Electro-magnetic Sensors for Online Condition Monitoring of Medium Voltage Cables

Author(s): Shafiq, Muhammad; Kauhaniemi, Kimmo; Hussain, Amjad; Kutt, Lauri

Title: Electro-magnetic Sensors for Online Condition Monitoring of Medium Voltage Cables

Year: 2020

Version: Published Version

Please cite the original version:

Shafiq, M., Kauhaniemi, K., Hussain, A. & Kutt, L. (2020). Electro-magnetic Sensors for Online Condition Monitoring of Medium Voltage Cables. In: *Proceedings of SMSI - Sensor and Measurement Science International, 2020*, 315-316. Sensor and Measurement Science International. https://doi.org/10.5162/SMSI2020/E6.4

DOI 10.5162/SMSI2020/E6.4

Electromagnetic Sensors for Online Condition Monitoring of Medium Voltage Cables

Muhammad Shafiq[1], Kimmo Kauhaniemi[1], Amjad Hussain[2], Lauri Kutt[3]
[1] University of Vaasa (Finland), [2]American University of Kuwait (Kuwait),
[3]Tallinn University of Technology (Estonia)
Muhammad.Shafiq@uwasa.fi

Summary:

Increased use of medium voltage (MV) cables demands for efficient condition monitoring in order to carry out timely predictive maintenance especially during incipient fault conditions emerging due to insulation degradation. This paper presents a comparison of the design and performance parameters of the Rogowski coil and high frequency current transformer sensors for measurement of partial discharge (PD) signals emitted from the PD defects. This work is performed in the laboratory environment that provides a practical approach for developing electromagnetic sensor for PD measurements.

Keywords: Electromagnetic sensor, condition monitoring, distribution network, medium voltage cable, partial discharge.

Background

Effectiveness of the predictive maintenance depends on the capability of the condition monitoring solution that requires suitable sensors for measurements in power system components. The performance of the sensors plays a vital role in reliability of the diagnostics during condition monitoring. Selection of suitable sensors and their design is determined based on the characteristics of the signals to be measured.

The use of MV cables is increasing around the globe and already installed cables are aging. Operational and environmental stresses deteriorate the dielectric insulation of the cables that causes the emission of the PD signals. PD faults are incipient and provide an early indication of the incoming cable failure [1]. Suitable sensors can be deployed to measure the PD signals for detection and location of the insulation faults. PD signals have high frequency (10s of megahertz-MHz) and low amplitude (few milliamperes- mA) that makes the design of the measurement sensors complex [2]. Specific sensors are used for measurements in specific power components. Because of non-intrusive sensing capability, installation possibility around the cable shielding, and operational behavior, Rogowski coils (RC) and high frequency current transformers (HFCT) are considered as the most suitable sensors for accurate PD monitoring in MV cables [3].

An ample amount of work has been done in order to explore the capabilities of RC and HFCT sensors for PD measurements [2]. However, the available work mostly describes the operation of these sensors standalone. This paper presents a comparative study to observe the design and operational performance of both the sensors (RC and HFCT) in order to assess their suitability for PD measurements in the MV cables based on experimental analysis.

Description of the Experimental Investigation

Sensitivity and bandwidth are the major performance parameters of these sensors. Sensitivity can be defined as the voltage output/PD input current at a certain frequency while the bandwidth is considered as the range of frequency across which the sensitivity of the sensors remains 0.707 of the peak output.

Tab. 1: Geometrical parameters

Parameter/Sensor	RC	HFCT
Inner diameter	3.4 cm	3.45 cm
Outer diameter	6.1 cm	6 cm
Core height	2 cm	2 cm
Number of turns	48	48
Wire diameter	1.7 mm	1.7 mm
Core shape	Rectangular	Rectangular

The geometrical dimensions of both the sensors has been taken as same (as shown in Table 1). However, the core of RC is air core while the HFCT has a ferrite core. The PD calibrator and associated circuitry is used to generate the typical PD pulse that is measured by both the sensors simultaneously as shown in the Fig. 1. A high frequency digital storage oscilloscope (DSO) is used for capturing the output signals measured by both sensors.

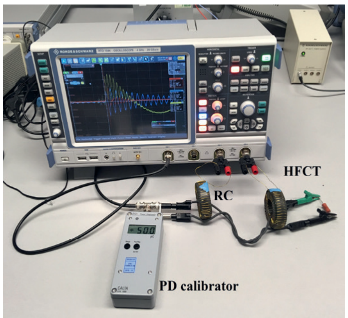

Fig. 1. Experimental setup for measurement of PD signals using RC and HFCT

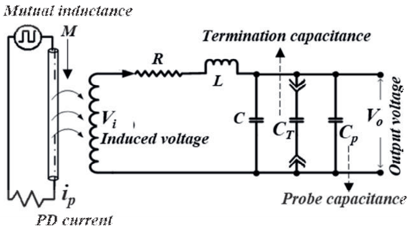

Fig. 2. Electrical model of the PD sensors

Reliability of the measurement and its interpretation depends on the accuracy of the electrical model (Fig. 2) developed during design stages. Inductance and capacitance of the sensors determine the sensitivity and bandwidth of the sensors. It has been found that geometrical parameters based mathematical models pose considerable limitations in obtaining the inductance and capacitance of the sensors accurately. In this work experimental method to determine the electrical parameters is used. The methodology is based on comparing the resonant frequencies (*f*) of RC and HFCT for different known capacitors (C_T) connected across the output of the sensors. The *f* is expressed as

$$f \bullet \frac{1}{2\bullet\sqrt{L\ (C_{,} \bullet C_T \bullet C_p)}}.$$

Results and Conclusions

Considering the inductance and capacitance of the sensors, frequency-dependent impedance characteristics determines its resonant frequency that formulates its bandwidth. Experimentally determined resonant frequency of the RC and HFCT sensors is 30.3 MHz and 1.9 MHz respectively. For the same calibrated PD current pulse i_p, the sensitivity of RC is observed as 0.013 V/unit Ampere at 30.3 MHz while the sensitivity of HFCT is measured as 0.05 V/unit Ampere at 1.9 MHz. For the same geometrical parameters, lower resonant frequency and higher sensitivity of the HFCT (as compared to RC) is because of its magnetic core. The magnetic permeability of the ferrite core in HFCT is considerably higher as compared to that of the air core RC. On one hand, the higher permeability u_r results in higher magnetic flux density (*B*) that increases the output voltage V_o. On the other hand, this increase in permeability increases the inductance of the coil that reduces the resonant frequency of HFCT sensor.

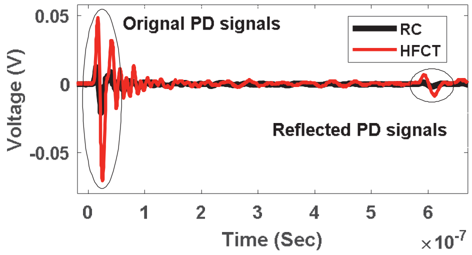

Fig. 3. Experimental PD measurements on MV cable

Comparing the sensors' performance, HFCT presents greater sensitivity while the RC shows greater bandwidth. As shown in Fig. 3, both the sensors are able to measure the PDs on a MV XLPE cable. However, the HFCT's measured signal is significantly stronger than that of RC. MV cables present significant attenuation and dispersion to the PD signals during their propagation that reduces the amplitude and frequency of the PD pulses. In such cases, sensitivity becomes more a concern. Therefore, based on the observed performance, HFCT can be considered as a preferred measurement solution as compared to RC for PD monitoring in cables.

Acknowledgement

This work is supported by Academy of Finland under project grant Grant No. 309412 and FUSE (Future Smart Energy) project funded by Business Finland (Grant No. 7038/31/2017).

References

[1] Eigner et al. "An overview on the current status of partial discharge measurements on AC high voltage cable accessories." *IEEE Electrical Insulation Magazine* 32.2 (2016): 48-55. doi:10.1109/MEI.2016.7414231

[2] Fernando, et al. "Application of HFCT and UHF sensors in on-line partial discharge measurements for insulation diagnosis of high voltage equipment." *Sensors* 15.4 (2015): 7360-7387. Dio: 10.3390/s150407360

[3] Shafiq et al. "Online condition monitoring of MV cable feeders using Rogowski coil sensors for PD measurements." *Electric Power Systems Research* 167 (2019): 150-162. doi:10.1016/j.epsr.2018.10.038