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Indirect monitoring of transformer insulation stability using energy-based partial discharge indication

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1.INTRODUCTION & AIM

Power transformers are critical assets in electrical power systems, where insulation reliability directly impacts operational safety and service continuity. The dielectric behavior of transformer insulating oil plays a major role in preventing electrical breakdown and ensuring long-term stability.
Monitoring dielectric degradation remains a major challenge, especially when continuous direct characterization of insulation properties is impractical during repeated experimental campaigns or real operating conditions.
Although impedance measurement provides useful information regarding the dielectric condition of insulating oil, repeated impedance characterization throughout the experimental campaign may not always be feasible.
This work proposes an indirect monitoring approach, where the dielectric state of the insulating medium is inferred through the stability of electrical partial discharge descriptors.

2.EXPERIMENTAL SETUP

The experiments were conducted using a custom high-voltage partial discharge platform designed for controlled laboratory investigations.

- Transformer insulating oil test cell
- Spherical electrode configuration
- Controlled inter-electrode spacing
- DC high-voltage source
- Current limiting resistor
- Non-inductive current measurement resistor
- Synchronized oscilloscope acquisition
- Faraday cage for electromagnetic shielding

Before the experimental campaign, the dielectric condition of the insulating oil was characterized using impedance measurements.
Impedance was measured over a frequency range of:
20 Hz to 10 MHz
using: GW INSTEK LCR-8110

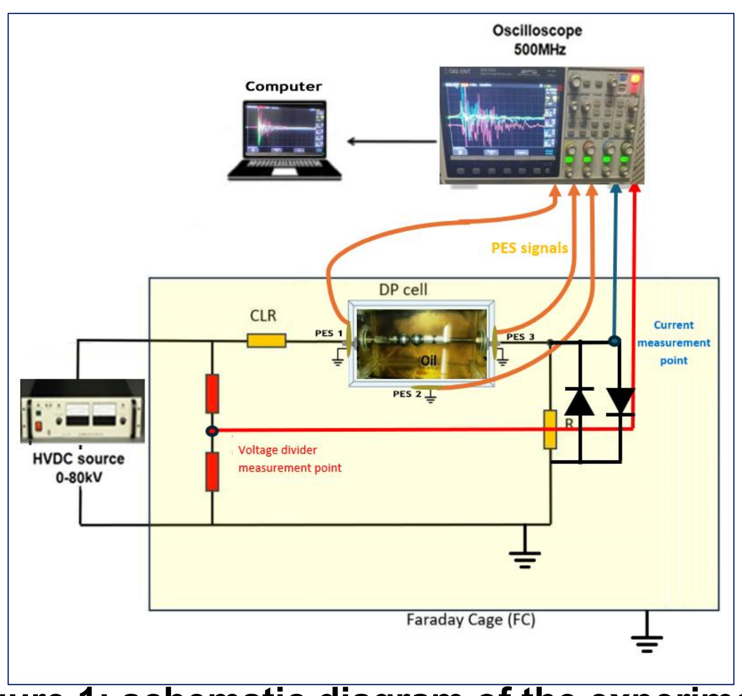


Figure 1: schematic diagram of the experimental setup

3.METHODOLOGY

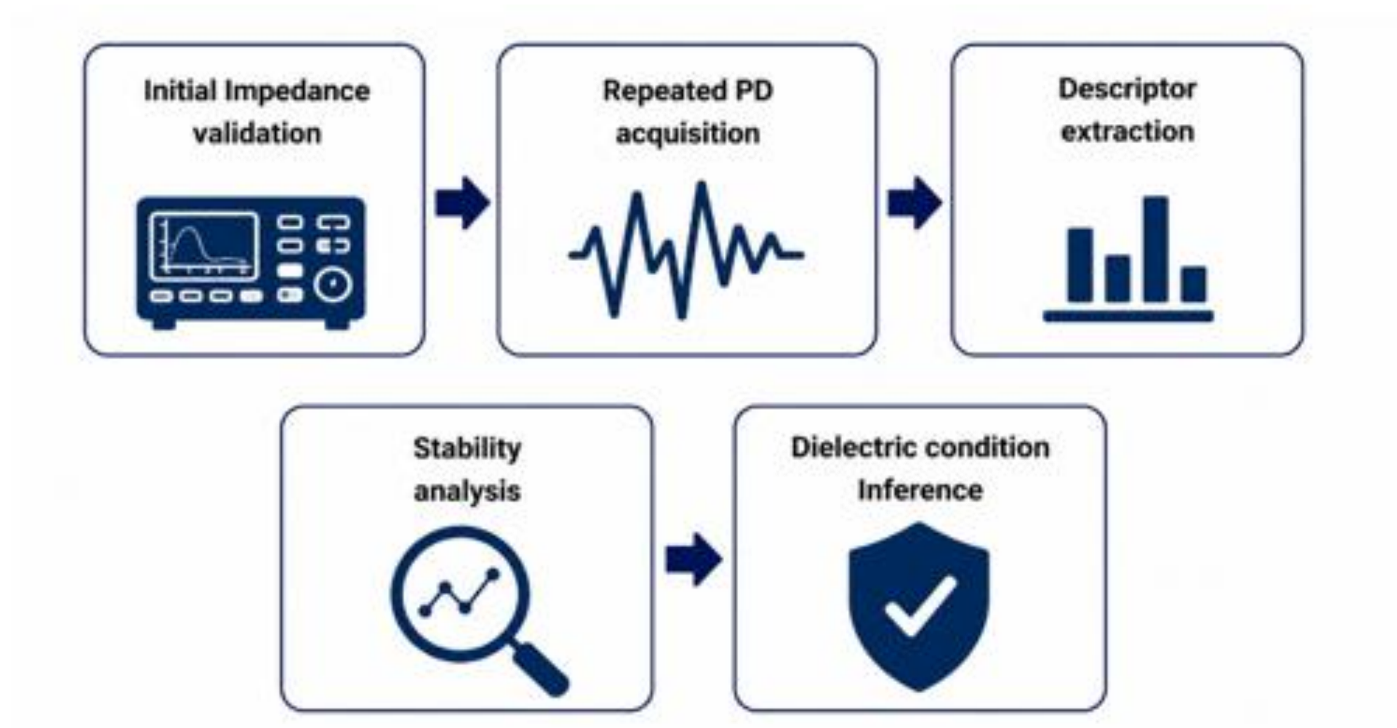
Step 1 – Initial dielectric characterization
Impedance measurement is performed before the experiments to validate the initial condition of the transformer oil.
Step 2 – Partial discharge generation
Controlled partial discharges are generated under fixed experimental configurations.
Step 3 – Signal acquisition
Electrical current signals are synchronously recorded during each partial discharge event.
Step 4 – Descriptor extraction
Two key descriptors are extracted: Peak current amplitude (Ipeak) and Electrical discharge energy (E). E is estimated from the electrical signal using:
$E \propto \Sigma\, i^2(t)$ where $i(t)$ = discharge current signal
Step 5 – Stability assessment
Descriptor evolution is analyzed across repeated experiments. Stable descriptor behavior indicates stable dielectric conditions.

4. ENERGY-BASED STABILITY ANALYSIS

Peak amplitude alone may be sensitive to stochastic discharge fluctuations. Energy descriptors provide stronger physical interpretability because they integrate the overall electrical activity of each discharge event.
The analysis focuses on:

- descriptor dispersion
- descriptor repeatability
- trend stability
- comparison within identical geometric configurations

5. PROPOSED INDIRECT MONITORING FRAMEWORK



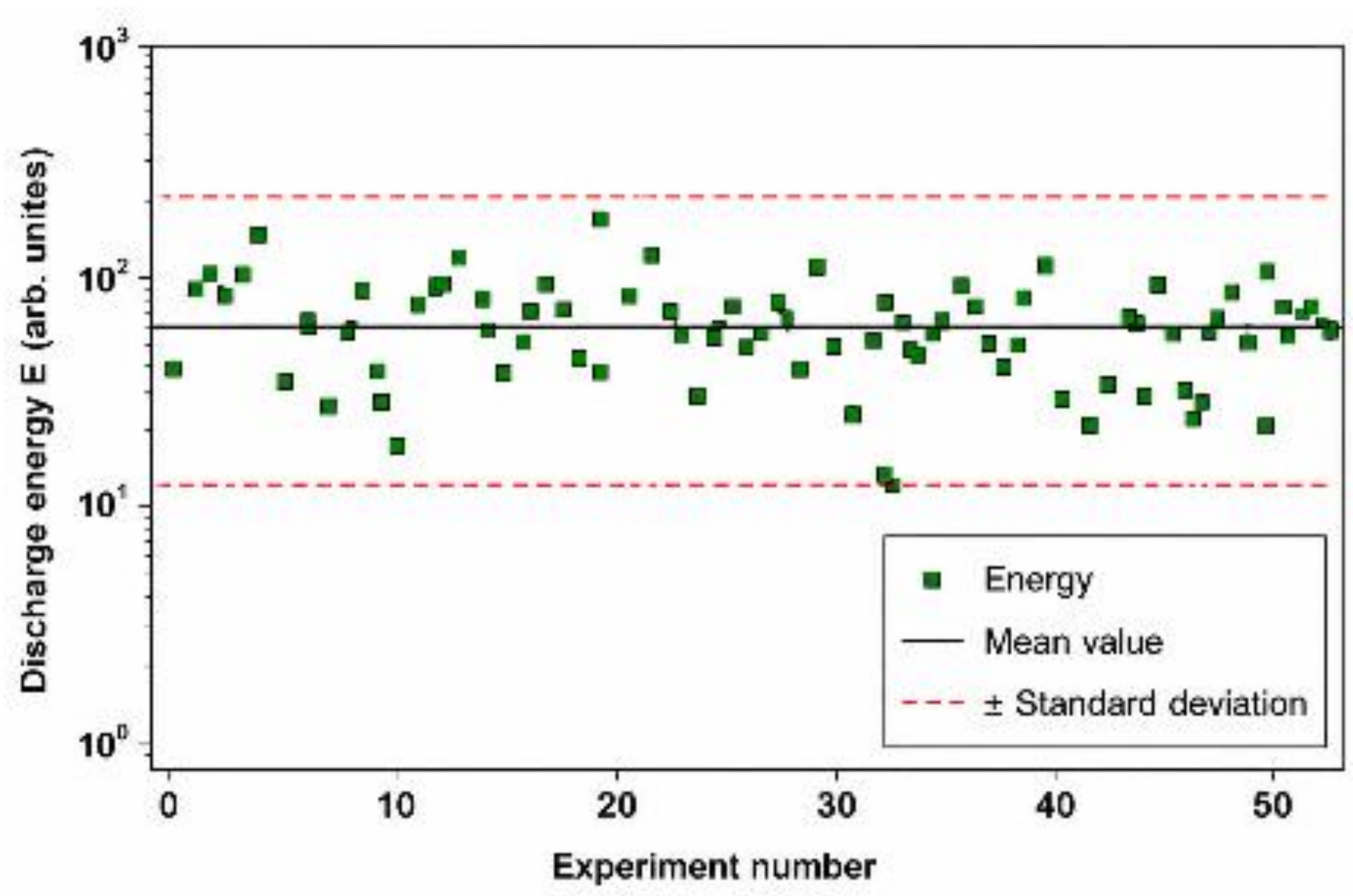
6. RESULTS & DISCUSSION

The results suggest that:
Repeated partial discharge events under identical geometric conditions show stable energy behavior.
No significant energetic drift is observed.
The dielectric medium likely remained stable throughout the campaign.
Advantages:

- Non-invasive interpretation
- Physically meaningful descriptors
- Compatibility with repeated test campaigns
- Potential applicability for predictive maintenance

Limitations:

- Laboratory validation only
- Limited dataset size
- DC excitation conditions only



7. CONCLUSIONS

This work introduces an indirect methodology for monitoring transformer oil dielectric stability through partial discharge electrical descriptors.
Rather than relying exclusively on repeated impedance characterization, the approach combines:
-Initial dielectric reference measurement
-Repeated partial discharge acquisition
Energy-based descriptor monitoring
The observed stability of discharge energy for identical configurations supports the hypothesis that the dielectric medium remained stable.
This approach opens promising perspectives for intelligent transformer condition monitoring using physically interpretable surrogate indicators.

8.FUTURE WORK

Validation under accelerated oil ageing
Thermal stress experiments
Humidity influence assessment
Contaminated oil studies
AC voltage conditions
Integration with AI-based predictive diagnostics

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