PD DETECTION AND LOCALISATION IN CROSS-BONDED HV CABLE SYSTEMS

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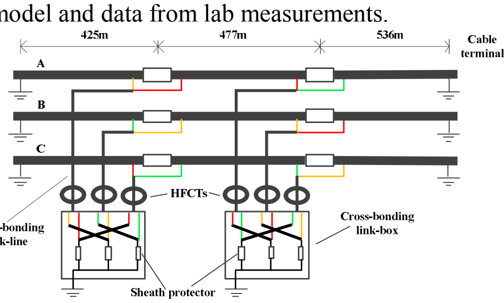
ABSTRACT

A great deal of research work on PD based cable insulation monitoring, diagnostics and localisation has been published in recent years on medium voltage (MV) cables. The work to be reported on extends PD detection and localisation into cross-bonded HV cable systems. The main challenge in PD monitoring of cross bonded HV cables lies in the interconnectedness of sheaths of the three phases, making it difficult to localise which of the three phases a PD signal has emanated from. A second challenge is the use of coaxial cables for connecting cable sheaths to cable link box for ease of installation and protection against moisture. The proposed paper addresses PD detection and localisation in cross-bonded HV cables. It presents experimental investigations into PD pulse coupling between the centre conductor and the cable sheath and the behaviour of PD pulse propagation in cross-bonded HV cables. It also proposes a model to describe the coupling effect in cross-bonding (CB) cable system for PD monitoring and localisation and demonstrates the effectiveness of the application of the model.

1. INTRODUCTION

Power cables are subject to electrical, thermal, mechanical, and environmental stresses on a constant basis when in service. These stresses, and occasionally problems resulting from inadequate installation and maintenance practices, lead to insulation degradation or defects [1] [2]. In many instances the deterioration leads to partial discharge (PD) which exacerbates the degradation of the insulation and shortens the cable life [3]. Detection of incipient fault through PD monitoring is therefore of great importance as it allows timely maintenance and replacement of assets to be carried out and unplanned outage to be reduced [4] [5].

Online, or in service, PD monitoring (detection) is often carried out through high frequency current transformers (HFCT) being installed at cable joints or terminations where the HFCTs can be clipped around the cable sheaths [6]. In HV systems co-axial cables are usually used to connect cable shields to earth via Cable-link Box, as shown in Figure 1, each HFCT is therefore monitoring current pulses in the shields of two phases, making it difficult to localise which of the three phases a PD signal has emanated from. The use of coaxial cable as CB link-line for connecting cable sheaths eases installation and protects against moisture ingress. However, PD detection is made more complex because of the resulting cross-talk effect when pulses propagate in coaxial cables. To address this issue the transmission characteristics of pulses propagating in the CB link-line are studied in the paper. The paper also establishes a model to describe the cross-coupling effect in a CB cable system for PD monitoring and localisation. Lastly, the paper demonstrates the effectiveness of the application of the model for PD localisation comparing simulation results of the model and data from lab measurements.



The figures are from a cross-bonding cable system of 110kV in Wuhan, China:

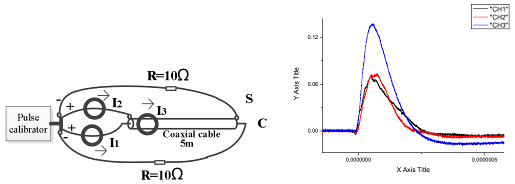
Diameter of all the three cable conductors (m)	$38.9*10^{-3}$	Relative permittivity of insulation	2.3
Rated load current flowing in phase A,B,C	965	Sheath resistivity coefficient	$2.84*10^{-8}$
Distance between phase A and B (m)	0.27	External diameter of the sheath (m)	$99.6*10^{-3}$
Distance between phase B and C (m)	0.27	Internal diameter of the sheath (m)	$97.3*10^{-3}$
Distance between phase A and C (m)	0.54	Sheath temperature coefficient	$4.03*10^{-3}$
Thickness of insulation (m)	$16*10^{-3}$	Ambient temperature (°C)	35

Figure 1 The CB link-system of cable

2. PULSE PROPAGATION CHARACTERISTICS IN CB LINK-LINE

To analyse the possibility of localisation of sources of PD pulses in CB link-line, different test set-ups were developed to investigate the characteristics of pulse propagation in CB link-line. In all cases, 50 Ω signal coaxial cables were used in the laboratory investigation due to unavailability of real-world cables of reasonable lengths.

In the first basic approach a test set-up was constructed, as is shown in Figure 2, to investigate the relationship between the detected pulse from HFCT clipped around the CB link-line and the pulses travelling along the centre conductor and shields of coaxial cable.

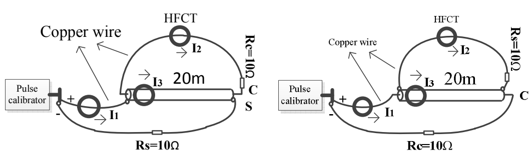


(a) Test setup (b) Measurement results

Figure 2 A test set-up for investigation of pulse propagation in a coaxial cable.

It can be seen from Figure 2 that where two pulses individually propagate along the conductor and shield of a coaxial cable, the measured pulse detected by a CT clipped around the coaxial cable is the resultant sum of the two pulses.

As the centre conductor and shield of the coaxial cable connects to two different, closed sheath circuits of a CB cable system, two main experimental set-ups were developed. Set-up one injects a pulse into the shield of the coaxial cable with two ends of the centre conductor in series with a resistor (Figure 3). Set-up two injects a pulse into the centre conductor with two ends of the screen in series with a resistor. In both the tests, the length of the coaxial cable is 20m. The pulse generated by the pulse calibrator and applied in both set-ups is shown in Figure 4.



(a) Set-up one (b) Set-up two

Figure 3 Set-up one --- injection of a pulse into the shield of the coaxial cable

Set-up two--- injection of a pulse into the centre conductor of the coaxial cable

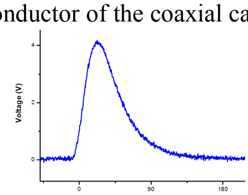
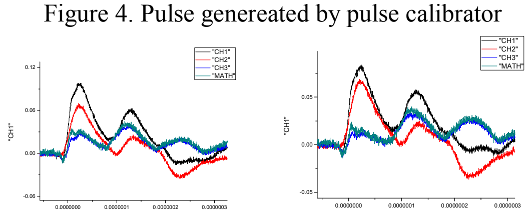


Figure 4. Pulse genereated by pulse calibrator



(a) Results of set-up one (b) Results of set-up two

Figure 5 Results of pulse propagation in two set-ups with 20m coaxial cable and Rc set to 10Ω

Results shown in Figure 5(a), indicate that a pulse resulting from coupling effect of the coaxial configuration, will couple onto and will travel in the centre conductor of the coaxial cable. The coupling efficiency in set-up one for convenience of presentation of the experimental work later in the paper, is denoted as Ks. Similarly the coupling efficiency in set-up two is named as Kc, using results from Fig. 5(b). It is noted that the value of Kc is greater than Ks.

In order to investigate the influence of the impedance of a sheath loop on the coupling effect a second series of tests was developed by using set-up one with a 20m coaxial cable and Rc set to 0Ω, the result is presented in Figure 6. Furthermore, to study aiming to study the influence of the length of the coaxial cable in a CB cable system, a test was carried out by using set-up one with 10m coaxial cable and Rc set to 0Ω, the result is shown in Figure 7.

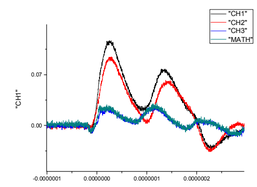


Figure 6 Results of set-up one with 20m coaxial cable and Rc set to 0Ω

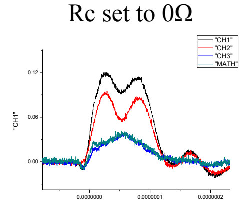


Figure 7 Results of set-up one with 10m coaxial cable and Rc set to 0Ω

From Fig.6 and Fig.5a, it can be concluded that the greater the resistor in the coupling circuit, the lesser is the coupling coefficient. By comparing results in Fig 6 and Fig. 7, the length of the CB link-line is directly proportional to the coupling coefficient.

3. MODEL FOR CB CABLE SYSTEM AND SIMULATION

3.1 Model

A simulation model has been developed for PD localisation in a CB cable system, as shown in Figure 8. The characteristics obtained with the aid of the results of pulse propagation characteristics presented in the preceding section of the paper are applied to the model. In the model, three CB link lines connect a CB link-box. These three lines are assumed as having different lengths, as is the case in practical situations.

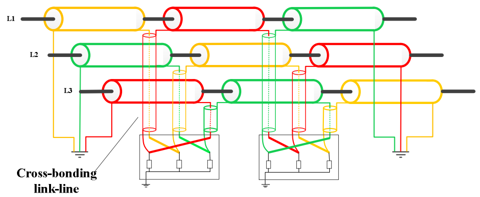


Figure 8 A simulation model of a CB cable system

3.2 Simulation

As the parameters of CB cable systems vary, such as the length of three CB link lines, the structure size of CB link lines, earth resistance and so on, vary the parameters of this simulation model is taken from a set of laboratory parameters. Figure 9 allows description of the different simulations that have been carried out using the model, to investigate the effect of signals emanating from four sites of origin. The first signal is a PD pulse originating from the joint of phase A, a second simulates interference signal from external circuit, coupled through the ground line of the CB link-box, the third simulates interference coupled into the system through phase C, the last one is PD from cable of phase C.

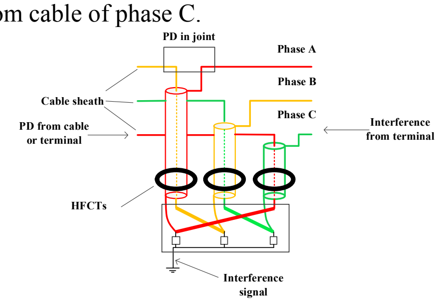


Figure 9 Simulation of a CB cable system with different source of signals

3.2.1 PD in the joint of phase A

Through numerical simulation using the aforementioned coupling effect, the pulse as originating from the joint of phase A will be detected by HFCTs at phase A, B, C of the CB link-line with magnitudes shown in Figure 10. This indicates that the signal detected in the phase where the PD occurs has the opposite polarity to that of the other phases, and the amplitude is about twice of the others.

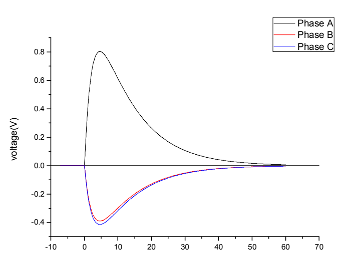


Figure 10 Signals detected by HFCTs in online PD monitoring when a PD pulse originates from cable joint of phase A

3.2.2 Ground interference

The interference signals coming from external circuits coupled through the ground line are shown in Figure 11. They are detectable by HFCTs at phase A, B, C of the CB link-line.

As can be observed in Fig.11, the polarity of the interference signals is the same and the amplitude is also almost the same.

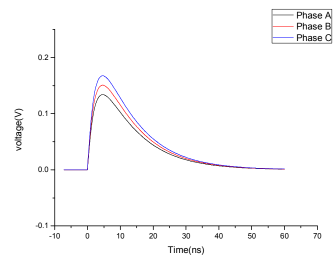


Figure 11 Interference from external circuit, coupled through the ground line of the CB link-box

3.2.3 Interference in phase C

When interference signals from one side of phase C are detected by HFCTs at phase A, B, C of the CB link-line, the results are shown in Figure 12.

Fig.12 demonstrates, as in the case of the PD pulse, that the polarity of the signal detected in the phase where the interference signal occurs is the opposite of that in the two other phases, but the amplitudes of the three signals show greater differences than simulation of PD in the cable joint.

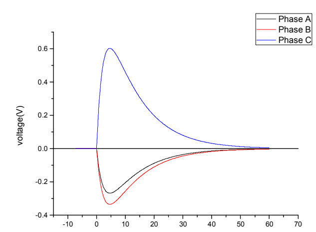


Figure 12 Interference coupled into the system through phase C

3.2.4 PD from one side of phase C

Consider that a signal due to a PD activity emanates from the side of phase C indicated in Figure 9 and is detected by HFCTs at phase A, B, C of the CB link-line. Results are shown in Figure 13.

As can be seen in Fig.13, the polarity of the signal detected in the phase where the PD signal occurs is the opposite of those detected at the other phases. However, although this pulse has the same magnitude as the original PD pulse in the cable joint, section 3.2.1, the amplitude of the three detected signals are different from the result of the PD in the cable joint. Furthermore, by comparing the signal magnitude and polarities in Fig.12 and Fig.13, although the polarities of the detected signals are the same, the amplitude of the monitored signals is different.

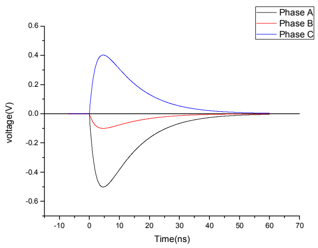


Figure 13 Signals detected when PD from phase C

3.2.5 Compare Simulation results with laboratory measurement results

The four sets of simulation results are in good agreement with data from laboratory measurements, as shown in Fig.2-5 of paper [7].

4. CONCLUSION

Online PD monitoring in CB cable system is usually carried out through HFCTs being installed at cable joints or terminations where the HFCTs can be clipped around the CB link-line. The construction of the CB link-line results in a cross-talk effect when pulses propagate in the coaxial cables connecting cable shields to cable link box. The propagation characteristics of pulses propagating in coaxial cables, similar to those in CB links, are reported following laboratory experiments.

A simulation model has been developed to analyse the cross-coupling effect for PD localisation in CB cable system. The simulation applies the characteristics gained from the laboratory work. Four sites of origin of signals are simulated using the model. Simulation results are found to be in good agreement with the laboratory results from practical situations, cited paper. Based on the model a localisation method could be developed for on-line or in service PD monitoring for HV cables.

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