Understanding failures with Power Forensics™

Failures of medium and high voltage electrical assets can result in serious power outages and often make headline news. Forensic science is best known for identifying the causes of aircraft crashes or gathering criminal evidence, but it is increasingly applied to the understanding of degradation and failure mechanisms which lead to electrical equipment failure and cause network outages. Just as investigations into air crashes have dramatically improved aircraft design and operation, and thereby made air travel much safer, lessons learnt through forensic investigations can reduce the occurrence or repetition of expensive and dangerous failures, and ultimately lead to an increase in the safety and reliability of assets and ensure network availability is maintained. This in turn leads to better asset management, through more effective condition monitoring techniques, maintenance policies, and investment or replacement decisions.

By Anne McIntosh, Director of HV5-9s at EA Technology

Catastrophic failures of electrical plant that were once regarded as 'unfortunate accidents' are increasingly classed as preventable incidents, for which somebody will bear responsibility. Forensic investigations may provide key legal evidence, assisting the courts in cases of prosecution under health and safety laws or charges of corporate manslaughter, as well as apportioning responsibility for the financial consequences.

Forensic investigation process

Our main role as forensic investigators is to determine the condition of electrical equipment, identify the primary degradation and failure mechanisms, and present recommendations to enhance the performance of the assets. Our ultimate aim is to *prevent future failures from occurring*. We are able to do this impartially and confidentially as we are independent of equipment manufacturers, owners, operators and maintainers.

Degradation and failure of equipment are caused by one or more factors, including: design, materials selection, fabrication and processing, operating and service conditions, human error, vandalism and illegal activity. To identify these factors requires a thorough process of forensic investigation.

A failed oil filled circuit breaker, shipped to our laboratories for investigation

Gather information

A forensic investigation starts with all relevant background and historical information. This includes manufacturing histories, service records, operational conditions and details of any repairs, maintenance or modifications, and a reconstruction of events leading to a failure.

Retrieve evidence

Making sense of the often charred and twisted remains of an equipment failure relies on using two approaches in tandem: sophisticated laboratory analysis of carefully preserved samples, and expertise in interpreting the evidence, results and patterns of events; comparison with similar equipment or surviving parts of the affected equipment is often useful.

But analytical results are only as good as the samples provided. This means that samples must be retrieved from the failure site and handled with the utmost care to avoid damage and loss of evidence. Then they must also be transported without damage or contamination to the analytical laboratory.

Laboratory Tests

In the laboratory, we perform comprehensive testing of equipment and samples, including non-destructive testing, electrical testing, materials analysis and mechanical testing. The tests employed will be different and appropriate to each investigation, and will be carefully targeted to gather all relevant information.

Visual inspection

Optical microscopy

Recording evidence

Low-powered optical microscopes are used to examine the condition of samples, while higher-powered microscopy with magnification up to x1250 is used in conjunction with image analysers to identify such things as the presence of material defects, impurities, degradation, inappropriate selection of materials, poor quality control and errors in the manufacturing processes used.

Scanning electron microscopy raises magnification as high as x1,000,000, and also enables x-ray elemental analysis quickly and accurately, while quantitative chemical analysis is carried out on features as small as $0.001m^3$. Using these techniques, we can study the surface of a sample to determine its elemental composition, identify any contamination, corrosion and degradation products and study fracture surfaces.

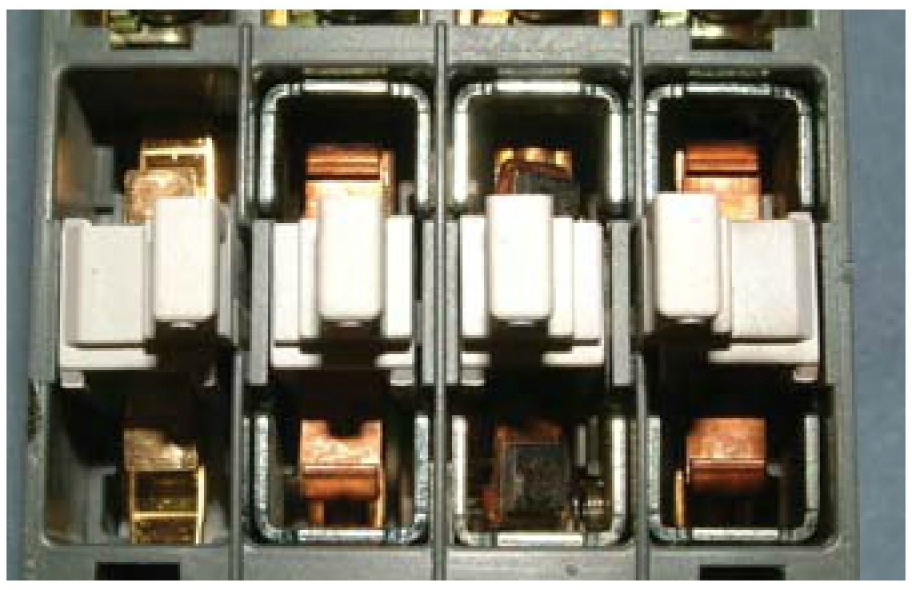
A variety of mechanical tests can be carried out to determine if the mechanical performance of the components contributed to the degradation and failure process.

High Powered optical microscopy image of intergranular stress corrosion and cracking of a brass bolt, as a result of Partial Discharge (PD) activity

Putting It All Together

EA Technology Analytical has nearly 50 years' experience in forensic investigations, specifically within the electricity industry. Our collective expertise is supported by a database of records of how thousands of assets have deteriorated and failed in the past.

Laboratory examination and testing produces a mass of detailed information for each investigation, but the most important part of our work is the ability to interpret such data, to present an accurate picture of how and why the degradation and failure occurred. Drawing on our accumulated past experience is an important part of our forensic analysis process.



Business Outcomes

Prevention is always better than cure (and more cost-effective!). Recommendations from a forensic investigation should be practical and cost-effective. The outputs should be used to initiate or support measures to ensure the future safety and reliability of individual assets and the electrical network as a whole resulting in reduced network interruptions and increased network availability.

PD activity on a cast resin monobloc, caused by a poor substation environment

Typically, recommendations are to implement improved condition assessment techniques and maintenance practices, in order to identify and measure degradation progress prior to failure. In some instances, improved training for personnel or changes in the design of equipment or the materials used are identified, which of course is important for manufacturers.

Conclusion

Forensic investigations of failed electrical equipment can assist in identifying what went wrong after the event. But of much more value are targeted recommendations which can lead to effective preventive actions, ensuring that failures do not reoccur – a far better outcome than the prospect of suffering the costs associated with failures or even a day in court!

Further information
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Power Forensics™ Case Studies

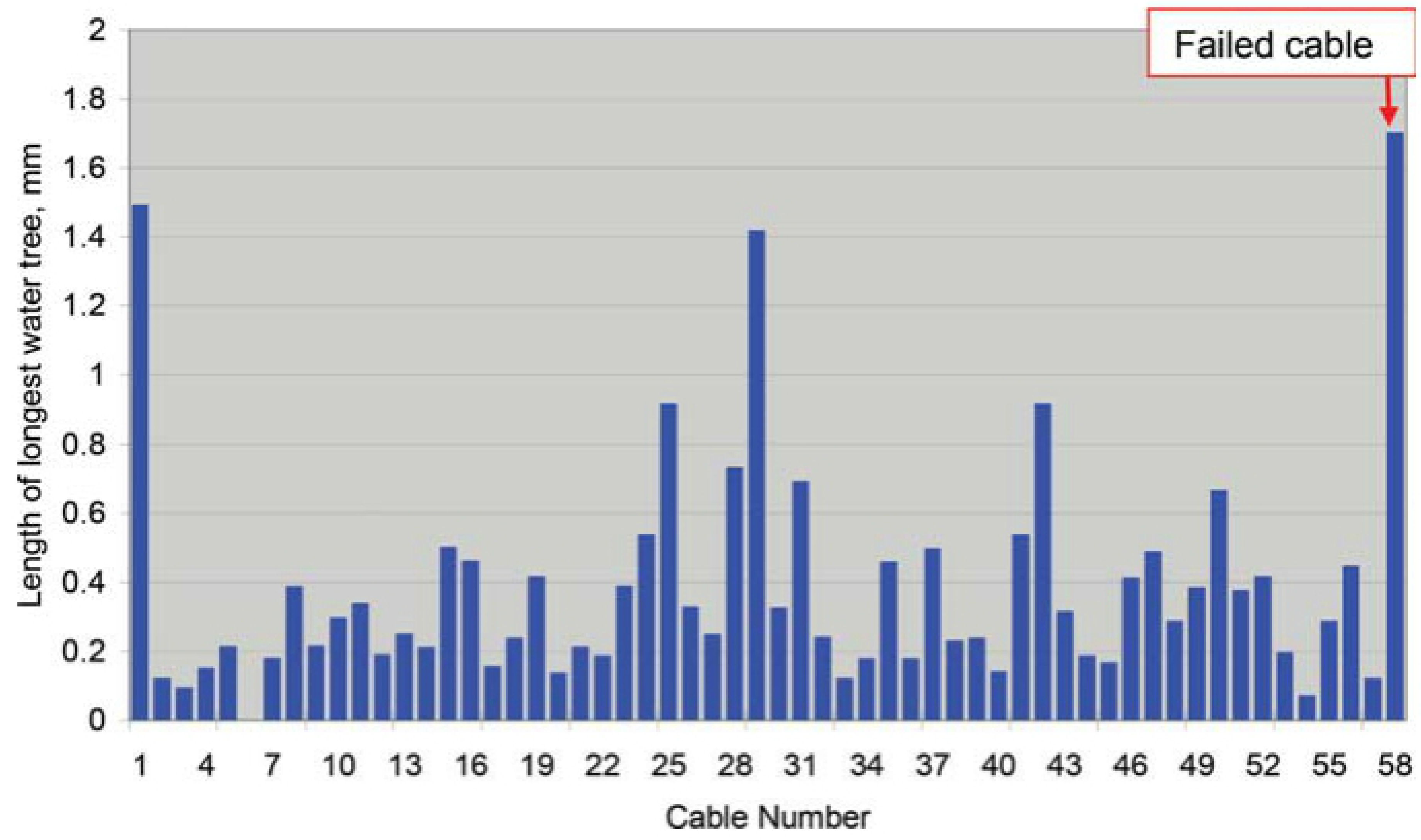
Several case studies demonstrate how forensic investigations have been used to improve the performance and operation of electrical network assets.

Case Study 1: Cable Failure

EA Technology Analytical's Power Forensics™ team investigated the failure of an 11kV XLPE insulated armoured cable from a UK industrial site. The failure disrupted production at the site causing significant financial losses. The cable was 15-20 years old and was manufactured to BS6622, a common specification for industrial cables.

The microscopic examination of the XLPE insulation showed a high density of large contaminants and extensive

Graph 1. Tree length data: failed cable compared with accelerated ageing tests

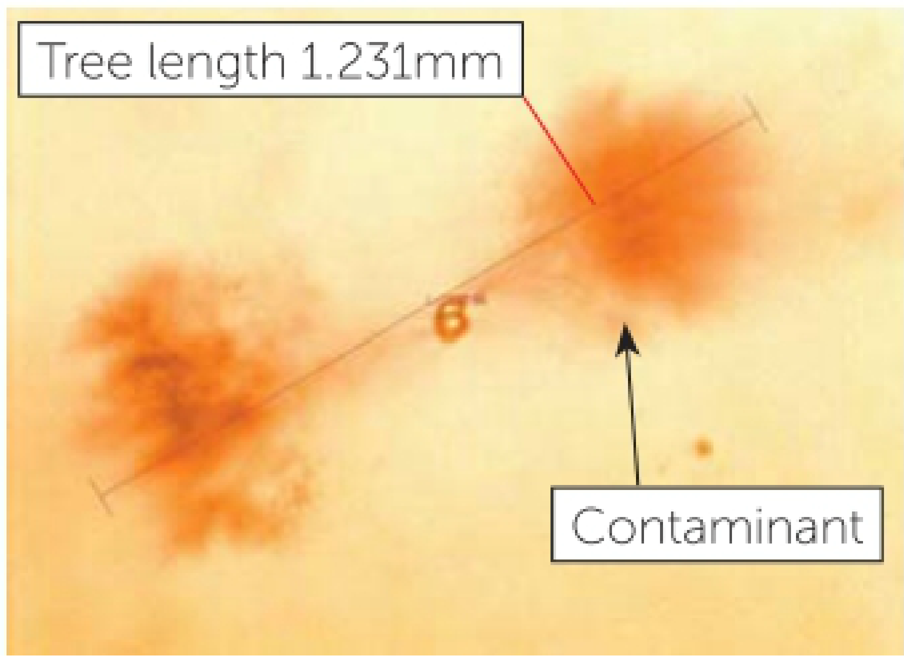


The trees were all centred on large contaminants (Figure 4), several of which exceeded the specified maximum allowable contaminant size.

water treeing. Data from the failed cable was compared with data from ageing tests on over 50 XLPE cables from a variety of sources. The ageing test represents 16 years of normal service life, giving results comparable with the real service of the failed cable. The longest water tree in the failed cable was compared with the longest tree in each cable from the ageing tests (Graph 1): the tree length in the failed cable was far greater than the majority of cables and approximately ten times longer than tree length in many of the good quality cables.

The trees were all centred on large contaminants (Figure 4), several of which exceeded the specified maximum allowable contaminant size.

It was concluded that the failure had been caused by excessive treeing activity, influenced by the large contaminants in the cable. As this was an issue for the whole length of cable, it was recommended that the cable be replaced as the risk of further failures was significant. It was also recommended that the new cable specification should have a limit on contaminant size to reduce the risk of a similar mode of failure in the future.



Example of a tree found in the failed cable

Case Study 2: CT Failure

Foreign body in failed CT winding

EA Technology Analytical's Power Forensics™ team investigated the failure of a cast resin current transformer (CT) from a 33kV circuit breaker at an industrial site.

After carefully removing sections of the remaining resin from the CT, a foreign body was seen on the outside of the winding (see arrow below).

The foreign body was removed and examined under a microscope. It was wrapped in layers of the binding tape, apparently trapped there while the tape was being applied during manufacture. The foreign body was enclosed in an air pocket forming a void in the insulation, resulting in partial discharge causing erosion of the surrounding insulation and a build up of heat, leading to catastrophic failure of the insulation.

Three other intact CTs from the same location were also destructively examined: one showed early onset of corrosion in a similar location, also putting it at high risk of partial discharge failure. It was therefore recommended that partial discharge monitoring be implemented to provide early warning of impending failure. It was also recommended that CT replacement should be actively considered to reduce risk of failure in the longer term.