Institution: Glasgow Caledonian University

Unit of Assessment: 15 General Engineering

Title of case study: Condition monitoring of power cables and motors to prevent power plant failures

1. Summary of the impact (indicative maximum 100 words)

Research conducted by Glasgow Caledonian University (GCU) has changed the way power cables and motors are monitored in EDF Energy's nuclear power stations in the UK and Wuhan Electrical Power Company, China, providing the companies with innovative techniques enabling them to identify insulation defects and improve their maintenance programme. Application of the research output has helped the companies to enhance practice in PD testing, reduce maintenance and repair costs by millions of pounds whilst reliably supplying over 20% of the UK's power generation, and an area with over 10 million people in China.

2. Underpinning research (indicative maximum 500 words)

Research work in the field at Glasgow Caledonian University (GCU) started in 1999 and has since involved around 15 academics and research staff/students. Professor Chengke Zhou's research interests include advanced signal processing for transient pulse extraction from strong background noise and PD data analysis and diagnostics in PD-based condition monitoring [1-4]. He has undertaken many pieces of funded research, working closely with industry to identify further scientific and technological advances to the meet the challenges faced by the power industry.

An EPSRC grant awarded to Prof. Chengke Zhou in 2006, with strong support from EDF Energy, allowed research work to develop novel techniques in automating the application of Wavelet transform in denoising of PD measurement, based on thousands sets of real-world data [4]. During the research project, not only did the GCU research group prove that the wavelet based technique was superior to earlier Fourier Transform and Matched Filter based denoising methods [1-4], they also developed a method for pulse classification enabling the localisation of insulation defect sites from which PD signals emanated [4,5]. The pioneering work is significant in practical PD monitoring practice in that (a) the removal of noise and classification of PD pulse shape means that any phase resolved pattern can be determined with improved resolution, allowing pinpoint of the location and the likely failure modes; (b) the novel denoising technique reduces the amplitude of the smallest significant PD waveforms observable, giving early warning of faults.

As a result of the findings, over 8 publications were produced in IEEE Transactions and IET Journals. Numerous speeches were delivered to flagship industrial conferences in the field such as IEEE UK/Ireland, CIGRE (International Council on Large Electrical Systems), CMD (Condition Monitoring and Diagnostics), Euro TechCon, (UHVnet) University High Voltage Network and CIRED (International Conference on Electrical Distribution).

An additional EPSRC funded project, titled "Knowledge Discovery from On-line Cable Condition Monitoring Systems: Insulation Degradation and Aging Diagnostics", was awarded in 2009. Two algorithms, i.e. Rough Set and Kohonen mapping, were developed for knowledge discovery for use in on-line condition monitoring systems and proved to have the (a) capability of interrogating and learning from any existing database; (b) ability to analyse PD activities from on-line PD monitoring system and learn and evolve continuously; (c) ability to remove redundant data from the system; (d) ability to produce knowledge rules on the level of degradation and the remaining life of cables in service; and (e) allow, by applying the knowledge acquired, continuous assessment of monitored cables, in terms of nature of insulation faults and associated criticalities.

In addition, a novel K-means based method [5] was developed for autonomous recognition of PD patterns recorded under conditions in which a phase-reference voltage waveform from the HV conductors is not available, which is often the case in cable on-line monitoring. The method has proven particularly useful as it is capable of recognising patterns of PD activity in on-line monitoring applications for both single-phase and three-phase cables and is also an effective technique for rejecting PD-like, pulse shaped, interference signals.

Furthermore, during the process of project work validation, time of flight and thermal techniques were utilised for defecting the location in cables. For the first time, defect analysis was carried out

using computer aided X-ray tomography and scanning electron microscopy to identify and characterise the defect and manufacturing errors in the surrounding region [6]. The findings provided EDF Energy with clear reasons behind their past cable failures, in addition to establish a knowledge base for the research group to conduct future PD based monitoring and diagnosis.

3. References to the research (indicative maximum of six references)

1. X. Ma, C. Zhou and I.J. Kemp: "Automated Wavelet Selection and Thresholding for PD Detection", IEEE Insulation Magazine, Vol. 18, No. 2, March/April, 2002. Citation: 160
2. X. Ma, **C. Zhou**, I. J. Kemp: "Interpretation of Wavelet Analysis and Its Application in Partial Discharge Detection", IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 19, No. 3, June 2002: Citation; 160
3. X. Zhou, C. Zhou, I.J. Kemp: "An improved methodology for application of Wavelet Transform to PD measurement denoising", IEEE Transaction on Electrical Insulation and Dielectrics". Vol.12, No. 3, June, 2005, citation: 80
4. C. Zhou, M. Michel, D. Hepburn and X Song: "On-line Partial Discharge Monitoring in MV Underground Cables", IET Science Measurement and Technology, Vol. 3, issue 5, Sept. 2009.
5. X. Peng, C. Zhou, D.M. Hepburn, M. Judd and W.H. Siew: "Application of K-Means Method to pattern Recognition in On-line Cable PD Monitoring", IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 20, No.3June 2013.
6. J. Reid, C. Zhou and D. M. Hepburn, M. D. Judd and W. H. Siew: "Fault Location and Diagnosis in Medium Voltage Shielded Power Cable: A Case Study", IEEE Transactions on Dielectrics and Electrical Insulation, Feb. 2013, Vol 20. No.1.

Grant Funding

- Prof. Chengke Zhou (Principal Investigator): "Automation and Optimisation of Wavelet Transform Techniques for Partial Discharge Denoising, and Pulse Shape Classification, in Power Plant". EPSRC EP/D048133, £177,000, Feb. 2006-Feb.2009.

- Prof. Chengke Zhou (Principal Investigator): "Knowledge Discovery from On-line Cable Condition Monitoring Systems: Insulation Degradation and Aging Diagnostics". Feb.2009-Feb 2012. EPSRC project EP/G028397/G029210. Joint grant with University of Strathclyde, total value £540,000. £275,000 from EPSRC to GCU.

- Prof Chengke Zhou: "Development of portable cable/motor PD monitor with bespoke denoising and asset management software package", EDF Energy, June 2011-Dec 2016, £260,000.

4. Details of the impact (indicative maximum 750 words)

EDF Energy owns 8 nuclear power stations which supply 22% of the electricity generated in the UK. These power stations suffered eight in-service cable failures over a period of two years prior to working with GCU, causing huge financial losses due to forced replacement and reduced revenue. Investigations by independent specialist companies indicated that localised insulation degradation was responsible for the problems and that the insulation of other similar cables at the station might also be significantly degraded due to insulation defects during manufacture.

The high level of electrical noise interference proved to be too great a challenge for commercial service providers aiming to undertake PD testing of the condition of the cables in service. EDF Energy learned of GCU's expertise in this area, having been present at the 2009 UHVnet Conference, where Professor Zhou was presenting a plenary speech on the application of the wavelet technique to cable PD data denoising.

Professor Zhou and the research team at GCU were commissioned to undertake a comprehensive measurement of the cables in eight switchboard rooms in Torness through an eight day consultancy project. Although challenges remained to be a significantly high level of noise, tests proved that the use of non-intrusive techniques developed at GCU, as described in [1-5] were able to identify PD activity in system components and distinguish PD activities from noise, in addition to

providing a specific indication of the location of the source of PD. GCU's work identified insulation problems which could be rectified.
Following the consultancy work at Torness power station, EDF Energy then provided further funding support (June 2011 – June 2014) which enabled GCU to develop a portable cable PD monitoring system. The hardware of the instrumentation and the software package, capable of detecting PDs with a magnitude of under 10 pico-Coloumb has been developed at GCU.
The system included high sampling rate (100M Sample/s) and high resolution (12 bits) data acquisition unit, second generation wavelet based data processing and denoising, K-means based PD pattern recognition, trending analysis, database management, and insulation defect diagnostics [1-6]. The prototype and the first version of the software package was completed in December 2012 and is still under further development, has been applied to Hunterston, Sizewell B and Hinkley Point B nuclear power stations. During the measurement campaigns, it was demonstrated that the cable PD monitoring system can not only detect PD activities emanating from cables but it is also capable of detecting and distinguishing PDs originating from motors located hundreds of metres away from the measurement point. In comparison with the existing practice of requirements for retrofitting on-line monitoring units, while power plant was off service, the technique allows the medium voltage motors driving gas cciculators and cooling water pumps at EDF Energy to be condition monitored much more conveniently and at significantly reduced cost. As a result, EDF Energy decided to fund GCU (Feb 2013-Sept 2016) to develop an add-on software package for PD based motor insulation monitoring and condition diagnostics.
EDF Energy's condition monitoring practice has been significantly improved as a result of GCU's continued activities because the PD monitoring system underpinned by GCU research has enormous technical and economic advantages over those available from commercial service providers as evidenced in the testimonial letter. Technically the GCU work enabled them to carry out regular PD testing which would otherwise impossible. Financially the research work, with potential of identifying incipient faults allowing timely maintenance and replacement, can help save them millions of pounds in avoided outages due to plant failures.
As a visiting professor to Wuhan University, China, a top 10 university in China, Prof. Zhou also applied the same technique to Wuhan Electrical Power Company and successfully identified two incipient faults, leading the company to deploy the technology as a routine test technique for the 500 plus kilometres of high voltage cables which supplies power to a region with over 10 million people. Potentially this can save the company tens of millions of Chinese Yuan a year through reduced workload which was required to patrol the cable circuits twice a day, in addition to providing improved effectiveness which, in turn, leads to better reliability.

5. Sources to corroborate the impact (indicative maximum of 10 references)

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