Cable Data Collector (CDC): Application Guide

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1. Introduction

The Cable Data Collector (CDC) is a portable instrument designed to allow the detection and possibly location of partial discharge in medium voltage cables. It is functionally similar to VLF cable mapping, but there are differences in how it operates that can offer significant advantages the customer (depending on their circumstances and network configuration).

This method can also be referred to as 'online' cable mapping or testing, as provided the circuit is configured in a manner that allows safe connection while the circuit is energised then no outage is required. [Note that in order to obtain measurements the phase conductors must be energised by the network they are connected to, or via a suitable power frequency test source].

The CDC instrument consists of both the data-gathering hardware and separate data analysis software (CDAS).

The hardware in its ready-to-use state is shown below with customer supplied PC (Figure 1).

Figure 1. CDC hardware

2. PD in cables

Partial discharge in cables is of the 'internal' type, and therefore generates transient earth voltages (TEVs) – as is detected by other instruments of our manufacture. CDC detects the currents that are the underlying cause of TEV. PD degrades the insulation in cables just as it does in switchgear (Figure 2), and if left to progress will eventually damage the insulation to a point where it can no longer withstand its working voltage and failure will occur. Depending on the fault level, cable containment and other factors this failure may be catastrophic, but in all cases that section of cable will be irreparably damaged and require replacement.

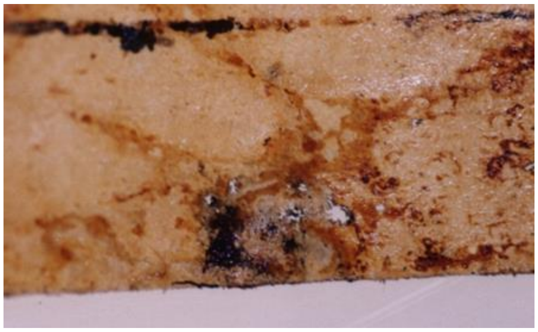
 

Figure 2. Degradation of cable insulation (left: paper, right: XLPE)

As the degradation is occurring within the structure of the cable, it cannot be detected by visual examination without destroying that cable. Clearly this would be an unacceptable method of monitoring condition, and this is where electrical test techniques play a critical role.

3. Principle of operation

"In *electrical engineering*, partial discharge (PD) is a localised *dielectric breakdown* of a small portion of a solid or fluid *electrical insulation* system under *high voltage* stress, which does not bridge the space between two conductors"

For the moment, let us consider a three-core cable with no individual screens around the cores but a steel wire armour layer around the cable's circumference. This configuration was extremely popular during the 1950s, 60s and 70s. A discharge from any phase will radiate energy onto the other two phases and to earth: this energy comes from the phase conductor itself and what is taken from there arrives on the other conductors. For simplicity, this is shown in the diagram below as all being transferred to earth (Figure 3).

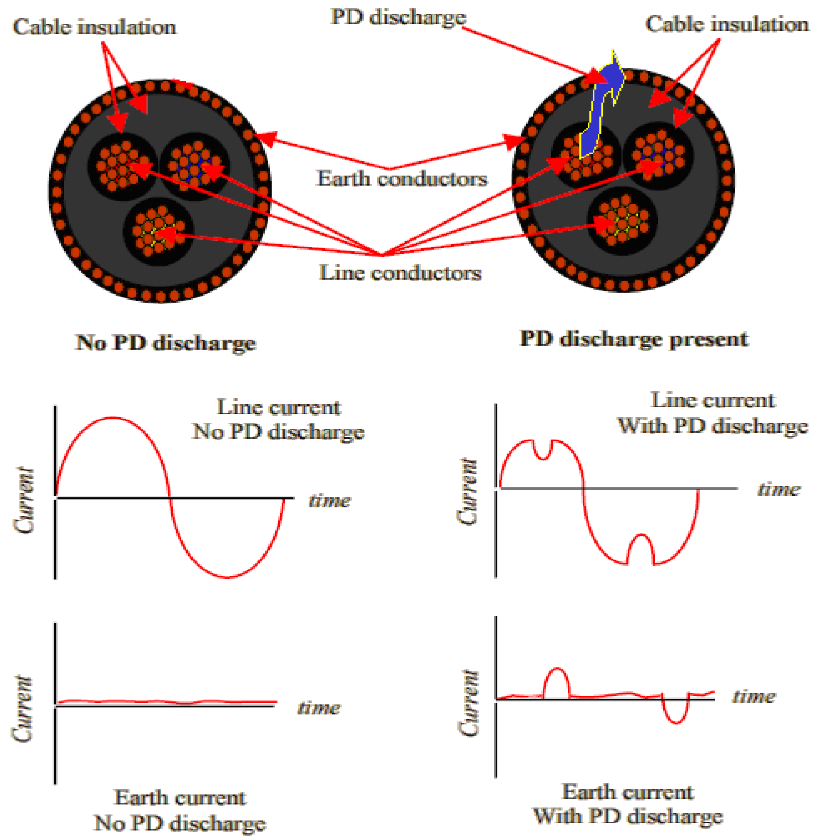


Figure 3. Simplified representation of cable PD

The signals that are present on the earth conductor are of very high frequency (up to several hundred megahertz) and very small magnitude (perhaps only a few volts at most but more commonly in the millivolt range). The CDC instrument detects signals, known as transient earth voltages (TEVs), by using a radio frequency current transformer (RFCT) that is clipped around the ground at a safe and accessible location. By determining the magnitude of the pulses in the signal, the magnitude of the discharges can be derived. A basic diagram of this is shown below (Figure 4 – note 3 RFCTs can be connected to the instrument simultaneously).

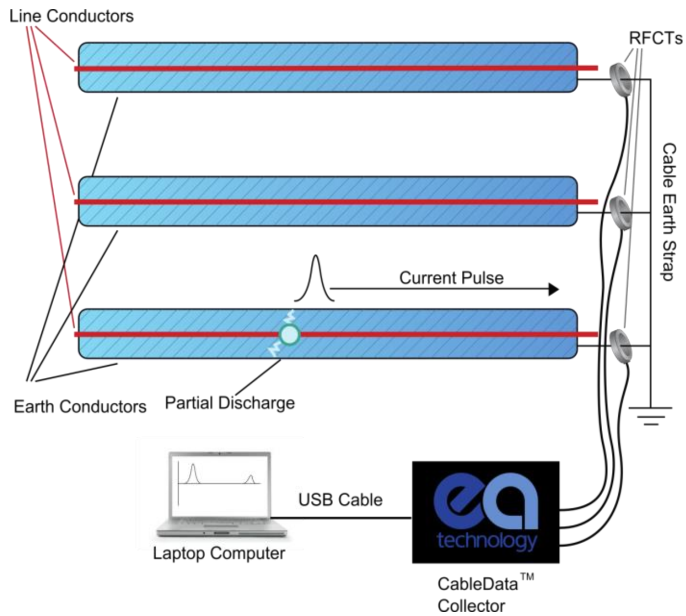


Figure 4. Basic diagram of CDC operation

There are many different kinds of cable construction in use around the world. They use different kinds of insulating material, may be three-core or single-core, have screened or unscreened conductors and may be armored or unarmored. However, provided that the nearest earth conductor to a phase that is to be tested is accessible at a safe location (most likely at its terminations) and the gland is insulated then the CDC can be utilised.

When the high frequency signal strikes the earth conductor, the energy in that pulse will set off in two directions to each end of the cable. To the CDC observing activity at one end of the cable, the pulse travelling towards it RFCTs will be 'seen' first as it has less distance to travel. The other pulse, travelling away from the RFCTs, will strike the far end of the cable and most of its energy will be reflected back at that change of impedance (this is transmission line theory). That reflected pulse will be seen by the CDC later as it has travelled further (Figure 5).

By comparing the time of arrival between each pulse it is possible, using the time-of-flight principle, to locate the point at which the discharge occurred. This is expressed as a percentage of cable length as the instrument does not know how long the cable is. However, as a reasonable approximation to the propagation speed will give a good indication of the cable length based upon these time measurements. As the instrument has a finite time 'window' in which it looks for the reflected pulse, which is necessary to separate out any extraneous signals/noise, the maximum length of cable that can be mapped is 10km. **Note: the detection of the reflected pulse is not guaranteed and therefore it is not certain that CDC can be used to locate the position of any PD activity – although it is likely to be able to do so.**

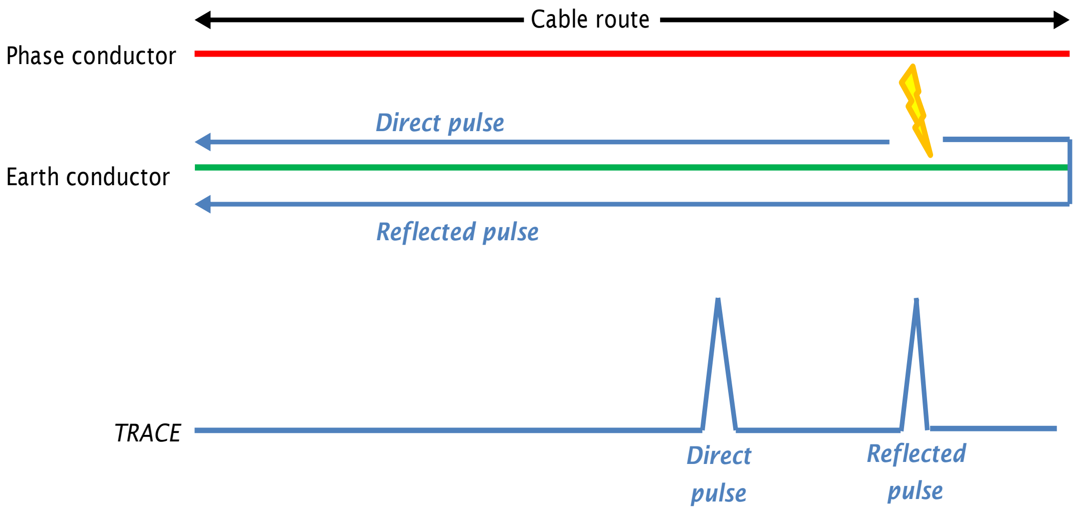


Figure 5. Representation of time-of-flight principle for discharge location

Depending on whether any changes of impedance are present along the cable's route, such as joints, then there may be other pulses present from additional reflections. These will typically be much smaller as they are only partial reflections from small impedance changes and attenuated as they travel along the earth conductor.

As the instrument relies upon the detection of small-magnitude high-frequency signals it can be susceptible to interference from background noise. Modern equipment utilising 'switch mode' power supplies (like PCs), uninterruptable power supplies (UPSs), variable speed drives (VSDs) and even fluorescent lighting all radiate similar signals and these can obscure real discharge and/or prevent PD's location. However, in most cases it is possible to differentiate between this noise and 'real' PD. This is achieved by considering the pulse waveform shape, using a series of software-based filters and a 'phase resolved plot'.

A phase resolved plot attempts to display at which point in the 360˚ mains cycle a discharge occurred. 'Real' PD will often be gathered in cloud-like formations near the positive and negative peaks of the cycle (e.g. at around 90˚ and 270˚) whilst other formations, such as a flat level, indicate an external source (Figure 6 and Figure 7 respectively).

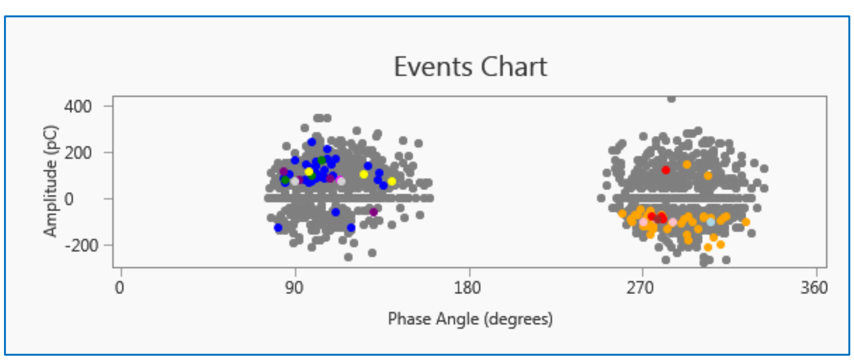


Figure 6. Phase-resolved plot showing true PD activity

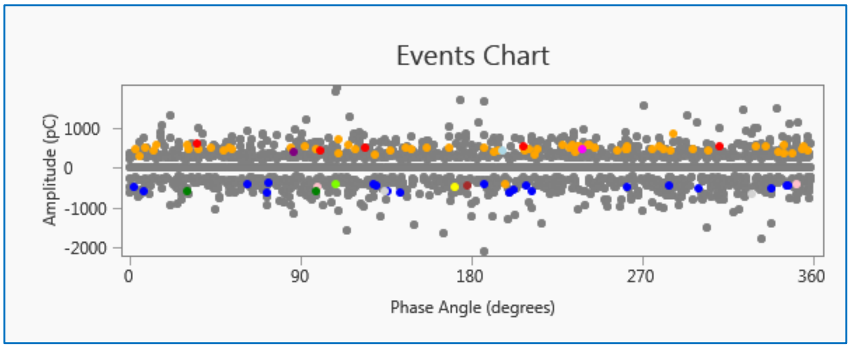


Figure 7. Phase-resolved plot showing background noise

The mains cycle is derived from one of two possible sources. In order of preference due to their inherent accuracy, which is selected automatically based upon their availability, these sources are: -

- The low voltage mains connection used to the instrument (this is not a power source as that is derived from the USB connection).
- Derived from the RFCTs by looking for a 50Hz or 60Hz component. This relies on there being an imbalance between the phases. This will be sufficiently accurate, provided the current can be measured.

As these will not necessarily provide a true representation of the power frequency sine wave present on the phase conductor being measured, the plots may be ‘skewed’ (i.e. phase shifted) left or right somewhat. This is not of particular concern when conducting an analysis as the patterns are still recognisable.

4. Advantages and disadvantages

First, it must be pointed out that techniques such as this are the only way of dealing with cable degradation. Cables cannot be maintained or, as stated earlier, visually inspected. Electrical testing is the only option available to customers wishing to manage the risk of cable failure.

The advantages of CDC are: -

- No outage of the circuit to be tested is required.
- The rate at which cables can be tested is higher than for VLF cable mapping, and therefore the costs are lower. *Measurements can be taken in 5-10 minutes then analysis takes approximately 45 minutes. As such, all circuits on a switchboard can generally be surveyed in a few hours at most.*
- It can be used to make decisions regarding future management of the circuit, which may include partial/full cable/joint replacements, targeted VLF mapping, further electrical measurements, etc.

The disadvantages of CDC are: -

- Can only be used where safe access to the earth conductor is available and the cable gland is insulated from the equipment the cable is connected to.
- Can be affected by noise, whether the source is external (such as an RF transmitter) or internal from the load(s) connected to the circuit.
- The instrument is only effective on circuits of 10km (6.2 miles). *This is because the maximum time window allowed to observe the reflection limits this (length based on propagation speed), and will be less because of signals being attenuated as they travel along the cable (likely 8km (5 miles) as a guideline for XLPE cables, but much shorter for paper insulated cables).*
- May not be able to locate discharges if there is excessive background noise.

For comparison against VLF cable mapping, the advantages of VLF are: -

- It is influenced much less by noise than online techniques.
- Circuits can be tested regardless of earthing configuration.

And its disadvantages: -

- An outage of the circuit is required and at least one termination must be broken down to allow for the test connections to be made.
- Time consuming and therefore considerably more expensive than online techniques.

5. Assessing circuit suitability

This is perhaps the most important stage, as the success of any subsequent project is entirely dependent upon the availability of access to suitable earth conductors.

5.1 Earth straps

The main problem of assessing suitability is that there must be earth straps accessible at the termination to allow the instrument's RFCTs to be clipped on and the gland must be insulated from the equipment it is connected to. In order to be valid connection points, these earth straps must be connected to the first earthed conductor that surrounds the phase conductor you wish to look for discharge upon. The 'basics' to look for are shown below (Figure 8 and a real-world example in Figure 9).

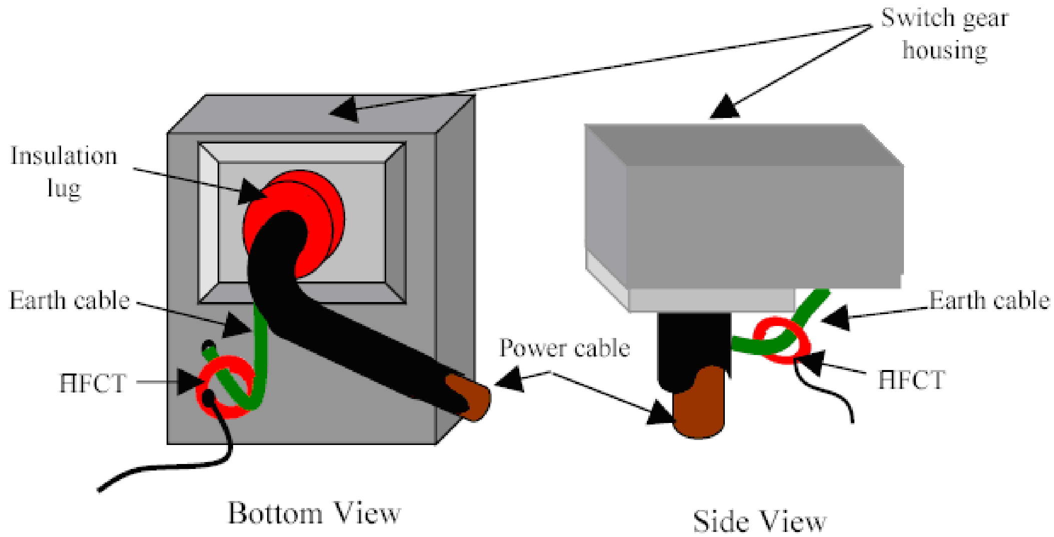


Figure 8. Connection point for RFCT on a 11KV Pad Mount Transformer

Figure 9. Real-world example of RFCT connection in the United States

This is valid for both single-core cables and three-core cables where there are no screens around individual cores that are bonded together prior to the location that the RFCT is to be applied at.

5.2 Safe access to earth straps

Access to earth conductors as illustrated previously is not always available from outside of the switchgear, although it may be from inside a cable termination box. In this situation, which is fairly common, a cover would have to be removed or door opened in order to apply the RFCTs. **Depending on the safety practices in place at a particular company this may not be allowed, or, and Arc Flash suite with hood should be used when placing the RFCTs on the grounds.**

In order to access the enclosed earth connections, each panel will have to be isolated in turn to allow the cover to be removed and RFCTs applied (if there are any exposed conducting parts within then earths must also be applied before any covers are removed). This will clearly negate some of the advantages of online cable mapping, but it should still be borne in mind that such an approach removes the need to remove terminations etc and is therefore still quicker than VLF. **As the CDC is not protected against high voltages, the operator must be certain that the RFCTs will not come into contact with live conductors, covers are securely replaced during measurements and that the leads are securely routed.**

When opening a cable box to undertake the alternative action above for access to enclosed earth connections, it may be considered that a loop of earth strap material could be passed through a new hole in the base of the cable box: this would facilitate simpler access for CDC measurements both immediately and in the future. For critical cables that will be tested on a regular basis one option is to permanently install the RFCTs and bring out the test cables to an external test box such as one shown below in Figure 10.

Figure 10. External Test Box wired to permanently mounted RFCTs

5.3 Sets of three phase conductors

The CDC instrument can gather measurements from three RFCTs simultaneously during any single measurement run. This means that it can measure the discharges on a single set of three phase conductors at any one time: this may be different to a 'circuit' and is an important distinction if the time required to gather and then report upon the data is to be estimated with any accuracy.

It may not be apparent from a single line diagram (SLD) what the composition of a single circuit actually is. Below is an example of a transformer with both upstream and downstream circuit breakers plus intervening cables (Figure).

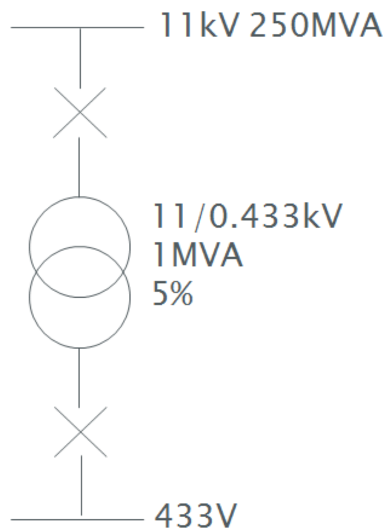


Figure 11. Example single line diagram (SLD)

Each single vertical line representing the cables actually consists of at least three individual phase conductors. These may be contained in a single three-core cable or three single-core cables; alternatively there may be more than one cable per phase! This can be confusing and you will need to refer to a site survey or a cable schedule to find this information.

6. Understanding cable construction

In order to assist with understanding how various cable constructions can impact on the suitability of the CDC instrument, this section gives an overview on common cable types.

Older cables will generally be insulated with paper which has been impregnated with an oil-based compound. There are still very large quantities of these cables in service as they are generally very reliable and most of the network expansions in the 60s and 70s used them.

Newer cables, particularly those installed from the mid-80s onwards, are much more likely to be insulated with cross-linked polyethylene (XLPE) – a form of plastic. Much less common, is ethylene propylene rubber (EPR) insulation.

The usability of the CDC is still mostly dependent on the termination of any cable type.

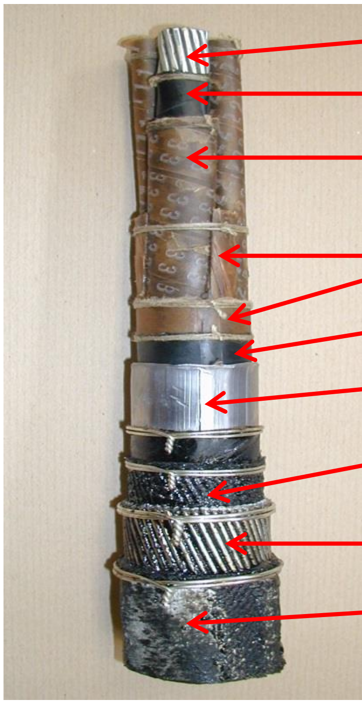
6.1 Paper insulated lead covered (PILC)

1. Conductor: Stranded copper.
2. Conductor screen: Semiconducting carbon paper tapes.
3. Insulation: Mass impregnated non draining (MIND) compound filled paper.
4. Insulation screen: Carbon paper and copper tape or aluminium foil.
5. Sheath: Lead.
6. Anti-corrosion: Bitumen layer covering lead.
7. Oversheath: Polyvinylchloride (PVC).

Figure 12. PILC cable

This single-core example has no armor layer. Earthing in this case is provided by the lead sheath, which should generally be bonded at one end of the cable's route to earth. If the termination at that end is suitable, it should be possible to attach an RFCT.

6.2 Paper insulated lead covered steel wire armoured (PILCSWA)



1. Conductor: Stranded aluminium/copper.
2. Conductor screen: Semiconducting carbon paper tapes.
3. Insulation: Mass impregnated non draining (MIND) compound filled paper.
4. Fillers and belt insulation: MIND.
5. Belt screen: Carbon paper tapes.
6. Sheath: Lead.
7. Bedding: Wrapped layers of paper and bitumen impregnated hessian tape.
8. Armour: Galvanised steel wire.
9. Serving coating: Wrapped layers of bitumen impregnated hessian tape.

Figure 13. PILCSWA cable

PILCSWA cable in the configuration shown above (which is also known as ‘belted’) is extremely common on older industrial sites. The earth is only provided by the combined lead sheath and armorings, which are commoned together at the terminations. The earth connection is generally only made at one end of the cable route, at which location it should be possible to attach an RFCT depending on the termination.

As all three phase conductors are contained within a single earth plane the phase on which any PD may be occurring cannot be differentiated.

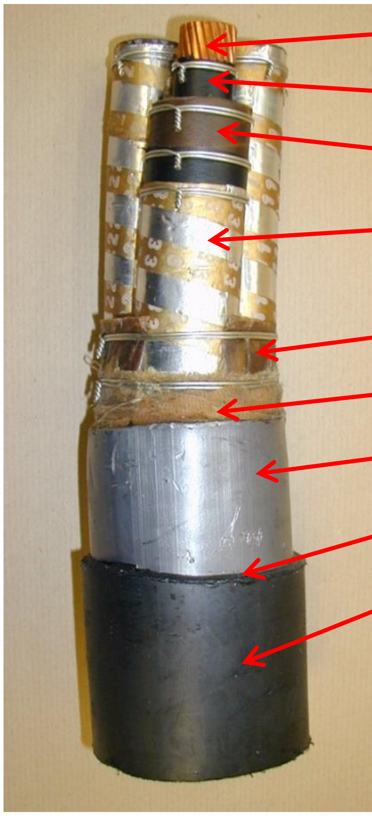
6.3 Screened PILCSWA

1. Note the only difference from normal PILCSWA is the presence of aluminium foil or copper tapes around each phase conductor's semiconducting layer.

Figure 14. Screened PILCSWA cable

Screened cables can be categorised into two sub-types, as outlined below.

6.3.1 Type ‘H’ screened PILCSWA



1. Conductor: Stranded aluminium or copper.
2. Conductor screen: Semiconducting carbon paper tapes.
3. Insulation: MIND.
4. Insulation screen: Typically pinholed aluminium foil laminate.
5. Filler: MIND.
6. Carbon woven fabric tape.
7. Sheath: Lead.
8. Anti-corrosion: Bitumen layer.
9. Oversheath: Medium density polyethylene (MDPE).

Figure 15. Type ‘H’ cable

The ‘H’ stands for ‘Hochstadter’, and refers to cables where there is a screen around individual conductors then an outer layer of lead sheath – therefore no belt insulation is required. In this cable type, it is unlikely that the RFCTs can be successfully applied as the screens will be commoned together at the termination with no access to them.

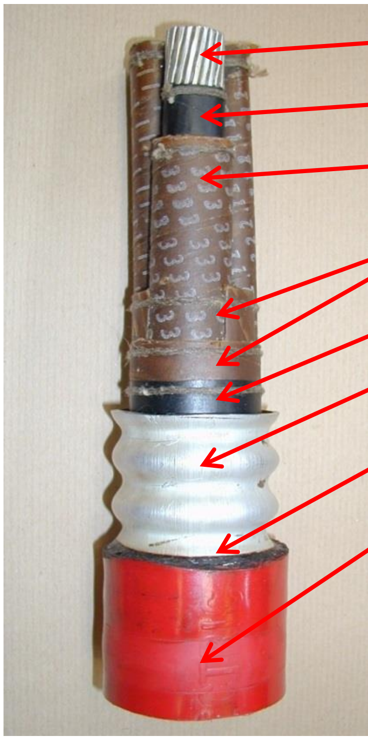
6.3.2 Type ‘HSL’ screened PILCSWA

1. Conductor: Stranded aluminium or copper.
2. Conductor screen: Semiconducting carbon paper tapes.
3. Insulation: MIND.
4. Insulation screen: Typically pinholed aluminium foil laminate.
5. Sheath: Lead.
6. Bedding
7. Filler: Bitumen impregnated jute.
8. Bedding: Bitumen impregnated hessian tape.
9. Armour: Galvanised steel wire.
10. Serving coating: Bitumen impregnated hessian tape or polyvinylchloride (PVC).

Figure 16. Type ‘HSL’ cable

‘HSL’ refers to cables where each phase conductor is individually both screened and sheathed, essentially so that it is a group of three single-phase cables in an oversheath. As with ‘H’ type, it is unlikely that the RFCTs can be successfully applied as the screens will be commoned together at the termination with no access to them.

6.4 Paper insulated corrugated aluminium sheath (PICAS)



1. Conductor: stranded aluminium.
2. Conductor screen: semiconducting carbon paper tapes.
3. Insulation: MIND.
4. Fillers and belt insulation: MIND.
5. Belt screen: Semiconducting carbon paper tapes.
6. Sheath: Corrugated aluminium.
7. Anti-corrosion: Bitumen layer.
8. Oversheath: Polyvinylchloride (PVC).

Essentially PICAS cable can be thought of as being functionally identical to PILCSWA, with the only physical difference being the lead and armour layers replaced with a corrugated aluminium layer. The same restrictions apply in that the phase on which any PD may be occurring cannot be differentiated.

6.5 XLPE and EPR insulated cables

In order to control the electric field stresses around the phase conductors, cables utilising these insulation materials are very similar in layout to ‘Type H’. However, in the case of these cables modern terminations in air-filled boxes allow access to the metallic screens around the phase conductors and the CDC is therefore usable.

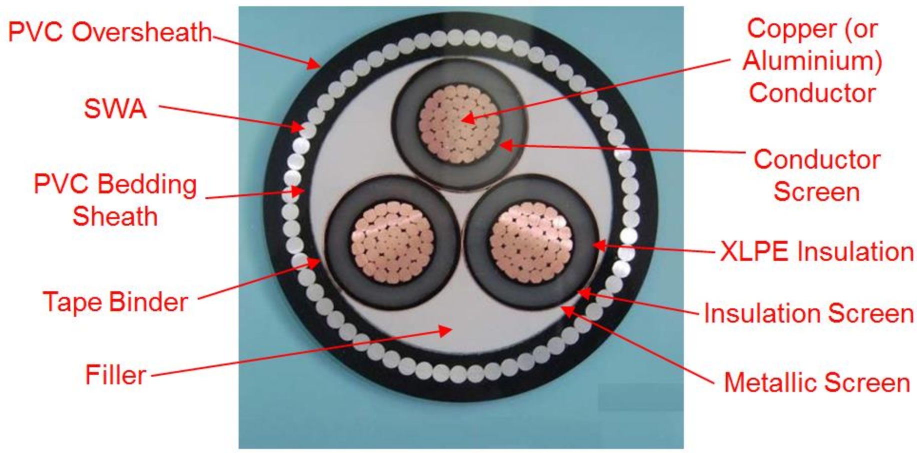


Figure 17. Typical cross section of 3-core XLPE cable

7. Example phase-resolved plots

These are provided for general information.

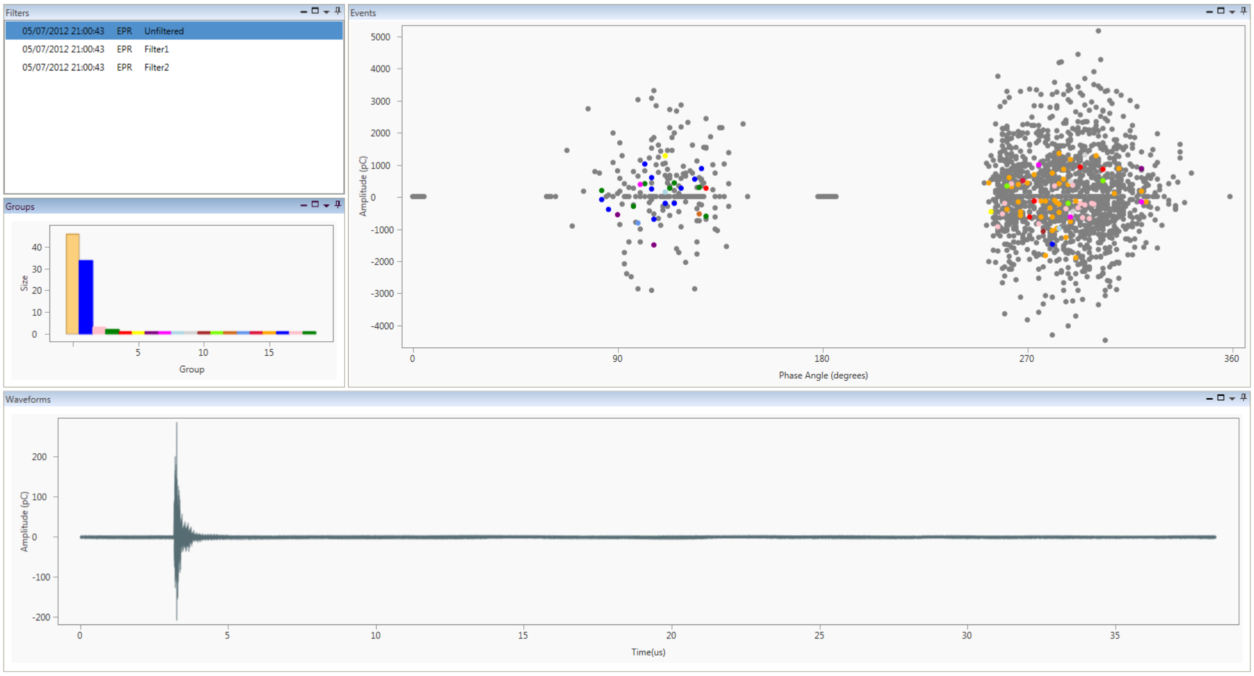


Figure 18. Clusters of PD activity

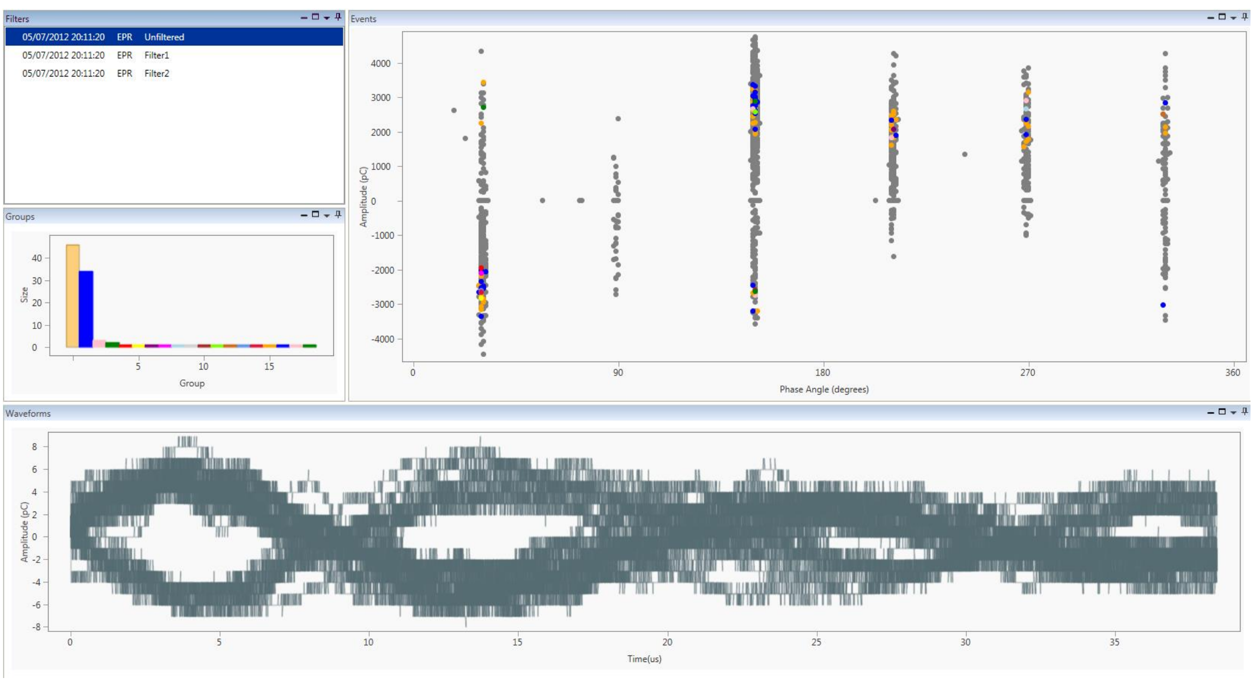


Figure 19. VSD/machine noise

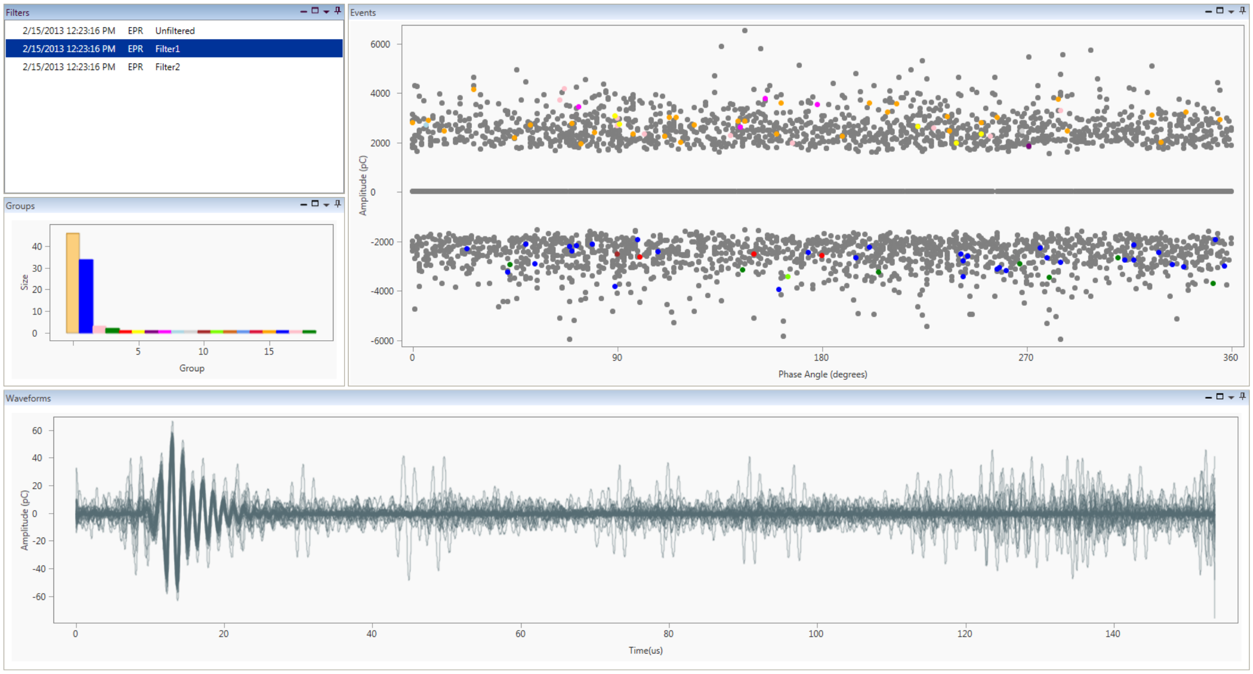


Figure 20. Background noise

8. Configuration types

There are a variety of propositions that we offer based upon this single instrument.

8.1 CDC hardware-only purchase

Customers may elect to purchase the hardware only with no CDAS software licence. In this case, they shall be reliant upon others to carry out the data analysis for them (see below).

8.2 CDC & CDAS purchase

This is a traditional approach to an instrument sale, the customer becomes self-sufficient in online cable mapping.

8.3 Training

Substation Assessment, Product Support and others can offer training to customers who have purchased a stand-alone CDC or combined CDC and CDAS.

8.4 Analysis and reporting only

EA Technology LLC can undertake data analysis and reporting on data gathered by others, particularly customers who have purchased the CDC hardware only.

8.5 Equipment Rental

EA Technology LLC has units available for rental on a weekly and monthly basis.

Global Footprint

We provide products, services and support for customers in 90 countries, through our offices in Australia, China, Europe, Singapore, UAE and USA, together with more than 40 distribution partners.

Our Expertise

We provide world-leading asset management solutions for power plant and networks.

Our customers include electricity generation, transmission and distribution companies, together with major power plant operators in the private and public sectors.

- Our products, services, management systems and knowledge enable customers to:
- Prevent outages
- Assess the condition of assets
- Understand why assets fail
- Optimise network operations
- Make smarter investment decisions
- Build smarter grids
- Achieve the latest standards
- Develop their power skills

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