Simulation of Partial Discharge Location in Medium-Voltage Power Cables

Keng-Wei Liang[1], Chang-Hsing Lee[1], Min-Yen Chiu[1], Chen-Li Fan[2], Yu-Chih, Lin[3]

[1]Power Diagnostic Service Co., Limited
[2]Taiwan Power Research Institute, Taiwan Power Company
[3]National Synchrotron Radiation Research Center, Hsinchu, Taiwan
Hsinchu City, Taiwan
javis@pdservice.com

***Abstract*—The medium voltage power cable with defects may generate partial discharge. An accurate location method of partial discharge source will protect system by repairing it as soon as possible. The conventional location methods, Time Delay Reflection (TDR) and Double-sided measurement, have different disadvantages. This paper proposes an accurate location method of partial discharge source, and improves the disadvantage of traditional location methods that the algorithm is related to time. Recognition and Synchronization are the problems. Our paper developed a location method having nothing to do with time, and used MATLAB to simulate the signal traveling along the cable under different environment to prove that the method is work.**

Keywords- Partial discharge, TDR.

I. INTRODUCTION

Partial discharge (PD) generates high frequency impulses in the insulation of the cable, and the impulses will propagate to the both end of the cable. It can be measured this partial discharge signals from the end of cable, which offers the effective information about the cable (i.e. Cable damaged status, the location of discharge).

There are two kinds of different measurements, off-line and on-line, to detect partial discharge of cables. In conventional off-line testing, the cable will be isolated from the system, connected to couple capacitor in parallel, and applying voltage by external equipment. This method may take more time to measure, but it can detect in a farther distance due to the PD signals transmit in the cable.

The method of on-line testing is installing sensors to the ground wire on the cable without cutting off the power. The advantage is easy to detect the PD signals and can process a lot of measurements at the same time. The disadvantage is the high frequency discharge signal only can be measured in a neighboring distance, as the PD signals propagate in the ground wire. The higher inductance of the ground wire and the frequency is, the impedance will be higher and the signals decay more. However, using lower measurement frequency, the background noises have to be concerned.

The common method to locate PD signals is TDR (Time Delay Reflection)[1].The impulse generated by PD will propagate to the both end of the cable. Receiving an original signal from one end and the reflecting signal will be produced at the another open end when the impulse arrive there. There will be a time delay between the receiving signal and the original one, this is because of the transmitting distance is further.

L_a is the distance for the original signal propagates during the time delay, and for the reflecting signal is $2L_b + L_a$

Therefore, it can be estimated the PD location by the propagation time delay in the Fig. 1.

TDR doesn't work when the cable length is too long to receive the reflecting signal or when there is high background noise. How to recognize the reflecting signal should be also considered when uses this method, as the signal is received from one single side of the cable. There will be a much series mistake if judging the un-reflection impulse as the reflection one.

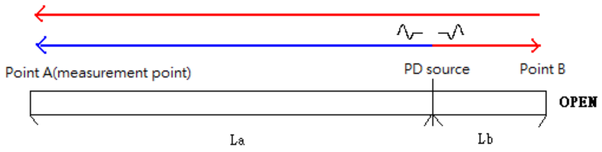

Figure 1. TDR method

Another method to locate PD is Double-sided measurement [1].Put sensors in both side of the cable, it can locate the PD by getting the time difference of the signal propagating. L_a , L_b are the distance from the PD source to the two sensors respectively to locate PD source. The method can overcome the two restrictions of TDR. First limit is under the condition the end of the cable is not open end, there might be no reflection impulse produce or only few reflection impulse. Second limit is when the decay rate of the cable is higher, the amplitude of the reflection impulse might less than the background noise. In order to calculate the time difference between two sides, synchronic signal is needed. Under the condition with an extremely long cable, it is unable to trigger by using Ethernet or transmission line but to synchronize by global positioning system (GPS)

In practice [2], the error of using GPS signal to synchronize will be 180 ns. That means the error of the PD location will be 36 m when the transmission rate is 200m/us. The accuracy of PD location will be affected by the error of synchronic signal, because this error is not constant so that it can't be calibrated.

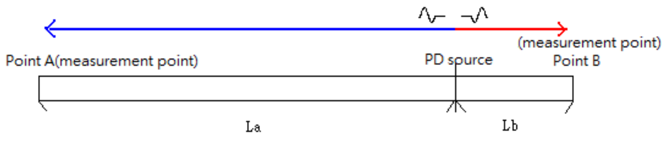

Figure 2. Double-Sided measurement

Here is a new method to solve the problem of synchronic signal, which contains the advantage of Double-sided measurement. Theoretically the exponential of decay in the cable is proportional to the length of the cable. The PD source can be known by calculating the decay ratio between the two received signals from the two ends of the cable.

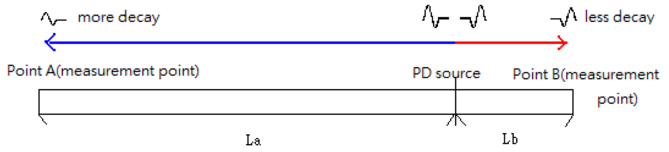

Figure 3. The method in this paper

The following content is to simulate signal decay in the cable and locate the PD source by using MATLAB.

II. METHOD OF PARTIAL DISCHARGE LOCATION

In the transmission line model, the feature of the cable can be modeled as a constant term

$$\gamma(\omega)=\sigma(\omega)+j\beta(\omega)=\sqrt{Z(\omega)Y(\omega)} \qquad (1)$$

$\sigma(\omega)$ is the attenuation constant, (multiple/meter)

$\beta(\omega)$ is the phase constant, (arc/m)

$Z(\omega)$ is the impedance of the cable and the admittance

$Y(\omega)$ is the function of the angle frequency ω

The transfer function of cascade-coupled cables can be calculated by [1], which is the cable can be modeled N cascade cables.

$$H_{cascade}(\omega,z)=\prod_{j=1}^{N} e^{-\gamma_j(\omega)l_j}\tau_{(j\to j+1)}(\omega) \qquad (2)$$

where l_j is the length of the j-th cable, z is the total length of cascade-coupled cables, $\tau_{(j\to j+1)}(\omega)$ is the transmission coefficient from the j-th to the (j+1)-th cable, and $\gamma(\omega)$ is the propagation constant that constant term mentioned above.

$$\tau_{(j\to j+1)}(\omega)=\frac{2Z_{c,j+1}(\omega)}{Z_{c,j+1}(\omega)+Z_{c,j}(\omega)} \qquad (3)$$

$Z_{c,j}(\omega)$、$Z_{c,j+1}(\omega)$ are the impedances of the j-th and the (j+1)-th cable, respectively. $\sigma(\omega)$ is the attenuation constant, $\beta(\omega)$ is the phase constant, and $Z(\omega)$ 、 $Y(\omega)$ are impedance and admittance, respectively.

The single cable with open end is only researched in this paper. The transfer function (2) mentioned above can be reduced to:

$$H_{one\,section}(\omega,z)=e^{-\gamma(\omega)z} \qquad (4)$$

The relation between the propagation signal and the distance can be described as follows:

$$V(\omega,z)=H_{one\,section}(\omega,z)V(\omega,0) \qquad (5)$$

The above equation represents that the signal magnitude attenuated and phase changed after propagating z meter at ω. Representing the transfer function as $H_z(\omega)$.

Supposing that the length of the cable is L(meter)and the propagation constant is γ.The distances between the two ends of the cable (a and b) and the discharging source are L_a, L_b respectively. The PD signal in PD source represents x ,and $x_a(n)$, $x_b(n)$ represent the received signals in two ends of the cable.

$$x_a(n)=h_a(n)\otimes x(n)+x_n(n)$$
$$x_b(n)=h_b(n)\otimes x(n)+x_n(n) \qquad (6)$$

$h_a(n)$, $h_b(n)$ are the impulse responses which are from PD source to the A-side and B-side.

Without considering the background noise($x_n(n)=0$), transferring the receiving signals $x_a(n)$, $x_b(n)$ into the frequency domain $X_a(k), X_b(k)$ by Fast Fourier Transform (FFT) (7)

$$X(k)=\sum_{n=0}^{N-1}x(n)e^{\frac{-j2k\pi n}{N}} \tag{7}$$

The equation (6) mentioned above is changed into:

$$\begin{aligned} X_a(\omega) &= H_{L_a}(\omega)X(\omega) \\ X_b(\omega) &= H_{L_b}(\omega)X(\omega) \end{aligned} \tag{8}$$

$H_{L_a}(\omega), H_{L_b}(\omega)$ are $h_a(n), h_b(n)$ of FFT, which is the transfer functions from the PD source of the cable to the both end. Thus the formula of the magnitude ratio between $X_a(k)$ and $X_b(k)$ will show as follow:

$$\frac{|X_a(\omega)|}{|X_b(\omega)|}=\frac{|H_{L_a}(\omega)X(\omega)|}{|H_{L_b}(\omega)X(\omega)|}=\frac{|H_{L_a}(\omega)|}{|H_{L_b}(\omega)|} \tag{9}$$

From Equation (4):

$$\frac{|H_{L_a}(\omega)|}{|H_{L_b}(\omega)|}=|e^{-\gamma(\omega)(L_a-L_b)}|=e^{-\sigma(\omega)(L_a-L_b)} \tag{10}$$

The natural log of both side can be gotton as follow:

$$\ln(\frac{|X_a(k)|}{|X_b(k)|})=-\sigma(\omega)(L_a-L_b) \tag{11}$$

Simultaneous equation can be solved by another equation $L=L_a+L_b$

$$\begin{cases} L_a=[\dfrac{L}{2}+\dfrac{1}{2\sigma(\omega)}*\ln(\dfrac{|X_a(k)|}{|X_b(k)|})] \\ L_b=[\dfrac{L}{2}-\dfrac{1}{2\sigma(\omega)}*\ln(\dfrac{|X_a(k)|}{|X_b(k)|})] \end{cases} \tag{12}$$

Thus the PD source from the 2 sides of the cable can be got without the synchronic signal.

III. SIMULATION OF PARTIAL DISCHARGE LOCATION

Supposing the impedance of cable length is $Z(\omega)=a+j\omega b$ and admittance $Y(\omega)=c+j\omega d$ to derive the transfer function $H(\omega,z)$ in the Fig. 4. Assuming the PD source are at 1km and 0.6km from the two ends, a and

b. Input the signal of the noise ratio(SNR) is 32db.

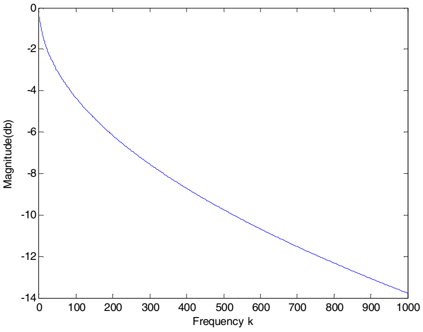

Figure 4. Transfer function of H

Using the three sin signals in difference frequencies gets the signal x and simulating the PD signal from the PD source in the Fig. 5. Let the signal x passing the transfer function $H(\omega,z)$ and add white Gaussian noise to get the signals of the both end $x_a(n)$ 、 $x_b(n)$ in the Fig. 6 and 7.

Then transferring $x_a(n)$ 、 $x_b(n)$ into the frequency domain.

Three obvious impulses can be observed from Fig. 8 and 9. The impulses represent three sin signals with different frequency, and taking these signals to calculate the PD source in the simulation. There will more frequencies in a normal PD testing, thus practically, it is propose to take out the larger magnitude frequency.

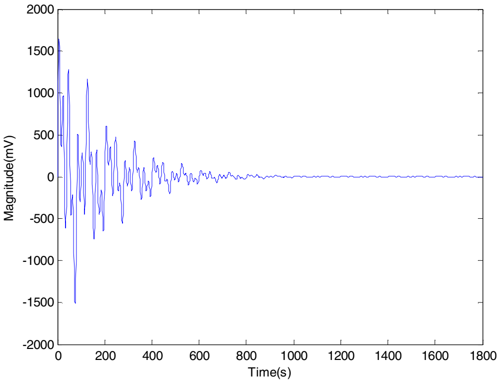

Figure 5. PD source signal(Simulation)

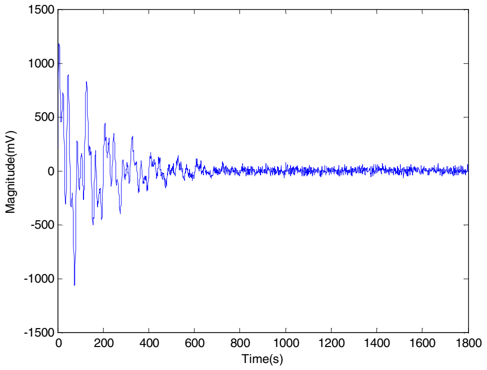

Figure 6. Signal of Point B in the Fig. 3

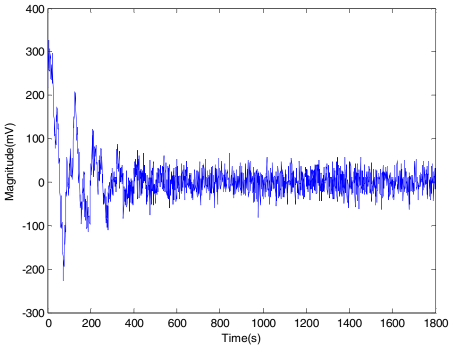

Figure 7. Signal of Point A in the Fig. 3

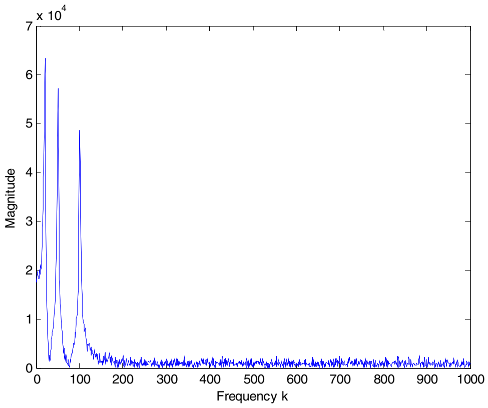

Figure 8. Frequency response of Point B in the Fig. 3

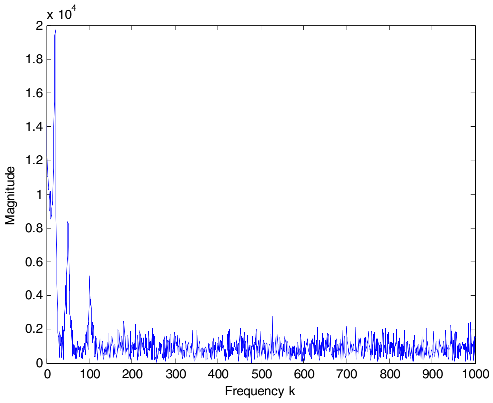

Figure 9. Frequency response of Point A in the Fig. 3

Input SNR means the SNR of PD source. When the signal propagates to the both ends, the SNR will reduce because of the signal decay. Therefore, the farther distance from PD source to the end, the more error by noise will cause in the Table 1.

TABLE I. RELATION BETWEEN ERROR AND SNR

	error(meter)
No noise	0m
Input SNR = 32db	43.3m
Input SNR = 20db	121.5m

In theory, it can be located PD source precisely by this method only if knew the propagation constant of the cable. This method can also save the hardware cost and reduces the error from synchronization.

IV. CONCLUSION

This paper addresses a new location method of PD source. The new location method mainly adopts the waveform attenuation under certain frequency to calculate the location of PD source, rather than utilizing the waveform identification and time synchronization. Hence, the recognition problem in TDR and the synchronization problem in double-side measurement can be avoided. Moreover, the errors caused by hardware could also be compensated by the calibration at preliminary arrangement.

TABLE II. METHOD COMPARISON

	advantages	disadvantages
TDR	Less hardware cost, easy to calculate	Reflected signal decay, Recognition problem
Double-Sided Measurement	No reflected signal problem, easy to calculate	Synchronization problem
Method in this paper	No reflected signal problem and Synchronization problem	Complex computation

Among these location methods of PD source, the common problem is that the accuracy is proportional to SNR. This issue could be improved in two ways. One is adding the de-noise process to lower down the noise level; another is moving the PD sensors close to the PD source. However, the latter can't be applied on the Double-Sided measurement due to the time delay will too short to be distinguished.

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