# ON-LINE CONDITION MONITORING OF DISTRIBUTION NETWORK ASSETS – MAKING THE NETWORK SMARTER

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## *ABSTRACT*

*There is a move to transform electricity systems to smart networks, with major changes to the way power is generated, moved and consumed. This change gives the opportunity to combine smart network management with smart condition monitoring solutions to improve network reliability, operator safety and efficiencies whilst reducing maintenance costs and downtime. This paper will show how substation condition monitoring solutions are being developed and deployed that can provide tangible benefits to the operation of networks.*

## INTRODUCTION

Large numbers of network operators around the world are having to deal with a large ageing asset base approaching or exceeding its original design life. At the same time there are ongoing changes to the composition of the network as distributed generation is introduced onto the system. Additionally network operators can be experiencing load growth and changes in traditional load patterns all of which put strain on the investment required in the network to maintain, or indeed improve, network performance. One of the inevitable consequences of these factors is that existing networks will be required to continue to provide good reliable service but also operate smarter.

## NETWORK RELIABILTIY

There are a number of factors affecting the reliability of Medium Voltage (MV) distribution networks. To increase or maintain existing levels of network performance it is important to understand the areas of weakness and causes of disruptive failure and system interruption. Figure 1 shows the main factors for disruptive failure and outages on the UK ground mounted MV asset population and the estimated annualised direct cost of repair, in simple financial terms money off the bottom line.

It should be borne in mind that the costs in Figure 1 only represent a fraction of the true cost of the failure. If account is taken of the additional cost in terms of network performance, safety, and environmental factors then the actual figure is likely to be 4 to 5 times higher than that shown. [1]

Analysis of the disruptive failures on the network shows that the major causes of failure are:

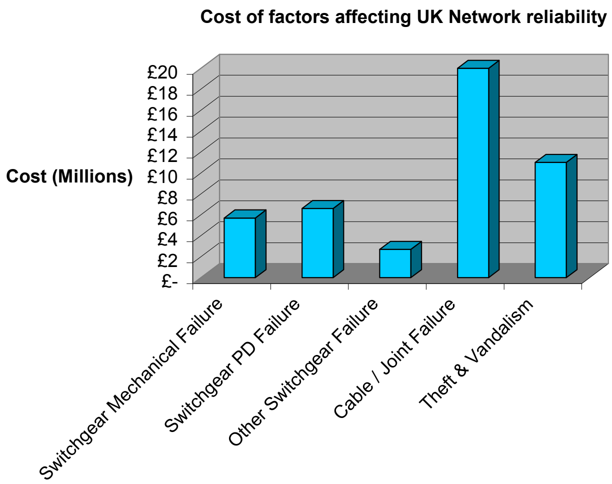


**Figure 1.** Estimated direct cost of faults on UK MV networks

- Mechanical Switchgear faults
- Switchgear Partial Discharge faults
- Cable faults (excluding third party damage)
- Other Switchgear faults including lightning damage, protection systems
- Theft and Vandalism

The total direct costs of repair to the MV Distribution Networks in the UK are therefore circa £45million per year and the cost in terms of network performance and other consequential factors is much higher again. These annual costs are based on current failure rates on the existing networks as they stand today. These same networks are ageing and wholesale replacement is not a viable option; therefore just maintaining the current rates of failure will require effective asset management and optimised investment planning. Understanding and monitoring the condition of equipment is the key factor in the effective management of assets and links good investment, operation and maintenance of network components.

It should also be considered that detection of incipient faults coupled with targeted maintenance and rectification work has significant cost benefits compared to restoration of unexpected failures. Therefore the level of expenditure and on-costs of these failures should be seen as an opportunity for cost reduction. Indeed some network operators have demonstrated that actively increasing network performance by implementing a programme, including condition monitoring, to reduce SAIDI (System Average Interruption Duration Index) and SAIFI (System Average Interruption Frequency Index) indicators has also provided significant cost savings [2].

## CONDITION ASSESSMENT OF MV ASSETS

### Partial Discharge Detection

The use of non-intrusive partial discharge detection instruments has been shown to be an effective technique for the condition assessment and management of MV plant and equipment. The use of hand held detection tools provides a relatively low cost solution for network operators to embark on a programme of partial discharge testing [3].

Field experience and laboratory experimental work has demonstrated that partial discharge activity, particularly when occurring on the surface of insulation, can be intermittent and greatly affected by environmental conditions. Therefore, although the effectiveness of regular spot check surveys has been established, there are instances where problems can remain undetected due to the prevailing environmental conditions at the time of the survey [4].

This has led a number of utility companies around the world to explore the widespread adoption of partial discharge monitoring solutions, particularly of critical plant, e.g. primary substation equipment. The requirements of the monitoring solutions can often be grouped into two distinct categories: early warning and detection of the onset of insulation deterioration; and quantification of known problems and detection of incipient faults.

Provision of a single monitoring solution to satisfy both of these requirements is eminently possible. Indeed, should a monitoring solution be able to satisfy the second requirement (quantification), it will automatically satisfy the first (detection). However, the cost benefit analysis of widespread adoption of the sophisticated partial discharge monitoring equipment may not always result in a sound financial case. There are two ways to address this conundrum; the first solution is the installation of a combination of simple monitors for the early detection of developing problems and more sophisticated monitors where problems are suspected or have already been identified; this approach has been implemented by a number of utilities worldwide.

The second solution is to provide additional functionality into the monitoring system such that partial discharge is just one parameter that is monitored by the system. For example the monitoring system could provide condition information on the switchgear and the cables, determine whether the circuit breaker mechanisms are operating within expected parameters, collect circuit loading and utilisation information, monitor the environmental conditions of the substations, provide security alerts when people enter the substations etc. In other words the solution addresses more of the causes of failure shown in Figure 1 and also starts providing operational information. This second solution effectively redefines the partial discharge monitor as a substation monitor which lends itself to the move towards active monitoring of assets and the adoption of 'Smart Networks'. Network operators require these monitoring solutions to take in data from a number of different sensors and devices and integrate into existing communication infrastructure and asset management systems. One example of such a monitoring system is the UltraTEV Monitor that has the detection of partial discharge activity as its core functionality but has optional and expandable capability to suit the specific requirements of individual installations and operators. In order to provide the core capability of monitoring over 200 PD measuring points simultaneously all time stamped to within 1nanosecond requires a powerful central processing system. This therefore provides the central system hardware that enables expansion to cover condition monitoring and analysis of a range of additional parameters other than partial discharge.

All condition events and indicators can be collected and analysed by a web enabled hub which can be programmed to provide alerts and alarms as required and allow immediate access to on line condition information for analysis so that incipient faults can be detected and remedial action planned in a timely manner. The ability to monitor additional parameters at little extra cost can make a big difference to the cost benefit calculations and allows more widespread adoption of the more sophisticated monitoring systems.

### Substation Environmental Conditions

Some of the simplest but beneficial additional parameters to monitor are the environmental conditions of the substation. Relative humidity has a major influence on initiating and sustaining surface partial discharge activity on MV/HV insulation. Laboratory and field work has indicated that keeping humidity below 60% dramatically reduces the likelihood of surface discharge occurring [4]. Stratification of humidity has also been observed so multiple measuring points are necessary in many substations [5].

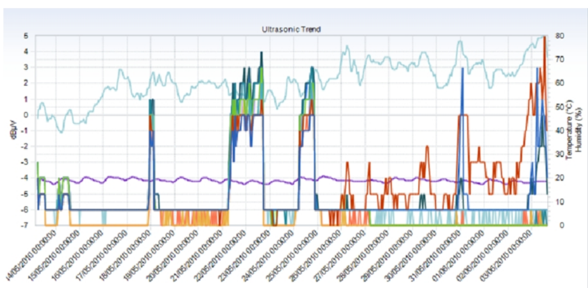


**Figure 2.** Ultrasonic PD activity correlating with relative humidity profile

The UltraTEV Monitor has the ability to include an ambient temperature and relative humidity temperature sensor plugged into each measurement node. This allows environmental conditions to be monitored and trended at various locations throughout the substation e.g. near the cable trenches. Alarms can be programmed to indicate when the conditions are moving outside the defined limits e.g. >60%RH which may indicate a problem with auxiliary equipment such as heaters or dehumidifiers. Early warning on this type of problem allows simple intervention and can prevent the onset of PD problems and degradation of the primary plant.

## Mechanical Monitoring of Trip Mechanisms

Figure 1 showed that a significant proportion of failures are associated with the mechanical elements of switchgear. Problems within the circuit breaker mechanisms themselves are often found to be due to things such as stiction, caused by over or under lubrication of the mechanism, distortion or corrosion of components with the circuit breaker external mechanism.

Condition monitoring of MV circuit breakers is reasonably well established with the basic principle being to detect deteriorating conditions within a circuit breaker operating mechanism prior to any malfunction or failure. In turn, this leads to improved system reliability and more effective maintenance.

Circuit breaker trip timing methods are generally carried out on a periodic basis e.g. during shutdowns or maintenance when the breaker can be tripped without affecting the network. It should be noted that it is very important to capture the first trip as this is a true indication of how the circuit breaker will perform under fault conditions. One major drawback in using portable instruments for this function is that it can be difficult to operate all circuit breakers during a single visit to the substation due to network constraints. Moving towards an installed monitoring solution connected into the substation hub allows all circuit breaker operations to be captured remotely (whether planned or not) and can yield useful condition information during normal operation of the network.

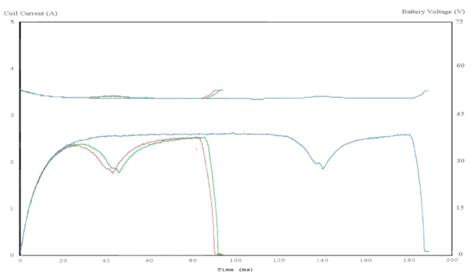

**Figure 3.** Typical trip timing profile with first trip showing abnormality

A monitoring solution will ensure that the all important first trip is always captured, providing information on the trip coil, plunger, main and auxiliary contacts. Circuit breaker trip timing monitoring can identify problems within the mechanism before they affect the safety and reliability of the equipment and continuous monitoring can remove the need to carry out maintenance on the mechanism unless it is required.

## Condition Assessment of MV Cables

Partial discharge can occur in voids in cable insulation and joints in a similar way to internal discharges in switchgear insulation. Offline methods such as energising via a VLF test source have long been used for the detection of PD in cables and provide an accurate one off measurement of discharge mapped for the length of the cable. However, it can be time consuming, expensive and requires an outage to perform the test.

In more recent years online PD testing using RFCTs on the earth connection between the cable sheath and the earthed switchgear has been introduced and the focus on online testing has been growing.

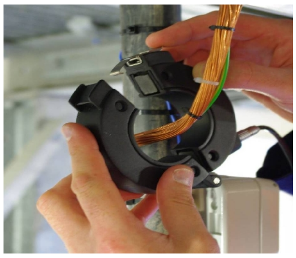

**Figure 4.** Connection of Current Transformer onto cable earth strap for online cable PD measurements

The powerful central processing unit of a substation hub combined with electronic circuits designed specifically for the detection of the PD in cables can allow partial discharge events occurring along the length of cables to be detected and time stamped much in the same way as PD occurring within switchgear. If the monitoring system determines that PD is occurring within one of the MV cables, PD waveforms can be captured such as shown in Figure 5. This provides information on the magnitude of the discharge and through time of flight calculations it is possible to calculate location information and build up a partial discharge map of the cable across its length as demonstrated in Figure 6.

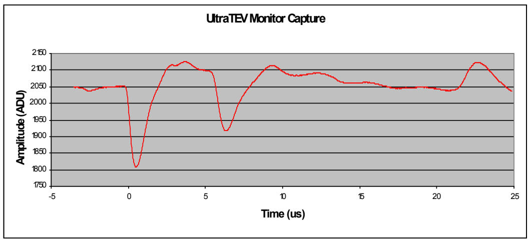


**Figure 5.** Cable PD waveform captured on-line

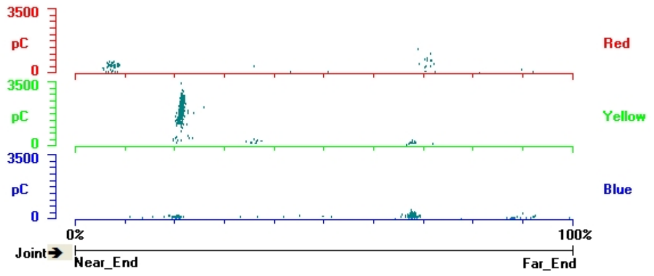


**Figure 6.** On-line Cable PD map showing PD along the cable

## Substation Security

Substation security has become an increasing problem with the price of copper attracting a greater number of attacks on substation assets. With a central web based monitoring system it is a simple step to introduce cameras that both detect and monitor the presence of people within substations. Following an unexpected presence with the substation an alarm can be activated and an email despatched with an image attachment to enable a level of response decision to be made.

## SUBSTATION MONITOR SOLUTION

It can be seen that a large percentage of the failure modes for MV assets can be non-intrusively detected to help reduce the unexpected failures and disruptions to networks. Using a central substation monitoring hub allows all of the parameters shown in Figure 7 to be measured and monitored today by various systems and sensors. Better value can be achieved by using systems such as the UltraTEV Monitor, which is a web enabled monitoring system, as a platform to collect, store, display, and make available all of this condition assessment data to the network operator.

Utilising automated data evaluation abnormalities or negative trends can be automatically identified which removes the need for monitoring by an engineer. The system has the ability to send alerts and intelligently configured alarms via e-mail and SMS, allowing engineers to remotely access and interrogate the data from their desk only as required.

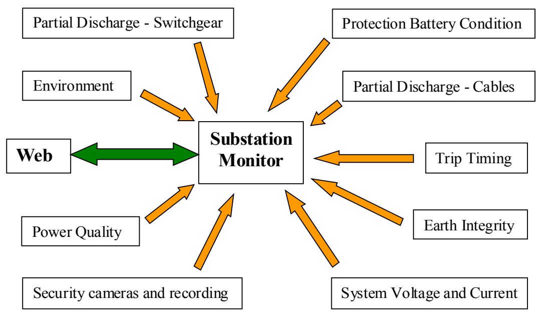


**Figure 7.** Substation Monitor Overview

Multiple substations can be monitored by a single engineer reducing costs and improving efficiency. Large scale implementation of substation monitoring with the intelligent combination of data from multiple substations at a central point would be a step towards dynamic network management.

## CONCLUSION

The importance of condition data in the effective management of distribution networks is well established and large numbers of utilities successfully employ condition monitoring programmes based on periodic assessment. There is a developing trend towards the adoption of condition monitoring systems, particularly on the more critical assets where the network performance costs of failure greatly outweigh the direct costs of the repair / replacement.

Adopting a combined multi parameter substation condition monitoring solution can reduce failures, maintenance and improve network reliability and more readily justify the capital outlay in the monitoring systems. When condition data from multiple substation monitors is combined, it is possible to build an overview of the current condition of the network. This introduces the possibility of active management of the network based on the condition, capacity and capabilities of the assets at any instance in time.

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