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Smart Piezoelectric Metamaterials for Partial Discharge Monitoring

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Introduction

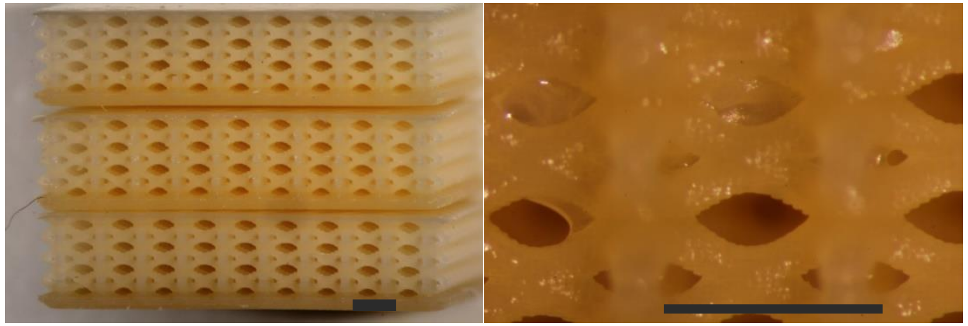
- Cable failures are typically monitored through partial discharges.
- Monitoring partial discharges via acoustic emissions has distinct advantages over inductive or RF in terms of immunity to electromagnet interference, high electrical resistivity and low price.
- However, low sensitivity and difficulty in localizing a source has prevented wide adoption of acoustic emission monitoring.
- This project addressed this by designing and manufacturing a novel piezoelectric acoustic sensor.
- Using 3D printed piezoelectric materials acoustic sensors may be designed with tailored, directional, piezoelectric coefficients and acoustic impedances which are matched to the properties and environment of a cable or connector.

Project Objectives

1. Design and manufacture a perovskite structured 3D printed piezoelectric sensor that provides directional acoustic emission information.
2. Evaluate the response of the designed anisotropic piezoelectrics in laboratory partial discharge testing in terms of signal strength, sensitivity and noise.
3. Compare this method of partial discharge detection in cables/cable connectors with existing acoustic methods and hybrid methods.
4. Report on the feasibility of using smart piezoelectric sensors to localize acoustic emissions from partial discharges in cables/cable connectors and land/sea connections.

Work Package 1

- A short literature review of existing designs for anisotropic sensors was carried out.
- A variety of material structure designs were investigated.
- Work was done with standard 3D printing materials (top right), then 3D printable piezoelectric nano-composites (bottom right).
- Numerous issues were faced in producing these.

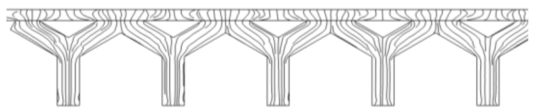


Example 3D prints of tessellated structures for sensors Scale: *1mm*

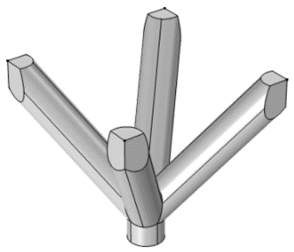
Printed structures made with a polymer piezoelectric particle nano-composite.

Work Package 2

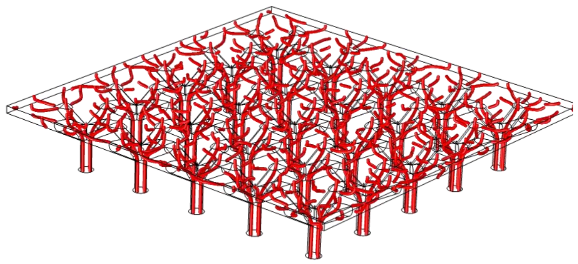
- Computer models of the structures for the new sensors were created.
- These were used to predict the piezoelectric effect and its directivity within the structure.
- Simulations of the different structural unit cells were carried out in order to examine the sensitivity and directional response of the different structures.
- This included the limits of the 3D printing techniques and materials available.



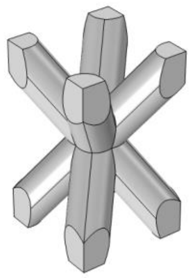
Piezoelectric polarization direction – cut plane



4-strut centre offset



Piezoelectric polarization direction



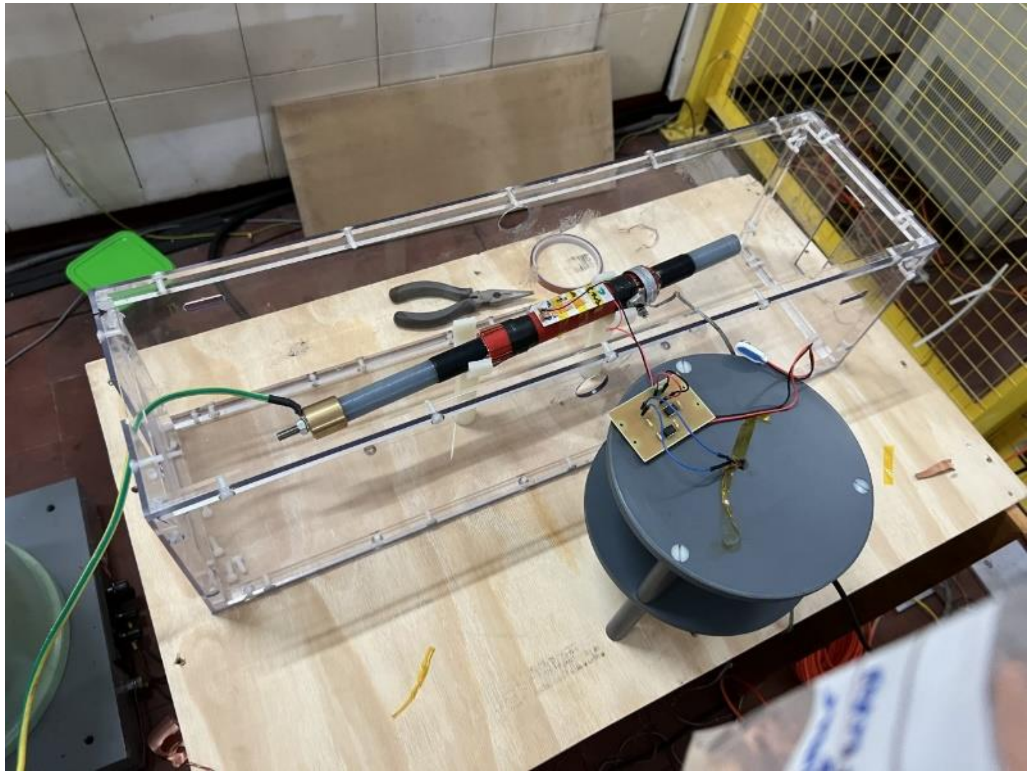
8-strut equal

Work Package 3

- Initial work within the project showed inconsistency, and lack of sensitivity, in the piezoelectric materials being created.
- Typically, samples had piezoelectric sensitivity that was at best equivalent to traditional commercial piezoelectric thin-films (~ 2 to 30 pC/N).
- A new strategy to create highly elastic piezoelectric polymers with strong piezoelectric behaviour using the sugar-template method was employed.
- Composite foams utilising 5 nm PMN-PT (lead magnesium niobate-lead titanate) nanoparticles with 3D printer polymer and fine sugar were examined.
- This was successful in creating materials of with piezoelectric sensitivity of up to 75 pC/N, with a relatively wideband frequency response.

Work Package 4

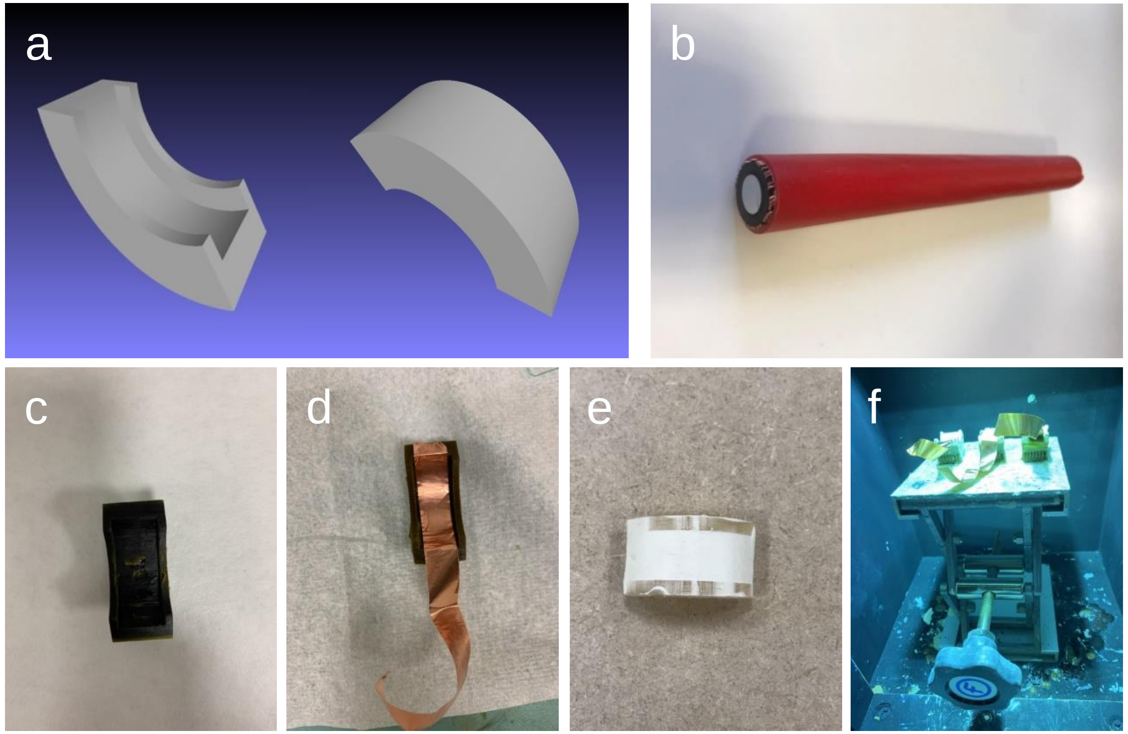
- A laboratory experimental setup for creating and detecting partial discharges in a mocked cable system was developed.
- Stable partial discharges were created by fractional removal of the cable from a joint.
- The experimental setup established was then used to test sensor responses to partial discharge events.



Photograph of the in-house experimental laboratory set-up in laboratory settings for recording induced partial discharges.

Work Package 5

- Sensors were designed and manufactured to fit around a specific cable example within the laboratory.
- This required CAD design, computer modelling and simulation, then 3D printing as casings, with piezoelectric elements then added, before the final sensor structure was cured and poled.



3D Printed Sensors (a) Structure CAD designs, (b) Sample cable, (c) Printed external structure, (d) Structure with conductive tape, (e) Piezoelectric material in sensor, (f) UV exposure for curing.

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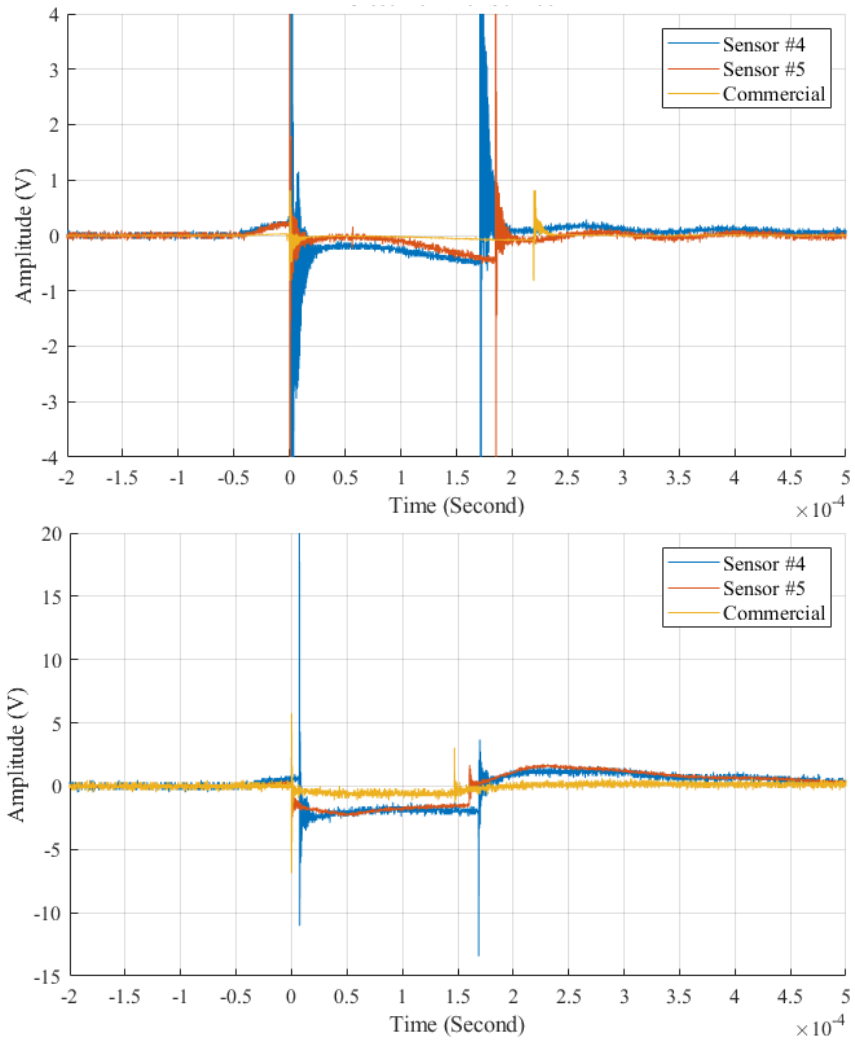
Work Package 6

- In this work package the acoustic emissions of experimentally simulated partial discharges were measured using the laboratory system and the new sensors created through the project.
- The new sensors significantly outperformed a commercial acoustic sensor under different PD conditions.



Comparison of acoustic PD detection from project and commercial sensors.

Outputs & Dissemination

- One journal publication published:
  - Omoniyi *et al.* (2021), Fabrication and characterization of a novel photoactive-based (0–3) piezocomposite material with potential as a functional material for additive manufacturing of piezoelectric sensors, Journal of Materials Science: Materials in Electronics, 32: 11883–11892. 10.1007/s10854-021-05818-5
- A second journal paper in preparation.
- Two conference papers presented:
  - IEEE International Conference on Flexible & Printable Sensors & Systems 2022
  - 10th European Conference on Renewable Energy Systems 2022
- Talks at:
  - Supergen ORE Hub Annual Assemblies
  - Electrical Infrastructures Research Hub monthly technical meeting
  - Supergen ORE Hub Autumn Assembly 2022