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On-line condition monitoring of transition assets

Jack A. Hunter and Paul L. Lewin

University of Southampton, Southampton, UK

Abstract

There are a number of medium voltage (MV) power distribution cable networks worldwide that are constructed predominantly of mass impregnated paper cables - London being one of these. Paper insulated lead covered (PILC) cables were extensively laid in the 50s and 60s before the introduction of cheaper polymeric alternatives that were sufficiently reliable. The current operational state of these networks has shown a gradual increase in failure rates of the previously reliable paper cables that are drawing to the end of their expected design life. Utilities are faced with the prospect of the impending failure of large sections of their prized asset and are keen to develop tools to better understand the health of their hardware. The analysis of partial discharge (PD) signals produced by the cables has been identified as a economically viable option to provide continuous condition monitoring of PILC cable circuits. Clearly, a comprehensive understanding of how PD activity relates to the various failure mechanisms exhibited by cable circuits in the field is required. A recently published technique for PD source discrimination was coupled with an understanding of the experiment and applied to the experiment data to isolate the signals specific to each degradation mechanism [1]. This technique has been applied to both rotation machines and transformer systems with promising results. PD signal discrimination is seen as the first step towards an autonomous condition monitoring future.

Overheating experiment

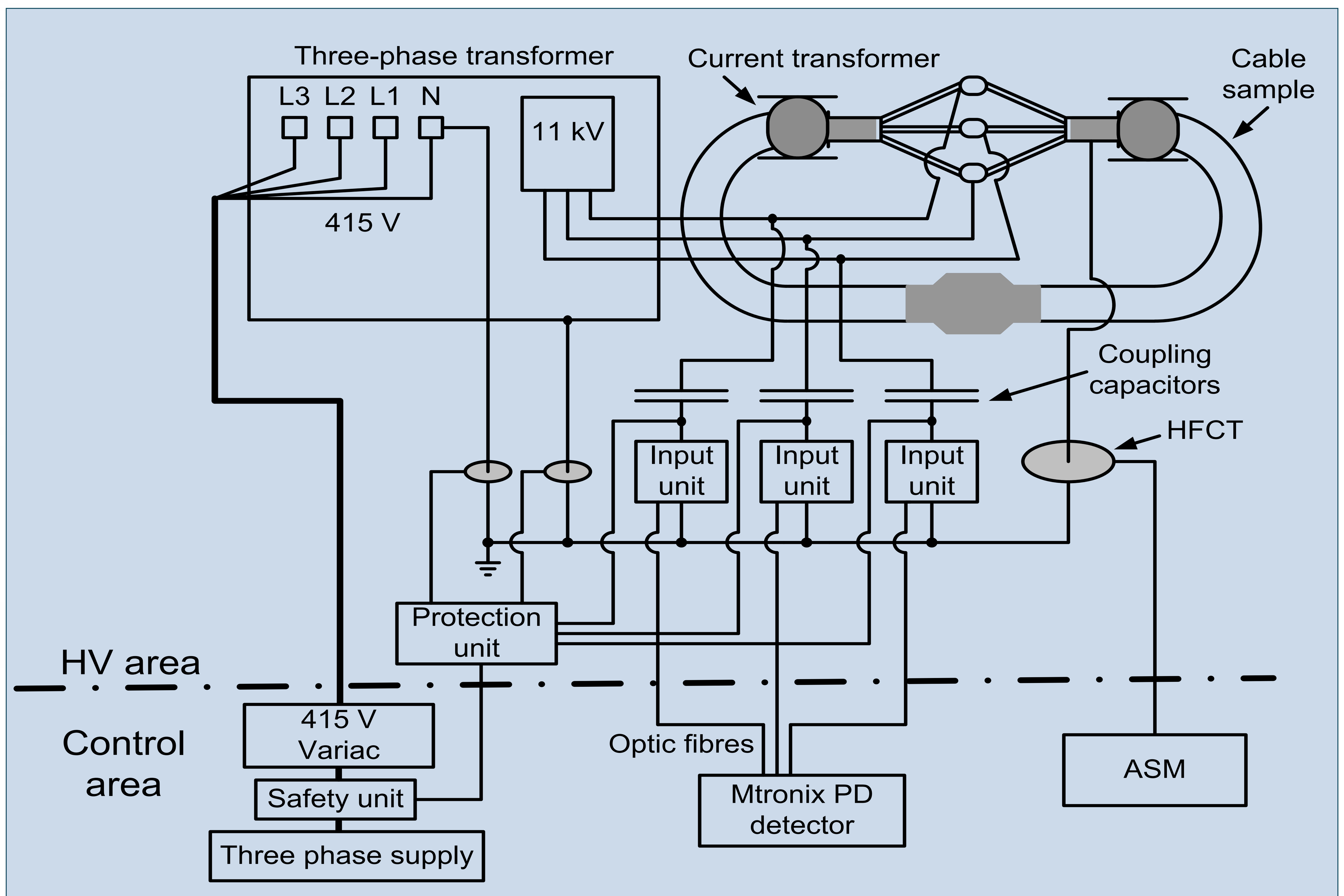
The degradation mechanism recreated for investigation involved thermally stressing a cable sample beyond its rated capability for an extended period. This was facilitated by inducing a power frequency circulating current into the sample with a magnitude of 500 A/phase. A conservative approximation of the conductor temperature under these current conditions is 97° C. Long term thermal stressing of these types of cables is understood to increase the rate at which the cellulose within the paper insulation is broken down. Given the relatively short period that the sample was exposed to these temperatures and the perfect condition of the new cable insulation before testing, it is thought that limited cellulose damage will have occurred in this case. The obvious effect that the overheating had on the cable sample was the expulsion of its mineral oil impregnate. This occurred due to the increase in pressure within the cable coupled with reduced viscosity of the oil impregnate at raised temperature. Due to the sealed nature of the cable, the increasing internal pressure forced fluid from both end terminations. The potential effects on performance linked to the loss of impregnate are linked to the generation of gas filled voids within the cable, leading to a general reduction in both dielectric strength and the self healing qualities attributed to this design of cable. The three-phase voltage was applied to the sample, PD data acquisition using the commercially available PD monitoring equipment was initiated and the experiment was left to run for three days.

Experimental data

The data that was analyzed from the overheating cable sample consists of 1424 cycles of data, recorded over a period of 72 hours. Three clusters of PD pulses were produced with the PD activity that is attributed to the overheating mechanism shown as cluster two.

In order to judge the consistency of the features attributed to the pulses within each cluster, the mean and standard deviation of WE distribution was calculated and is shown below. The standard deviation of the data links to the size of the cluster in feature space. Comparison of the WE distribution for each type of defect shows a significant difference in the frequency component associated with the respective pulses. Analysis of the WE distribution exhibited by the water ingress defect reveals a significant lower frequency component, with ~28% of the signal energy residing in the D3 coefficients.

Experiment design



Schematic diagram of the three-phase experiment

PD discrimination technique

Noise rejection Pulse extraction → Wavelet analysis Wavelet Energy calculation → Dimension reduction using t-SNE → Automatic clustering of localised points using DBSCAN → Visual verification of the clustering process → Identification of different PD sources given the history of the asset → Further analysis of individual source activity

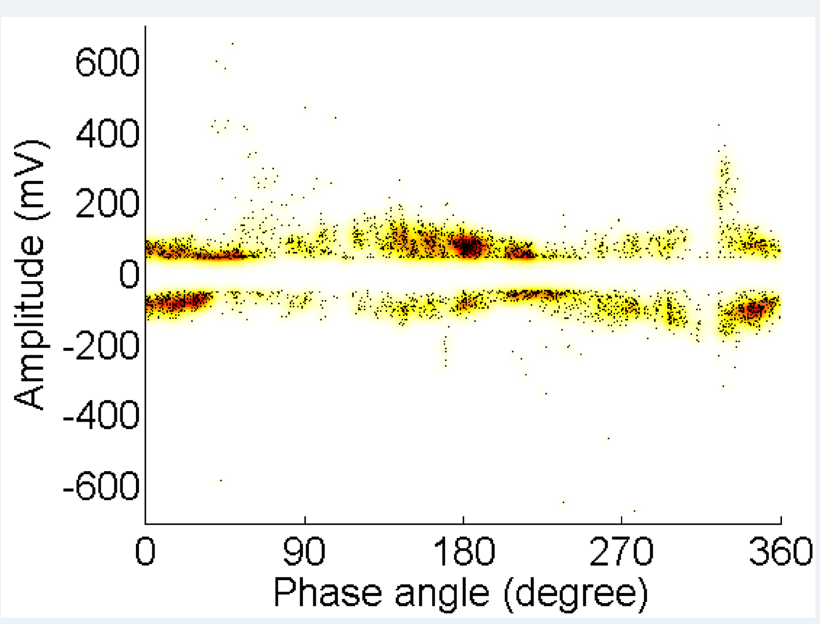
$$E_{Di} = \frac{\sum_{j=1}^{N_{ci}} Cd_{ij}^2(t)}{\sum_{i=1}^{n}\sum_{j=1}^{N_{ci}} Cd_{ij}^2(t) + \sum_{j=1}^{N_{cn}} Ca_n^2(t)} \times 100$$

$$E_{An} = \frac{\sum_{j=1}^{N_{cn}} Ca_n^2(t)}{\sum_{i=1}^{n}\sum_{j=1}^{N_{ci}} Cd_{ij}^2(t) + \sum_{j=1}^{N_{cn}} Ca_n^2(t)} \times 100$$

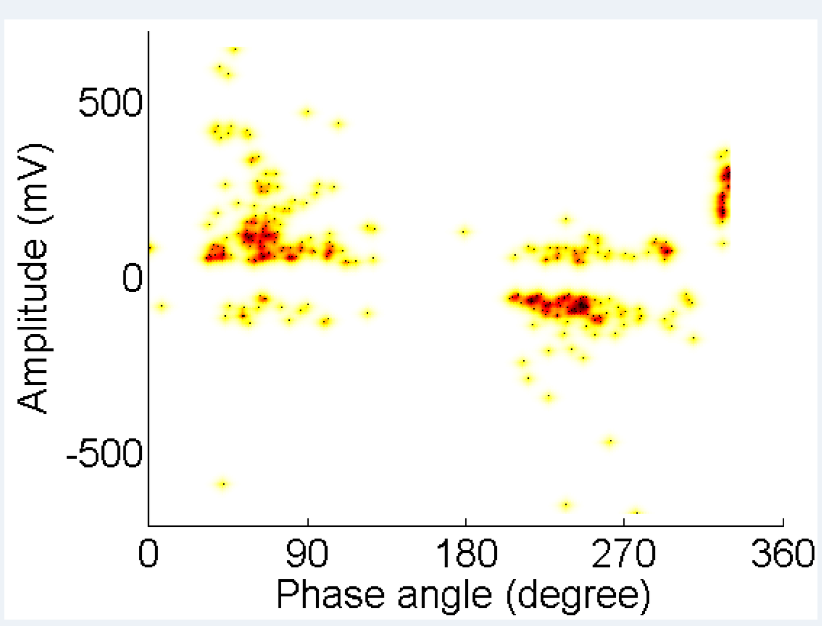
Detailed (top) and Approximation (bottom) Wavelet energy equations

Flow diagram of PD pulse discrimination algorithm

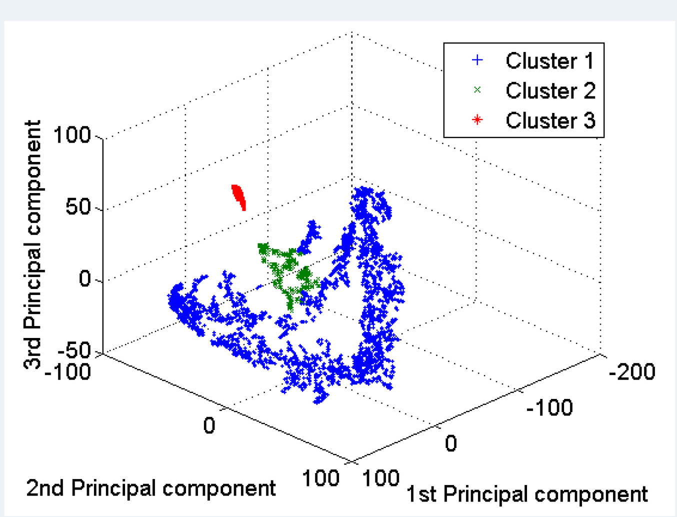
Results



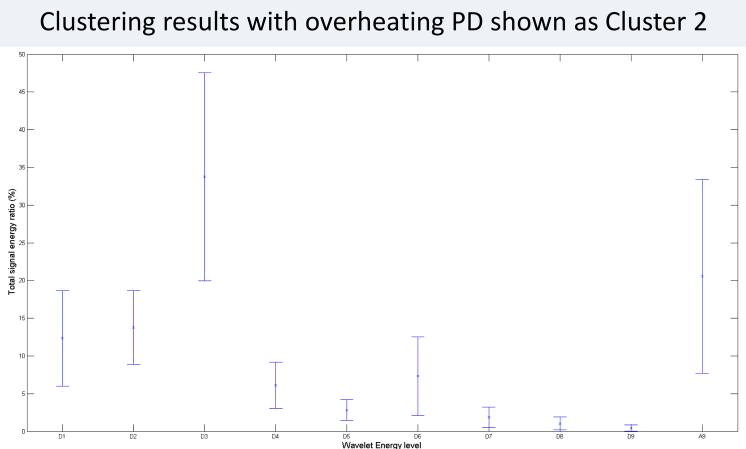
Phase resolved PD pattern of the raw data from overheating experiment



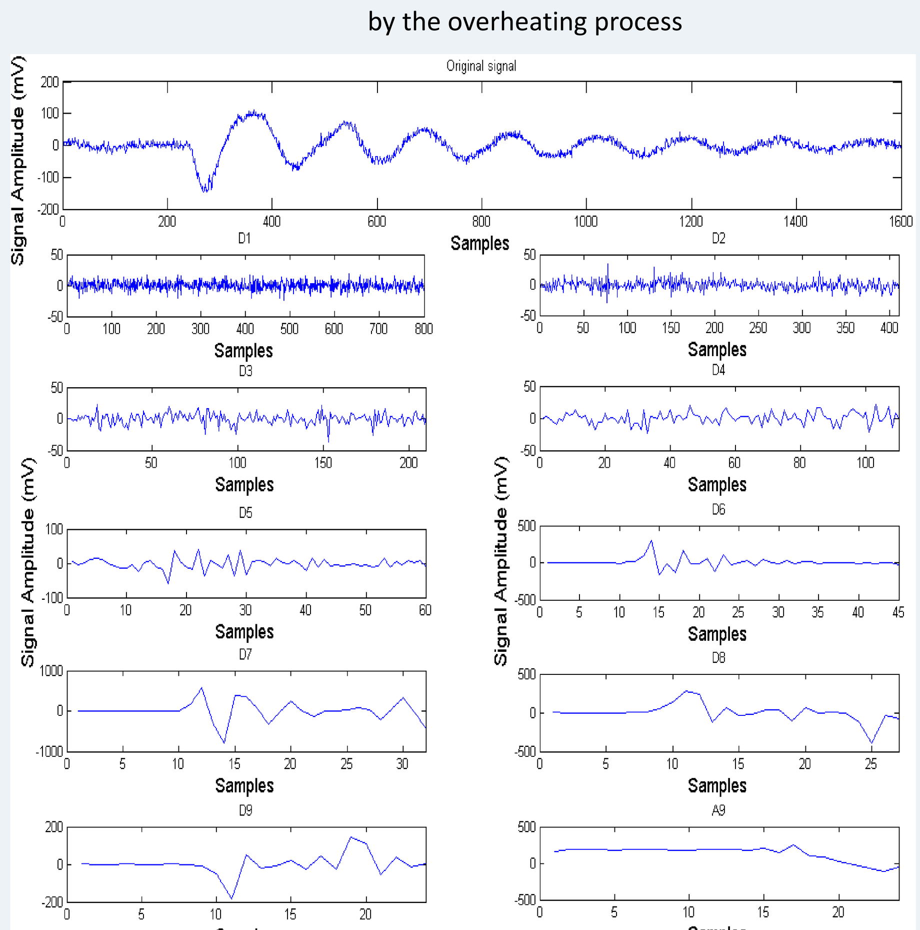
Phase resolved PD pattern of the source activated by the overheating process



Clustering results with overheating PD shown as Cluster 2

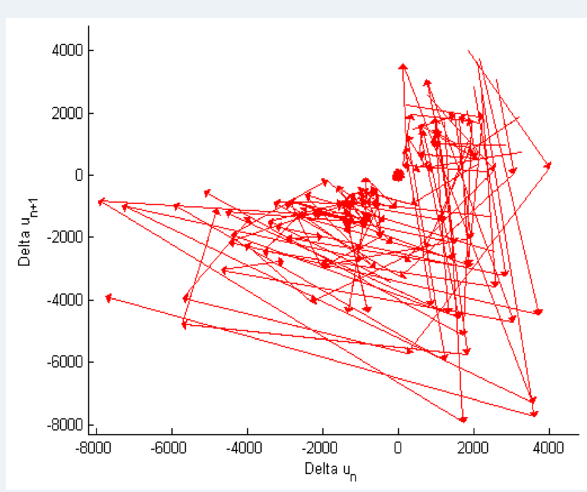


Mean and standard deviation of the WE distribution for all overheating pulses

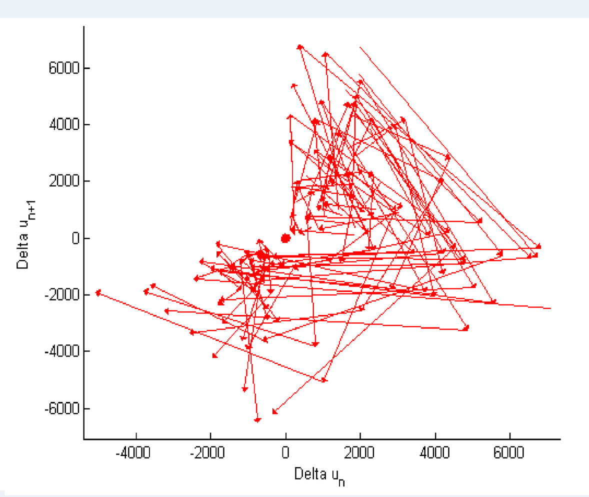


Wavelet analysis of a single overheating PD pulse

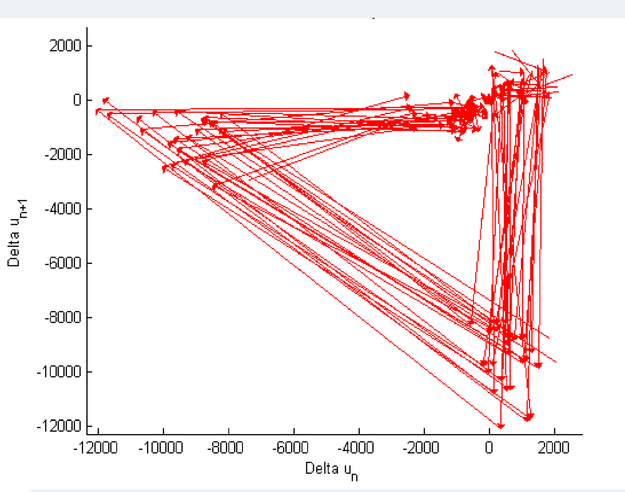
PSA vector analysis of each phase voltage



PSA vector plot for overheating using the phase one to earth voltage waveform



PSA vector plot for overheating using the phase two to earth voltage waveform



PSA vector plot for overheating using the phase three to earth voltage waveform

An iteration of the standard PSA analysis tool has been designed that includes the connecting vector between two PSA point. It is felt that this tool provides a clearer representation of patterns of sequences within the data. Analysis of the three waveforms shown above probes the fundamental nature of the data. The plots for phases one and two show a random scattering of vectors. The plot for phase three however has a distinct repetitive pattern, implying that the data is deterministic in nature.

Conclusions

An experiment has been designed that allows for on-line PD monitoring of a range of cable samples that are exposed to damage whilst under realistic in-service conditions. A cable sample has been exposed to an overheating process over a period of 72 hours. A bespoke PD discrimination algorithm was applied to the raw PD data and the PD produced by the degradation mechanism was isolated. Further analysis of the PD data suggests that the PD activity produced by the experiment is deterministic in nature. Further analysis of field data recorded in the same manner is to be undertaken to develop these findings.

Contact details : jh09r@ecs.soton.ac.uk

University of Southampton, Highfield, Southampton, SO17 1BJ, UK

References

[1] Hao L. , Lewin P.L. , Hunter J. A. , Swaffield D.J. , Contin A. , Walton C. , Michel M. , " Discrimination of multiple PD sources using wavelet decomposition and principal component analysis", IEEE Transactions on Dielectrics and Electrical Insulation, Volume 17, pp. 1702-1711 October 2011