Calibration Methods for Reproducible and Comparable Electromagnetic Partial Discharge Measurements in Power Transformers

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Abstract

The reliability of electrical energy networks depends on the quality and availability of their electrical equipment, e.g., power transformers. Local failures inside their insulation can lead to breakdowns resulting in high outage and penalty costs. To prevent these destructive events, power transformers are tested for partial discharge (PD) activity in a routine test before shipment. Furthermore, PD activity can be evaluated as a diagnostic measurement on-site (on-line or off-line) or be constantly monitored during service using the ultra-high frequency (UHF) method.

In this thesis, a calibration procedure is proposed for the UHF method used in power transformers, which is lacking so far. The calibration process is required to ensure both reproducibility and comparability of UHF measurements. Only a calibrated UHF measurement procedure can be deemed reliable and eventually be introduced to supplement in (site-)acceptance tests of power transformers. The proposed calibration method considers two factors: The influence of the UHF sensors' sensitivity and that of the UHF instrument characteristics, including accessories like cables, pre-amplifier, etc. The UHF instruments' influence is corrected by using a defined and invariable test signal as a reference for all recording devices comparable to the calibration method used in IEC 60270 [1] for electrical PD measurement.

The sensitivity of the UHF sensor is addressed by a characterization of UHF sensors using the antenna factor (AF) measured in a special reproducible setup, i.e., a GTEM cell. In this thesis, a self-built GTEM cell is presented, which is oil-filled to address the environmental conditions inside a transformer where the sensor will be used. With such a cell, influences on the AF of UHF sensors are investigated, and it is shown that sensor sensitivities measured in an air-filled cell can be corrected to the oil environment.

A practical evaluation of the proposed calibration procedure is performed in a laboratory setup on a distribution transformer with different UHF instruments and sensors using artificial PD signals and real high voltage driven PD sources.

Finally, this thesis identifies future research topics, which may be needed to improve the proposed UHF calibration procedure for power transformers and the UHF method in general.

Kurzfassung

Die Zuverlässigkeit von elektrischen Energienetzen hängt von der Qualität und Verfügbarkeit ihrer elektrischen Betriebsmittel, z.B. Leistungstransformatoren, ab. Lokale Fehler innerhalb ihrer Isolierung können zu kompletten Ausfällen führen und damit hohe Ausfall- und Neuanschaffungskosten verursachen. Um diese Ausfälle zu verhindern, werden Leistungstransformatoren vor der Auslieferung in einer Stückprüfung auf Teilentladungen (TE) getestet. Darüber hinaus kann die TE-Aktivität als Diagnosemessung vor Ort (online oder offline) ausgewertet oder während des Betriebs mit der Ultrahochfrequenz (UHF)-Methode ständig überwacht werden.

In dieser Arbeit wird ein Kalibrierverfahren für die bisher unkalibrierte UHF-Methode an Leistungstransformatoren vorgeschlagen. Das Kalibrierverfahren ist notwendig, um die Reproduzierbarkeit und Vergleichbarkeit von UHF-Messungen zu gewährleisten. Nur ein kalibriertes UHF-Messverfahren kann seine Zuverlässigkeit nachweisen und schließlich ergänzend in (Vorort-)Abnahmetests von Leistungstransformatoren eingeführt werden. Das vorgeschlagene Kalibrierverfahren berücksichtigt zwei Faktoren: den Einfluss der Empfindlichkeit der UHF-Sensoren und die Eigenschaften des UHF Messgerätes inklusive Kabel, Vorverstärker, etc. Der Einfluss der UHF Messgeräte wird korrigiert, indem ein definiertes, unveränderliches Prüfsignal als Referenz für alle Aufzeichnungsgeräte verwendet wird, vergleichbar mit der in der IEC 60270 [1] verwendeten Kalibriermethode für die elektrische TE-Messung.

Die Empfindlichkeit des UHF-Sensors wird durch eine Charakterisierung der UHF-Sensoren mit Hilfe des Antennenfaktors (AF), der in einem speziellen, reproduzierbaren Aufbau, einer GTEM-Zelle, gemessen wird, berücksichtigt. In dieser Arbeit wird eine selbst gebaute, ölgefüllte GTEM-Zelle vorgestellt, um die Umgebungsbedingungen im Inneren eines Transformators, in dem der Sensor eingesetzt werden soll, zu berücksichtigen. Mit dieser Zelle werden Einflüsse auf den AF von UHF-Sensoren untersucht und es wird gezeigt, dass die in einer luftgefüllten Zelle gemessenen Sensorempfindlichkeiten auf die Ölumgebung korrigiert werden können.

Eine praktische Evaluierung des vorgeschlagenen Kalibrierverfahrens wird in einem Laboraufbau an einem Verteiltransformator mit verschiedenen UHF-Instrumenten und Sensoren unter Verwendung von künstlichen TE-Signalen und echten TE durchgeführt.

Schließlich werden in dieser Arbeit zukünftige Forschungsthemen identifiziert, die zur Verbesserung des vorgeschlagenen UHF-Kalibrierverfahrens für Leistungstransformatoren und der UHF-Methode im Allgemeinen notwendig werden/sein könnten.

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