IMPROVING THE MANAGEMENT OF MV UNDERGROUND CABLE CIRCUITS USING AUTOMATED ON-LINE CABLE PARTIAL DISCHARGE MAPPING

Matthieu MICHEL
UK Power Networks – UK
matthieu.michel@ukpowernetworks.co.uk

Carl EASTHAM
IPEC Ltd – UK
carl.eastham@ipec.co.uk

ABSTRACT

On-line location of Partial Discharge (PD) or cable mapping is a relatively new technique that enables asset operators to target the replacement of deteriorating cable sections that would likely have progressed to failure (provided that a number of pre-requisites such as the type of earthing are met). On-line cable testing of underground MV cables has already been proven to provide an accurate location for incipient faults and gives a number of key advantages over off-line testing [1], one of which being the fact that no outage is required.

UK Power Networks is in the process of increasing the number of preventive investigations carried out based on indications from an on-line condition monitoring system, and is able to demonstrate the success of the preventive actions taken (Figure 1).

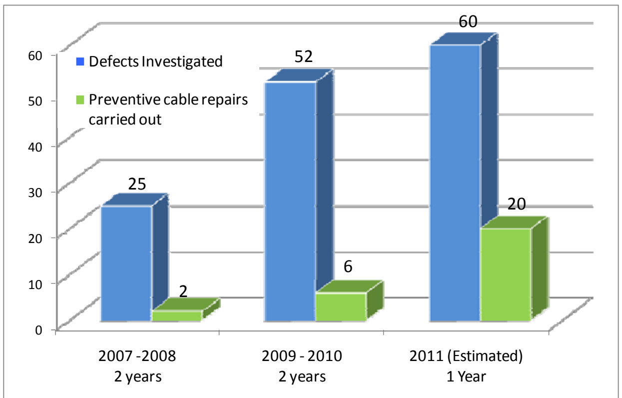

Figure 1: Increasing number of preventive repairs carried out by UK Power Networks

INTRODUCTION

Traditionally, on-line cable PD mapping has been conducted over short periods of time as a complex test procedure has to be followed in order to ensure the accuracy of the testing. This has resulted in a number of drawbacks:

- Only a small number of data points can be collected, reducing the accuracy of the testing.
- PD activity in cables can vary significantly in magnitude and repetition rate over time, resulting in some defects being only active for a few hours a day.

Manual on-line cable mapping is not thought to be a viable option to manage a large underground cable network, as a considerable number of competent and experienced field engineers would still be required.

Recent developments from UK Power Networks and IPEC have allowed this process to be automated, enabling the activity and location of incipient defects to be tracked over extended periods of time. This improved methodology has shown to produce more representative results and has the potential to be deployed on a large scale as limited human intervention is necessary.

MANUAL ON-LINE CABLE MAPPING THEORY

On-line cable mapping is a non-intrusive measurement method of locating PD in MV and HV cables. The tests are conducted with the network live and under normal operating conditions. Cable mapping uses Time Domain Reflectometry (TDR) to locate the source of a PD, based on the differences in arrival time of a PD pulse and that of the reflected PD pulse from the far end of the cable.

The major steps undertaken whilst carrying out on-line cable mapping (as used by UK Power Networks and IPEC) are summarised below and illustrated in Figure 2.

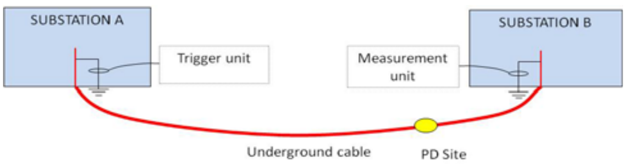

Figure 2: On-line cable mapping setup

Step 1: A trigger unit is connected to the cable sheath of Substation A using a High Frequency Current Transformer (HFCT), and set to trigger (inject a large pulse with a specific signature) on detection of PD.

Step 2: A measurement unit is connected to the cable sheath of Substation B using a HFCT. The measurement unit incorporates software which is able to detect the unique signature of the pulse injected by the trigger unit.

Step 3: The Measurement unit is setup to collect a number of waveforms so that the location of PD can be plotted accurately. The time difference measured between the PD signal detected initially at the Measuring unit, and the subsequent arrival of the Trigger unit pulse at the Measurement unit, provides the accurate location of the discharge source and is defined as a ’data point’.

MANUAL ON-LINE MV CABLE MAPPING

Manual on-line cable mapping can be labour intensive as it may require the testing engineers to adjust both the trigger and measurement units during a test, requiring several visits to a substation. PD locations are therefore limited by working hours and travel time.

A typical map will be conducted during the daytime with the actual data acquisition period being very short. An on-line cable map is usually made of approximately 300 data points which, in the majority of cases, will be suitable for producing a PD map (as illustrated by Figure 3).

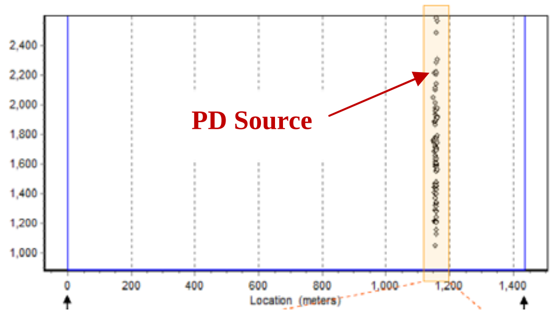

Figure 3: Typical manual on-line cable map (City Road feeder)

The conditions whilst carrying out cable mapping can vary. They can be:

- Ideal with a single PD source with a low level of background noise.
- Complex with multiple PD shapes and background noise as is more frequently found. In these conditions, manual cable mapping requires a lot of experience and expertise. The results could miss some of the PD locations, as a result of magnitudes varying with load at different times of the day (i.e. not being detectable at the time of testing).

The latter could result in a preventive cable replacement to appear unsuccessful as PD will still be detected following the repair and re-energisation, as illustrated by Figure 4.

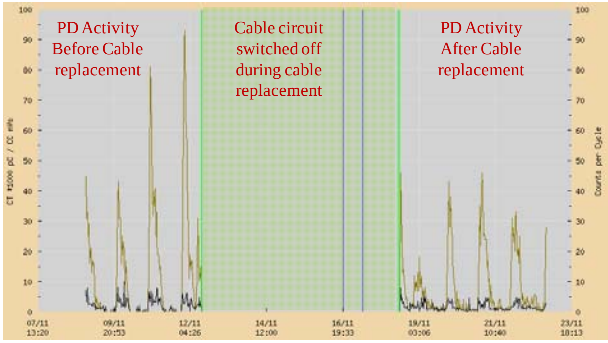

Figure 4: PD Monitoring data of a partially successful on-line cable map carried out in Hatchard Road substation.

In this case, an on-line manual cable map successfully located a single source of discharge, a preventive cable replacement was carried out and the circuit was re-energised. The activity returned to a slightly lower level and it was concluded that the replacement had been unsuccessful.
Following a detailed investigation involving a 24 hour manual cable map (equipment left unattended), it was discovered that the circuit had in fact 2 different sources of discharges, the largest one only being active in the middle of the night.

Experience from over 80 on-line maps

UK Power Networks, in conjunction with IPEC, have installed 70 permanent partial discharge monitoring systems in both primary and secondary substations. The systems continuously record PD activity from over 2000 assets (including cables and switchgear).
This data is collected by a remote server, classified and displayed on a web based front-end so it can be analysed and interpreted (Figure 5).

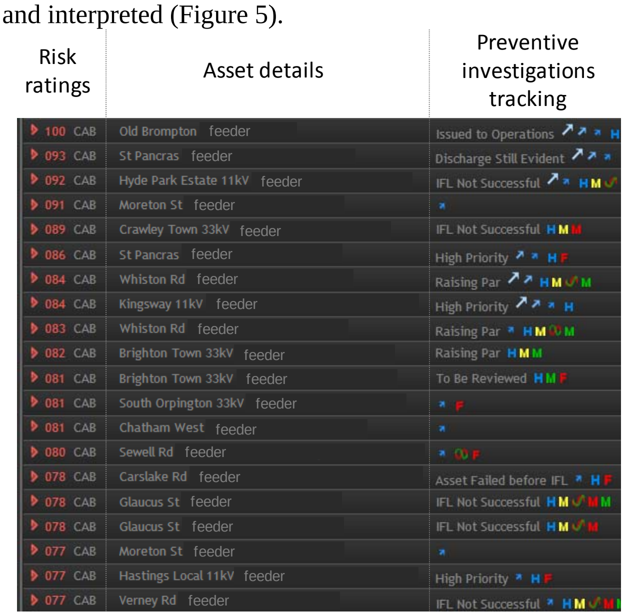

Figure 5: Web front-end: Classification of worst performing cable circuits is used to prioritise cable mapping.

Each asset is given a risk rating based on the probability of failure and a consequence evaluation. The probability of failure is mainly based on the level and type of PD activity, whilst the consequence is primarily based on the number of connected customers and whether the circuit can be remotely reconfigured. The risk rating is used to prioritise cable mapping and preventive replacements. The web-based system also incorporates the ability to track the progress of investigations on individual assets, enabling large scale management of on-line cable mapping on hundreds of cables.

Over the past three years, IPEC has carried out over 80 manual on-line PD maps on the UK Power Networks distribution networks. The key learning points from these are:

- On-site cable length measurement is necessary to ensure an accurate location.
- Some PD pulses can be masked by larger or closer PD sources.
- Some sites may only be active at specific times of the day and may be missed during daytime testing.
- The time between an on-line cable map and a preventive cable replacement should be kept to a minimum to ensure that the results are still relevant.

These learning points, as well as recent developments in computational power, battery cell life and mapping technology have enabled some of the limitations of manual on-line cable mapping to be addressed by developing automated on-line cable mapping, or auto-mapping.

AUTOMATED ON-LINE MV CABLE MAPPING

The theories of manual and auto-mapping are very similar as both are based on TDR. However, the need to setup, calibrate and supervise testing is reduced significantly using auto-mapping as the acquisition software runs through pre-defined routines, allowing for significantly longer testing times (days or weeks), an increasing number of data points to be captured and human errors to be avoided.

The auto-mapping trigger unit includes a 'sweeping gain', meaning that the device can capture PD pulses from several sources. The measurement unit can either be an already installed monitoring equipment (often covering multiple feeders within a primary substation) with specific software installed, or a standalone unit.

Figure 6 demonstrates the improved accuracy and more representative results that can be achieved using auto-mapping, compared to manual cable mapping. The 3D map can be built from thousands of data points captured over several days, reducing the probability of smaller PD sources not being detected.

In this example, the same circuit was tested using both techniques; auto-mapping revealed two PD sources not detected whilst carrying out the manual mapping.

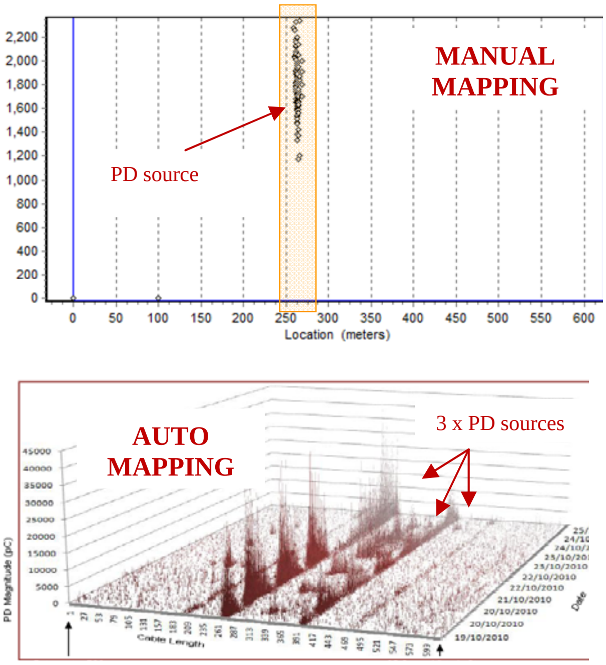

Figure 6: Comparison of manual and auto-mapping

LARGE SCALE DEPLOYMENT OF AUTO-MAPPING

Manually mapping each circuit with detected PD will not be a cost and resource efficient solution for the long term. A rollout of the auto-mapping technology is already underway in UK Power Networks. Most of the 70 permanently installed monitoring systems (covering approx 900 cable circuits) installed in substations around London and the South East of England are already configured to act as an auto-mapping measurement unit, only requiring a trigger unit to be connected and powered up at the remote end of the circuit (Figure 7).

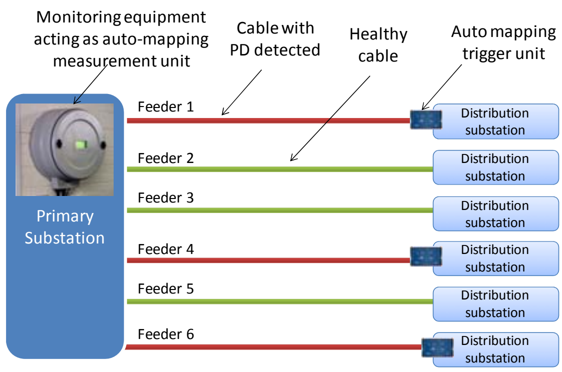

Figure 7: Example of multiple feeders equipped with trigger units.

Over the next few years, it is anticipated that a single resource could manage the redeployment of a number of auto-mapping trigger units, allowing a fast, reliable and cost effective way of carrying out a large number of investigations into the location of incipient cable faults.

In the longer term, it can be envisaged that an auto-mapping trigger unit could be part of the standard substation remote terminal unit design. Provided that a neighbouring substation is equipped with PD monitoring equipment, any incipient cable fault could be automatically located without the need to install additional hardware or engineers to visit site.

CONCLUSIONS

An increasing proportion of MV cables were installed more than 40 years ago. Network automation and remote control have significantly reduced the duration of customer interruptions, but have not addressed the problem of fault incidence or provided a way to target cable replacements. If nothing or too little is done to replace degrading cables, an increasing number of faults can be expected with more customers being interrupted [2].

As the cost of equipment decreases and the performance of PD detection systems improves, on-line condition monitoring is expected to play an increasingly vital role in the management of this ageing underground asset. The recent developments in auto-mapping provide a robust platform for accurate and cost effective location of incipient defects.

REFERENCES

[1] Matthieu Michel, 2005, 'Comparison of Off-Line and On-Line Partial Discharge MV Cable Mapping Techniques', *CIRED*

[2] Matthieu Michel, 2007, 'Innovative asset management and targeted investments using on-line partial discharge monitoring & mapping techniques', *CIRED*