Institution:
Glasgow Caledonian University

Unit of Assessment:
12: Engineering

Title of case study:
Big Data and Machine Learning Research for High Voltage Equipment Condition Monitoring

Period when the underpinning research was undertaken:
August 2015 - present

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:
Alan Nesbitt	Head of Department of Electrical & Electronic Engineering	1992 - present
Gordon Morison	Head of Department of Computing	2010 - present
Imene Mitiche	Research Assistant	2019 - present
Jack Slater	PhD Student	2017 - present

Period when the claimed impact occurred:
September 2015 - present

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

1. Summary of the impact

Between 2015 and 2020 the collaboration between Glasgow Caledonian University and Doble developed a novel Electromagnetic Interference (EMI) surveyor instrument which captured, stored and analysed data from a major UK power station, increasing the company's sales revenue by 50% and saving hundreds of millions of pounds for clients in the UK and EU. It also represents a substantial societal benefit in terms of the sustainable electrical power supply achieved through monitoring instruments. The collaboration between Doble and GCU has transformed the company's roadmap of services and products innovation worldwide, ensuring the company maintains its position in the market.

2. Underpinning research

Doble has invested £700,000 to carry out research on Big Data and ML applications for improved condition monitoring at the Innovation Centre of Online Systems (ICOS) at GCU and made an additional £132k investment on a Knowledge Transfer Partnership (KTP) to assist the research work and its adoption with clients in the field. The mission of this research is to innovate new knowledge services and products to their clients worldwide [R1]. This allows Doble to maintain their position within a competitive market. The ICOS handles R&D activities and identifies new opportunities to enhance the reliability and integrity of power stations, developing new Partial Discharge (PD) monitoring products and technologies [R2]. Working with GCU, ICOS are developing the next generation of condition assessment instruments. The outcome of this research enables the development of integrated monitoring, smart analysis algorithms and complete condition assessment tools that help the electric supply industry around the world as it moves towards online monitoring systems and predictive maintenance programs [R3] to [R6]. HV power generating assets are expensive to manufacture and their value depends on their longevity and hence their effective and efficient maintenance through condition assessment.

Since 2015 the GCU research team focused on ML algorithms to predict HV asset failure. Their research covers a number of areas:

- Big Data - The existing collaboration focused on developing an enhanced instrument capable of acquiring radiated or conducted EMI data and store data in a ‘private cloud’ database for processing. A prototype was developed, implemented and tested, which successfully demonstrated synchronisation between database instances and the instrument [R1], [R4]. The deployed prototype is currently capturing and analysing live surveillance data produced by HV generators within a major UK power station.

- Fault classification using ML techniques - The research on the data processing utilised ML and deep learning techniques. The research demonstrated that it is feasible in the field to identify fault patterns from the EMI data and classify PD among other faults. The developed ML algorithms captured and learned expert knowledge from advanced practitioners [R2], [R3], [R5], [R6].

- Linking Big Data to ML classification - The captured and stored data in the deployed prototype (see (1) above) were pre-processed and passed to the optimum ML algorithm for fault type classification [R4].

- Instrument implementation of the ML algorithm - The optimum algorithm, in terms of computation and performance, was implemented into the Doble Portland instrument, developed by the collaborative partnership of Doble and GCU, for PD detection, monitoring and analysis [R3]. A combination of tests at a major UK power station and in the HV laboratory at GCU have contributed to a successful domain expert labelled dataset from which the algorithm has been trained and optimised to match experts’ analytical level of EMI diagnosis [R6]. The instrument is currently being used in PD surveys across Doble’s clients in the UK, EU and overseas, where condition monitoring reports of the measured and analysed data are provided to the clients.

3. References to the research

- [R1]. J. Slater, A. Nesbitt, G. Morison, P. Boreham, "A Hybrid Cloud for Data Analytics in Electrical Substation Condition Monitoring Systems", IEEE International Conference on Computational Science and Engineering (CSE) and IEEE International Conference on Embedded and Ubiquitous Computing (EUC), 2019, pp. 283-288. Impact Factor: N. A. Citations to Date: 0. Industrial Usage: the database solution is currently used by Doble for data ingestion, storage and query for analytics associated with the EMI analysis. This paper proposed a Hybrid cloud database to automatically acquire and store large measured data from a major UK power group, Drax, quickly. The work has been very beneficial in industrial use as the data query was the foundation of the machine learning based condition monitoring.

- [R2]. I. Mitiche, G. Morison, A. Nesbitt, M. Hughes-Narborough, B. G. Stewart, P. Boreham, "Classification of EMI Discharge Sources Using Time-Frequency Features and Multi-Class Support Vector Machine", Electric Power Systems Research, 2018, 163, pp. 261-269. Impact Factor: 3.2. Citations to Date: 4. Industrial Usage: updated prototype superseded by [R3]. For the first time, this work transferred expert’s knowledge on EMI faults to an intelligent system through signal processing analysis and machine learning based algorithm. The high classification accuracy in this work demonstrated that it is feasible in the field to identify fault patterns from the EMI signals and classify Partial Discharge among other insulation faults. The developed algorithms captured and learned expert knowledge from advanced practitioners and encouraged further research.

- [R3]. I. Mitiche, A. Nesbitt, S. Conner, P. Boreham, G. Morison, "1D-CNN based real-time fault detection system for power asset diagnostics", IET Generation, Transmission & Distribution, 2020, 14 (24), pp. 5766-5773. Impact Factor: 3.3. Citations to Date: 1. Industrial Usage: the final model which is currently used by Doble for EMI data classification. An end-to-end fault classification algorithm based on real-world

Electromagnetic Interference (EMI) time-resolved signals was developed in this paper. The proposed optimum algorithm, in terms of computation and performance, was implemented into the Doble Portland instrument, for fault detection, monitoring and analysis. A combination of tests at a major UK power station and in high-voltage laboratory have contributed to a successful domain expert labelled dataset from which the algorithm has been trained and optimised to match experts' analytical level of EMI diagnosis.

- [R4]. J. Slater, A. Nesbitt, G. Morison, P. Boreham, S. Conner, "Application of Empirical Mode Decomposition in identifying key frequencies for EMI diagnostic measurements", 53rd International Universities Power Engineering Conference (UPEC), 2018, pp. 1-5. Impact Factor: N.A. Citations to Date: 0. Industrial Usage: the frequency peak detection method is currently used by Doble for EMI analysis. This work proposes an algorithm to automatically select key frequencies for an end-to-end condition monitoring that is linked to [R1]-[R3] and [R5]-[R6]. The results show that the EMD process captures all the frequency points the engineer would manually select for further analysis. This aids engineers in the field to identify these key frequencies instead of relying on eye or knowledge only.

- [R5]. I. Mitiche, G. Morison, M. Hughes-Narborough, A. Nesbitt, B. G. Stewart, P. Boreham, "Classification of Partial Discharge Signals by Combining Adaptive Local Iterative Filtering and Entropy Features", IEEE Conference on Electrical Insulation and Dielectric Phenomena, 2017, pp. 335-338. Impact Factor: 1.17. Citations to Date: 16. Industrial Usage: initial prototype superseded by [R6]. This paper elaborates upon a previously developed software condition-monitoring model for improved EMI non-stationary signals classification based on time-frequency signal decomposition and entropy features. Since this method is demonstrated to be successful with real field data, it inspired the peak detection work in [R4]. This paper attracted the editors of the journal it was published in, who offered a cross-institutional collaboration with Universidad Politécnica de Madrid. Furthermore, they invited the authors to submit another paper in their open-source journal for free. This was followed-up by the paper entitled "Imaging Time Series for the Classification of EMI Discharge Sources" published in the same journal. The citations indicate that this work encouraged other researchers to derive similar algorithms for bearings fault diagnosis, for instance, and PD detection at various power equipment.

- [R6]. I. Mitiche, M. D. Jenkins, P. Boreham, A. Nesbitt, B. G. Stewart, G. Morison, "Deep Residual Neural Network for EMI Event Classification Using Bispectrum Representations", 26th European Signal Processing Conference (EUSIPCO), 2018, pp. 186-190. Impact Factor: 4.79. Citations to Date: 5. Industrial Usage: extended prototype superseded by [R2]. This paper applied deep learning for the first time to the EMI data and achieved higher performance than traditional ML methods followed in [R3] and [R5]. This interesting work led to underpinning a future research grant. This paper was a motivation to carry out the research and produce more publications. The paper was cited in areas of research beyond this field including urban construction and resource exploration. The citation of this paper by [R1] indicates that the captured and stored big data in the deployed prototype in [R1] was passed to the developed algorithm in this paper for fault type classification.

4. Details of the impact

Doble is a market leader in the electric power industry with a revenue of £100 to £500 million per year. In existence since 1920, Doble has been providing enterprise management systems, engineering consulting and expertise, on-line and off-line diagnostic instruments to over 5500 clients across 110 countries to improve operations and optimise system performance. Doble's mission is to ensure all people have reliable, safe and secure energy, and the GCU research team has contributed to this mission through the pioneering research in Big Data and ML which has made improvements in Doble's EMI diagnostic capability [C1]. The impact of this work can be quantified by its impact on technology, economy and society. The technology is used for improving the EMI diagnostic technique and the data analytics to provide actionable information to transmission and generation network operators.

Impact 1

The developed instrument captured, stored and analysed EMI data from Drax, a major UK power station and utility. The analysed data reported changes in data patterns during power asset downtime. This is something they have been unable to collect and analyse before, giving additional insight into the nature of faults occurring and providing early warning signs for fault prevention. This is an essential step to build client and test engineer confidence in the developed technology and increase the value of their service offering to their customers [C2]. The developed instrument, Big Data collection and storage method are deployed across Doble clients through application of survey tools to support site engineers as they examine detailed spectra generated by assessment of rotating machines and transformers. The approach has been one of support for key decisions by an engineer and not an attempt to replace the engineer. The assessment at Drax has been covered in papers at International events (CIGRE 2020) where the use of advanced diagnostic tools has allowed suspect assets to remain in service or be removed from service with confidence [C3].

Impact 2

The new technology deployment is now exploited into the analysis to retrieve important information regarding the operational integrity and safety of a client's power asset. The impact on client savings to be had are measured in millions when a potential fault is detected before a power outage [C1, C4]. "To date, the investment by Doble has been over £1.2M. Since working with GCU, Doble's product and service sales increased by 50%. Although the cost of sales and input from other sources cannot be shared in detail, the benefit from the GCU R&D input has been significant. The future revenue to Doble will grow as more elements of the R&D are commercialised" [C4].

Impact 3

Early fault detection helps to avoid power outage and society is the beneficiary from a sustainable power supply in line with United Nations Sustainable Development Goals 7 & 11. On 9th August 2019, two unexpected simultaneous power losses at two power generators amounting to 5% of the grid supply created a power blackout that extended across the UK affecting 1.5million customers. Although the power loss was brief, it affected homes, businesses and hospitals, while rail services were disrupted for days. The unavailability of generation capacity in the country at the time exacerbated the problem. The system should have been able to cope had it been provided with the actionable information provided by the GCU research. Three energy firms paid a total of £10.5m in redress. This came on the back of a number of near misses.

Impact 4

The collaborative efforts were incorporated into Doble's existing roadmap of innovation and changed its strategic direction from an approach where the engineer must check every spectrum generated to one where the AI tools pick out those which are anomalous and worthy of further investigation by identifying possible causes of the anomaly through use of the cloud based automatic diagnostic toolset [C2]. The impact of GCU research in Big Data and ML technology, change in their roadmap is evidenced in Doble Solutions Architect's letter [C4]. The research and progress benefit has been substantial reaching out a global market sector of client sites in USA (Maine, Dakotas and Black Hills), EU (Drax, SSE, EDF) and Middle East (Dubai Airport, Electra and OPC Rotem in Israel) [C4].

5. Sources to corroborate the impact

- [C1] Letter from Doble Solutions Director.

- [C2] Feedback evaluation recorded from Doble Principal Engineer was provided to the R&D team.

- [C3] The following paper: S. Rhoads, J. White, M. Foster, M. Rowbottom, J. Beardsall, T. McGrail, P. Boreham, I. Mitiche, “Integration of Condition Monitoring into Substation Asset Risk Management”, CIGRE 2020.

- [C4] Letter from Doble Solutions Architect.