Institution:
Glasgow Caledonian University

Unit of Assessment:
12: Engineering

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

Period when the underpinning research was undertaken:
2002 – current date

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Chengke Zhou	Professor	1994 - present

Period when the claimed impact occurred:
2002 – current date

Is this case study continued from a case study submitted in 2014?
No

1. Summary of the impact

Research on power plant condition monitoring led by Prof Chengke Zhou has continued to grow outputs since 2014, and has had further impact on the way power cables and motors are monitored. Insulation defects are analysed at a major power generation company which supplies over 20% of the UK's power generation, providing the company with innovative techniques enabling them to identify the existence and nature of insulation defects, taking pre-empt actions and improve their maintenance decision making. In January 2018, the research output helped the company to reduce maintenance and outage costs by over ten million pounds in one incident. Further research work on power plant asset management contributed to the International Council on Large Electric Systems (CIGRE) Brochure 706: International Guidelines on use of Statistics and Statistical Tools for Analysis of Asset Life Data, and has had an impact on optimal maintenance and replacement of power assets owned by power industry worldwide, via asset life redefinition and extension.

2. Underpinning research

Research work underpinning the impact on the topic of condition monitoring started in 1999 and has since involved around 25 academics and research staff/students. Research outputs enabled autonomous partial discharge (PD) pulse identification, phase resolved pattern recognition and knowledge discovery from condition monitoring data accumulated over time. The work received six pieces of grant awards [G1-G6], including two major EPSRC funded projects prior to the current REF assessment period. The work led to the development of novel PD monitoring kits for EDF Energy, and enabled the power generation company to monitor their 11kV cable conditions in noisy environments where previous technology from commercial service providers failed.

Since 2014, Prof Zhou has collaborated with EDF to identify further scientific and technological advances required to meet the challenges faced by the power industry. Two research grants awarded from the company between 2013 and 2019 allowed research work to further develop novel techniques in automating the denoising and pattern recognition of PD measurement, whilst extending the previously developed smart PD recognition techniques from power cable to motor monitoring. Building on previous research work, Prof Zhou developed another autonomous

pattern recognition method, namely, the Fractal methods [R1], for separating the source and identifying the types of defects within cables and motors. This pioneering work is significant in that the classification of PD activities using the fractal pattern enabled any phase resolved pattern to be determined with improved resolution, allowing the identification of the defect location (cable or motor connected at the end of cable) and the determination of likely failure modes, which allows the appropriate measures to be taken against the nature of the defect. Previously developed pattern recognition techniques failed to function because of the lack of voltage phase resolved reference signals in online monitoring. Novel thermal models and sheath currents monitoring techniques [R2] were developed and enabled examination of the severity of defects [R3].

Research underpinning the second impact lies in the use of statistical models developed to forecast the remaining life of essential assets and to evaluate the outcome of various maintenance actions. Contributions at GCU included the selection of statistical models and processing of historical asset failure data [R4, R5], and the design of a technique to identify significant factors of failure which would enable a utility to improve the asset's procurement, its maintenance and replacement due to redefined asset life. The contribution is extremely important as it signposted how to manage when there is incomplete information, which is often the case among utilities worldwide. Research also presented methods in how to evaluate remaining life of cable assets, with findings showing that many high voltage cables may provide reliable service of 60 years, which is double the design life of 30 years [R6]. Recently, the Scottish Power Energy Network has commissioned Prof Zhou to deploy his research work to improve the PD monitoring and life redefinition of their cable assets [G6].

3. References to the research

- [R1] Zhuo Ma, Yang Yang, Martin Kearns, Kevin Cowan, Huajie Yi, Donald M. Hepburn, Chengke Zhou: "Fractal-Based Autonomous Partial Discharge Pattern Recognition Method for MV Motors", IET High Voltage 3(2), p. 103–114 12, June 2018. https://doi.org/10.1049/hve.2017.0109 (SCI journal, IF: 3.027, double blind review, Google citation: 8)

- [R2] Xiang Dong, Yang Yang, Chengke Zhou, Donald M Hepburn: "Online monitoring and diagnosis of HV cable faults by sheath system currents", IEEE Transactions on Power Delivery, 32(5), p. 2281-2290, Oct 2017. https://doi.org/10.1109/TPWRD.2017.2665818 (SCI journal, IF: 4.42, double blind review, Google citation: 31)

- [R3] Huajie Yi, Chengke Zhou, Donald Hepburn, Martin Kearns, Graham Peers: "Diagnosis of Abnormal Temperature Rise Observed on a 275kV Oil-filled Cable Surface – A Case Study", IEEE Transactions on Dielectrics and Electrical Insulation, 26(2), p. 547-553, April 2019. https://doi.org/10.1109/TDEI.2018.007545 (SCI journal, IF: 2.554, double blind review, the paper contains case study as cited in [C1])

- [R4] Zeyang Tang, Wenjun Zhou, Jiankang Zhao, Dajiang Wang, Leiqi Zhang, Haizhi Liu, Yang Yang, Chengke Zhou: " Comparison of the Weibull and the crow-AMSAA model in prediction of early cable joint failures", IEEE Transactions on Power Delivery, 30(6), p. 2410-2418, Dec 2015. https://doi.org/10.1109/TPWRD.2015.2404926 (SCI journal, IF: 4.42, double blind review, Google citation: 31)

- [R5] Zeyang Tang, Chengke Zhou, Wei Jiang, Wenjun Zhou, Xiaoping Jing, Jianhui Yu, Babakalli Alkali, Bojie Sheng: "Analysis of significant factors on cable failure using the cox proportional hazard model", IEEE Transactions on Power Delivery, 29(2), p. 951-957, Mar 2014. https://doi.org/10.1109/TPWRD.2013.2287025 (SCI journal, IF: 4.42, blind review, Google citation: 53)

- [R6] Chengke Zhou, Huajie Yi, Xiang Dong: "Review of recent research towards power cable life cycle management", IET High Voltage, 2(3), p. 179-187, Oct 2017. https://doi.org/10.1049/hve.2017.0037 (SCI journal, IF: 3.027, double blind review, Google citation: 23)

Grants awarded:

- [G1] 2006-2009: EPSRC grant, Wavelet Transform for Partial Discharge Denoising, £177k
- [G2] 2009-2012: EPSRC grant, Knowledge Discovery for HV Plant Condition Diagnosis, Total: £520k, £260k to GCU
- [G3] 2010-2013: EDF Energy, Development of a Portable Partial Discharge Equipment for Cable Condition Monitoring, £150k
- [G4] 2013-2016: EDF Energy, Development of Technique for Remote Monitoring of Motor Partial Discharge, £93k
- [G5] 2016-2019: EDF Energy, A Novel Approach to Insulation Resistance Measurement in Nuclear Power Plant, £116k
- [G6] 2019-2022: Scottish Power Energy Network, Redefining Cable Asset Life by Integrating Statistical Failure Models with Analytical Models and Development of Risk-based Asset Replacement Strategy, £295k

4. Details of the impact

Impact 1:

The power generation company in question owns eight nuclear power stations which supply 22% of the electricity generated in the UK. Prior to January 2014, the PD monitoring equipment which came as a result of the GCU research work helped in identifying insulation problems. This led one of the nuclear power stations to replace all existing cables with cables from the same manufacturer, thereby avoiding further breakdowns [C1]. The hardware of the instrumentation and the software package, capable of detecting PDs with a magnitude of under 10 pico-Coulomb has been developed at GCU. The system included high sampling rate (100M Sample/s, 4 channel synchronous sampling) and high resolution (12 bits) data acquisition unit, second generation wavelet based data processing and denoising, K-means and Fractal [R1, R6] based PD pattern recognition, trending analysis, database management, and insulation defect diagnostics. The product has since been applied to 7 UK nuclear power stations between 2015 and 2020. 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 requiring retrofitting on-line monitoring units while power plants are off-service, the technique allows the medium voltage motors driving gas circulators and cooling water pumps in the nuclear power stations to be condition monitored much more conveniently and at significantly reduced cost [C1], as research work enabled autonomous signal analysis and PD events recognition. This allowed maintenance engineers to gain an insight into the location, nature and severity of the problem instantly during condition monitoring and inspections.

In January 2018, the GCU team successfully undertook a measurement campaign in a power station where a 275kV cable was found to have 6 Celsius degrees local elevated temperature rise, and ruled out that the event was due to PD activities as reported by other commercial providers. They further provided in-depth simulation and analysis, with the thermal insulation model developed at GCU [R2], and identified the reasons behind, as well as the severity of the

problem. Based on the scientific evidence and recommendations provided by GCU research, the company decided to defer the replacement and avoided an unnecessary outage, and saved potentially tens of millions of pounds [C1]. Technically the GCU work enabled them to carry out regular PD testing which would otherwise be impossible.

Impact 2:

Based on the research in the last 8 years in the area of asset management and statistical analysis of failure events, over 10 publications were produced in IEEE Transactions and IET Journals [R1-R6]. As a result, Prof Zhou was invited to become a key member in the CIGRE working group D1.39 and C1.38. He then contributed 2 chapters to the CIGRE Brochure 706: "Guidelines for the Use of Statistics and Statistical tools on Asset Life Data", which is impacting on the practice among power utilities worldwide [C2]. This has become essential for utilities to extend the service life of existing power plant assets, which has a potential saving of billions of pounds. Recently, The Scottish Power Energy Network has commissioned Prof Zhou to deploy his research work to improve the PD monitoring and maintenance practice of their cable assets [G6].

5. Sources to corroborate the impact

- [C1] Testimonial from Chief Electrical Engineer, Nuclear Generation, EDF Energy, GSO Business Park, East Kilbride, G74 5PG.
- [C2] CIGRE Brochure 706, to which Prof Zhou contributed 2 of the 8 chapters, International guideline on the use of statistics and statistical tools for analysis of life data.