

NFC Based Current Sensor for Medium-Voltage Lines

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Summary:

The presented work focuses on developing a flexible NFC sensor patch, capable of being implemented in a medium-voltage underground cable. The measurement principle is based on the measurement of the magnetic field, which is directly proportional to the current in the cable. The sensor patch can be integrated into the cable, shielded, and covered with a shrinking repair sleeve. The measurement results prove the feasibility of such an NFC-based integrated sensor patch solution.

Keywords: NFC sensor, current measurement, Hall effect sensor, medium-voltage cable monitoring

Introduction

The actual current load is the main parameter to monitor in medium-voltage lines. The generated magnetic field under load conditions is proportional to the current within the conductor. Due to the cable's coaxial setup, an indirect measurement based on the magnetic field strength is the proper method [1].

A free-space configuration must be used for an integrated version, as it is impossible to attach any flux-concentrating magnetic materials around the wire or realize an inductive system like a Rogowski coil, [2]. The Hall sensor provides a measurable output voltage proportional to the magnetic field and therefore also proportional to the current according to Ampere's law given by (1),

$$\oint \vec{B} * d\vec{l} = \sum \vec{B} * \Delta\vec{l} = \mu_0 * I \quad (1)$$

with the magnetic permeability of free space given by $\mu_0 = 4 * \pi * 10^{-7}$ Tm/A. As the medium-voltage cable is built up as a coaxial cable the field must be measured in offset to the central wire center, refer to Figure 1.

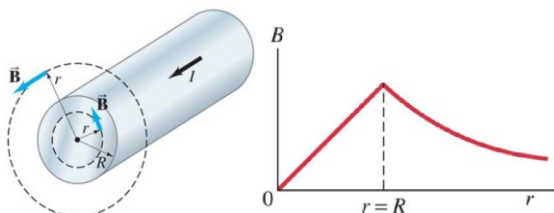


Fig. 1. Magnetic field characteristic of a single wire.

The current density or magnetic field B within the conductor of radius R is uniform. At the same time, it decays if the distance r is further increased $r > R$. By applying equation (1) and

assuming a circular path around the wire, \vec{B} is tangent to $d\vec{l}$ at every point, resulting in (2),

$$B = \frac{\mu_0 * I}{2 * \pi * r} \quad (2)$$

Due to the specification of the medium-voltage cable of the type NA2XS(FL)2Y 1X95/25, the diameters of all the layers are known, and according to equation (2) the current can be calculated based on the measured magnetic field strength B .

Description of the System

As the sensor patch is wrapped around the cable, the printed circuit board (PCB) comprises a 300 μm thick flexible polyimide. The cable's shielding is conductive; therefore, to enable NFC communication "on-metal", the antenna must be electrically separated, which is realized using a ferrite antenna of the type W3509 of Pulse Electronics. To establish near-field communication (NFC), the NTAG 5 link IC of the type NP5332 from NXP Semiconductors is implemented. It enables the connection to any sensor chip featuring an I²C interface. The magnetic field is measured with a TLI493D sensor chip of Infineon. Figure 2 shows the realized sensor patch.



Fig. 2. Developed NFC-based magnet field measurement sensor patch.

Description of the Measurement Setup

Two medium-voltage cable samples of two meters in length were prepared, with the sensor patches integrated for testing. These two pieces were connected in the measurement setup, forming a short circuit loop. A plug-through transformer is used to generate the current flow, and an external Rogowski coil controls the current level. A high-voltage transformer generates the 11.55 kV, supplied to the connecting part of the cables forming the loop. The setup is shown in Figure 3. Commercially available NFC reader evaluation boards are used to read out the sensor patches. In this case, it is the RE12 development kit of Silicon Craft Technology.



Fig. 3. Measurement setup within the high-voltage laboratory.

Measurement Results

To verify the measurement principle, the current is increased stepwise from 50A to 250A every few minutes, and the measurement results are recorded with the reader kit connected to a computer, refer to Figure 4. The NFC sensor patches can be read out using special commands. As the NFC-based passive sensor patch is not intended for high sampling rates, the measured values depend on the current level of the 50 Hz current signal. The system is therefore strongly under-sampled, but as the current represents a periodic waveform, it is valid to sample over a longer time interval and capture the maximum occurring value.

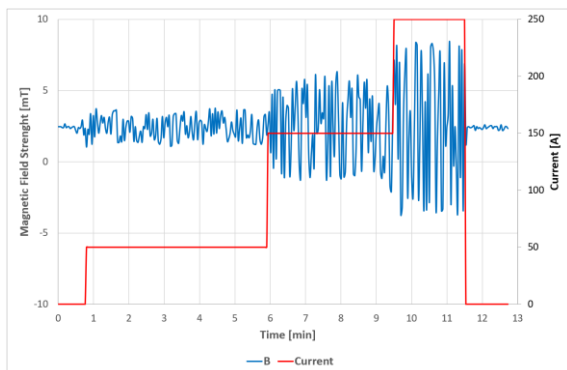


Fig. 4. Magnetic field (blue signal) versus applied current value (red signal). The current represents the effective value.

In a further postprocessing step, the adjusted current value is transformed to a B field value by applying equation (2). Before that, the respective effective value must be converted to the peak-to-peak value by multiplication with the factor of $2\sqrt{2}$, as the sensor detects the magnetic field strength proportionally to the current signal. The table (1) shows the calculated values and the measurement results up to the tested maximum current level of 400 V_{eff}.

Tab. 1: Comparison of calculated values according to equation (2) and measured values.

I_{eff} [A]	Calculated [mT]	Measured [mT]
50	2.1	2.2
150	6.4	6.9
250	10.7	11.5
300	12.8	14.4
400	17.1	19.8

Conclusion and Outlook

Integrating a flexible sensor patch into a medium-voltage line with NFC current read-out was shown and verified. The read-out system works without interference even under load conditions with applied high voltage and high current levels. Minor deviations between the measured and calculated signal appear due to unstable control of the supplying current within the plug-trough transformer caused by temperature increase. In the next step, the sensor patch should be implemented in the medium-voltage grid, to investigate the behavior under real environmental conditions.

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