Condition monitoring of offshore wind turbine generators using machine learning from phase-resolved partial discharge plots

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Introduction

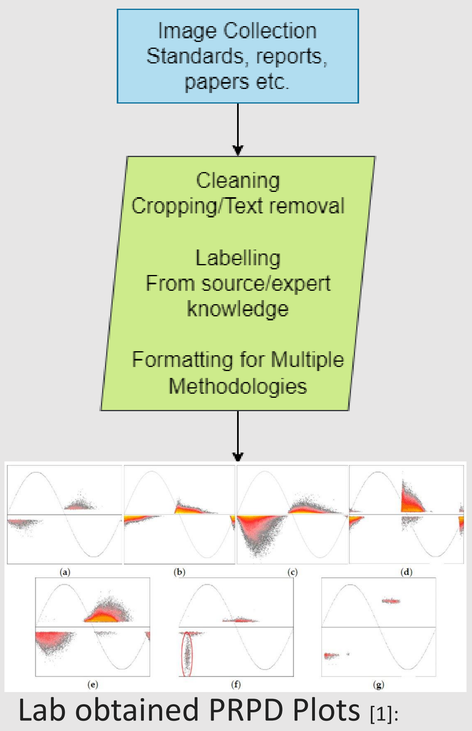
- As wind turbines continue to grow in size, wind turbine drivetrains are evolving, and high-speed generators are increasingly being replaced by direct drive generators.
- As such wind turbines often operate at 3.3kV which can make generators susceptible to insulation degradation, of which partial discharge is a symptom.
- This paper proposes a condition monitoring system that can independently extract the overall progression of partial discharge from phase-resolved partial discharge (PRPD) plots

Conclusions

- With a very small dataset < 100 images, the suggested approaches were able to achieve up to 76% accuracy (Top 3) when detecting and classifying Partial Discharge.
- With more data/images this percentage would undoubtably increase.
- It is expected that these types of algorithms could help monitor insulation health in real-time, allowing for pre-emptively scheduled maintenance to take place and avoid unexpected generator failure.

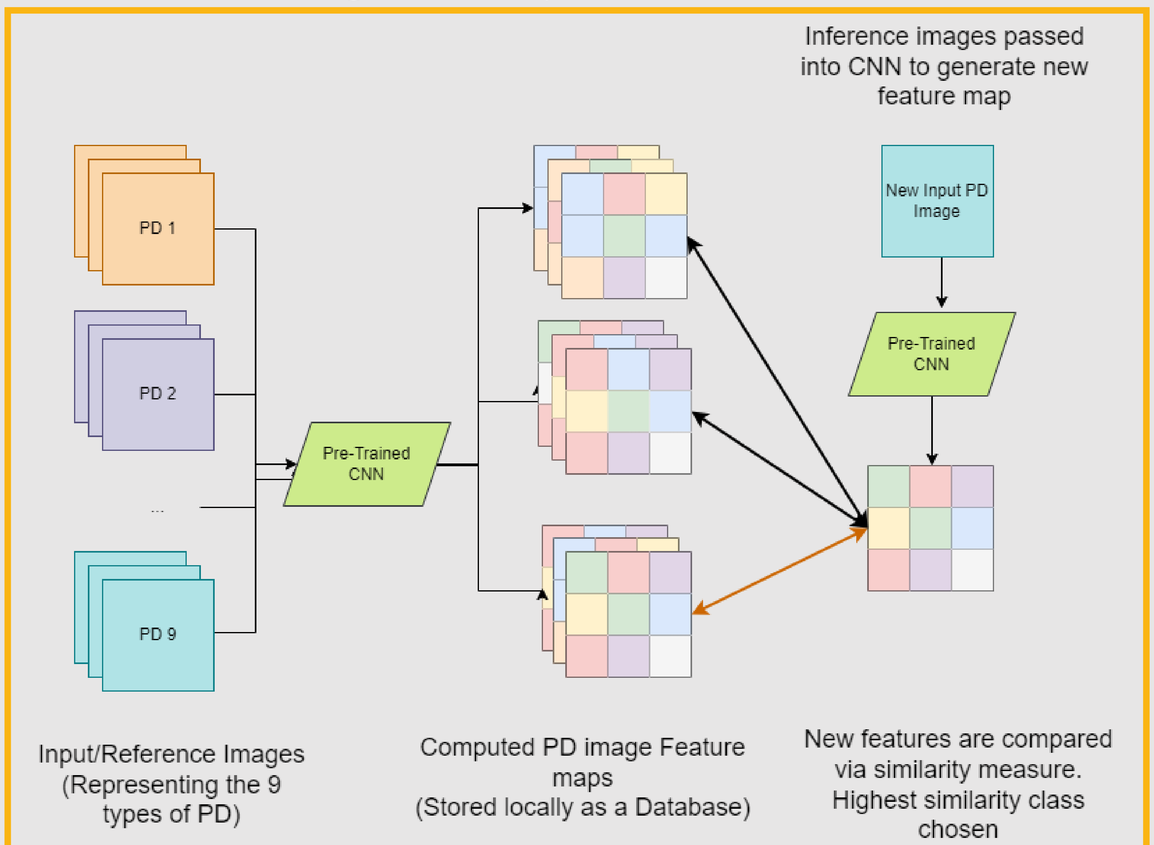
Methodology

Dataset Creation



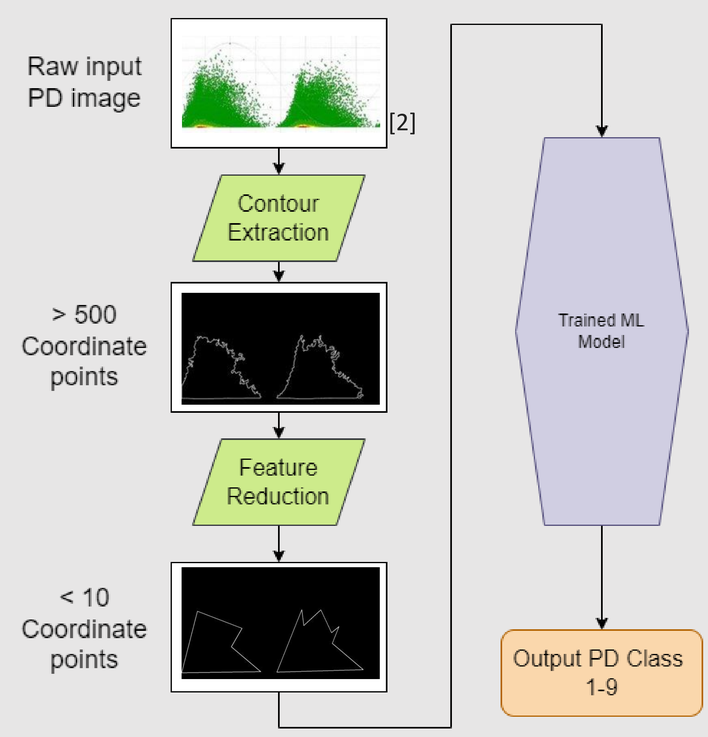
Lab obtained PRPD Plots [1]:
(a) internal voids,
(b) internal delamination,
(c) Insulation delamination,
(d) slot discharge,
(e) end-winding corona,
(f) surface tracking,
(g) Gap Discharge.

Method 1 – Image Similarity



Pre-trained CNNs are used to embed images to feature representations. Distance/similarity metrics from these embeddings are compared to inference image embeddings and the closest image class is chosen.

Method 2 – Learned Contours



PRPD Images are passed through edge detection methods to determine shape. These are reduced in dimensionality to train and infer a small Neural Net. Large scale CNNs preferred when dataset size increases.

Results

The image similarity method achieved a top-3 accuracy percentage of 76%. A more in-depth breakdown per class is shown in Table 2.

Image Sim Acc	
Top-3	76%
Top-5	92%

Table 1: Overall % Accuracy

	Insulation Delam.	Corona Discharge	Gap Discharge	Internal Delam.	Internal Void	Slot Discharge	Surface Tracking
Top 1	67	22	75	0	29	25	0
Top 3	100	22	100	67	86	83	75
Top 5	100	78	100	100	100	92	75

Table 2: % Accuracy breakdown for 7 PD classes

These results were generated with only 1 reference image per class as represented within the BSI standards. This standard only provides examples of 7/9 types of PD.
There was reasonable overlap/confusion within the insulation delamination and end-winding corona. The image similarity approach struggles to determine the difference due to the visual similarity of the PRPD plots. With a more robust dataset it is expected accuracy would increase while reducing this confusion.

Next Steps

- Increase dataset size – Either by scraping open sources or collaborating with PD specialists/researchers.
- Train own embedding/feature map networks more tailored to the approach. This could help the confusion in what can be similar looking PRPD plots.
- Combine methods, either standalone ensemble methods, or an ensemble of the 2 discussed approaches in an attempt to increase overall accuracy.

References

1. IEC, “PD IEC/TS 60034-27-2:2012 Part 27-2: On-line partial discharge measurements on the stator winding insulation of rotating electrical machines,” BSI Standards Limited, 2021.
2. Wu, Min & Cao, Hong & Cao, Jianneng & Nguyen, Hai-Long & Gomes, João & Krishnaswamy, Shonali. (2015). An Overview of State-of-the-Art Partial Discharge Analysis Techniques for Condition Monitoring. IEEE Electrical Insulation Magazine. 31. 22-35.