (10 V/div, 2 ms/div)



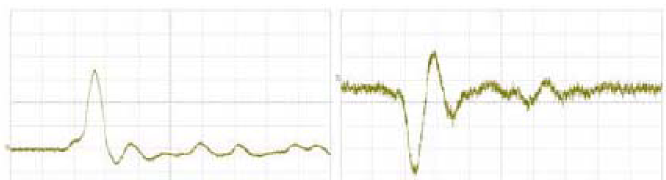
(c)coupling capacitor output (d) TM output
(76 mV/div, 2 ms/div) (7.6 mV/div, 2.0 ms/div)



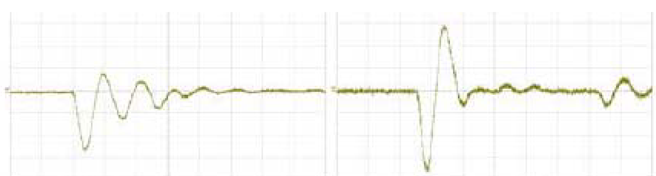
(e) UHF output (f) TEM output
(2.01 mV/div, 2 ms/div) (1.5 mV/div, 2.0 ms/div)

Figure 5 Phase-resolved pattern@24 kV, 1000 pC

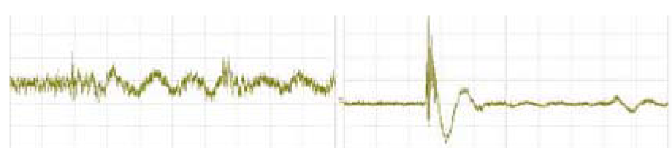
FIgure 6 and figure 7 is the waveforms of single partial discharge signal measured by different sensors at the same trigger level, and it is quite same as figure 3. Comparing figure 6(f) and figure 7(b), CC has similar amplitude at two figures, but UHF don't. It implies that the same reading of apparent charge by conventional PDM may be resulted from different partial discharge source, and will be ranged widely in frequency. This is one reason why phase-resolved patterns of conventional PDM and on-line PDM will be different sometimes.



(a) coupling capacitor output (b) HFCT output
(200 mV/div, 100 ns/div) (2.0 mV/div, 100 ns/div)

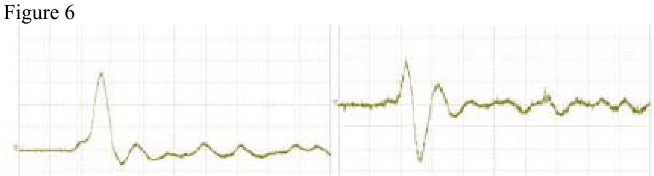


(c)HFCT output with amplifier (d) TM output
(50 mV/div, 100 ns/div) (10 mV/div, 100 ns/div)



(e) TEM output (f) UHF output
(2.0 mV/div, 100 ns/div) (5.0 mV/div, 100 ns/div)

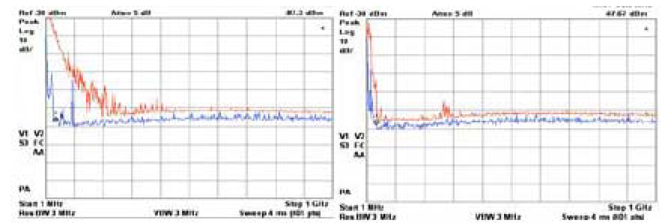
Figure 6



(a) coupling capacitor output (b) UHF output
(200 mV/div, 100 ns/div) (4.0 mV/div, 100 ns/div)

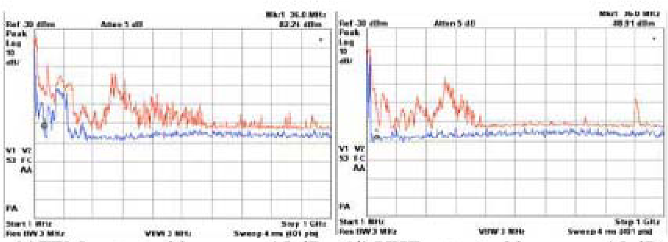
Figure 7

Figure 8 is the spectrums of partial discharges measured by different sensors. The properties of measured bandwidth are similar to figure 4.

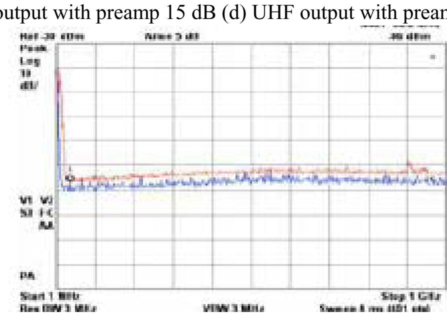


(a) coupling capacitor output (b) TM output
with preamp 15 dB with preamp 15 dB

Fig. 8



(c)TEM output with preamp 15 dB (d) UHF output with preamp 15 dB



(e) HFCT output with preamp 15 dB

Fig. 9

IV. CONCLUSION

As shown in figure 3, figure 6, and figure 7, the degree of partial discharge activity measured by on-line PDM is better represented in terms of the amplitude of oscillation waveforms, rather than apparent charge. Table 2 shows that coupling capacitor has best sensitivity among test sensors, and transient magnetic field sensor has best sensitivity among sensors for on-line PDM. The bandwidths of these two sensors are below 50 MHz, and the frequency spectrum of background noise in authors' experience spread up to 40 MHz as shown in figure 9. Therefore, advanced filter technique may need to be adopted in the dirty electric environment, and some partialdischarge-like noise also needs to be taken into account. As mentioned above, UHF and TEM sensors have good SNR due to their high measuring and wide bandwidth, and they have worst sensitivity among tested sensors. Moreover, An amplifier can amplify the partial discharge signal only as the sensor measured the signal. Hence, the amplifier can only improve the SNR rather than the sensitivity of UHF and TEM. Due to this reason, small degree of partial discharge activity may not be measured by UHF and TEM sensors even though good amplifier and filter are adopted. This will shorten the measurement period of on-line PDM.

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