Vibration-based Diagnosis of Core Fractures in Composite Insulators

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***Abstract*— The most serious condition of a non-ceramic insulator is when the core is damaged, increasing the possibility of a catastrophic failure resulting in the conductor being released. This condition is unacceptable, as it may lead to safety issues both for the public and workers. Furthermore, core damage may occur without any detectable sign on the surface of the insulator. This paper presents a method aiming at the detection of core damages by testing the insulator based on mechanical excitation and measurement of the resulting vibration in the ultrasonic range. The testing arrangement and results on new and damaged insulators are presented in this paper.**

***Keywords*— composite, insulator, diagnostics, vibration, core fracture**

I. Introduction

Composite insulators are widely used in transmission lines because of their excellent properties, such as high toughness, low weight and good insulating properties. However, as several insulators in service have ruptured without warning, some operators have become wary of using composite insulators. This is particularly true in places where live work is carried out because the extra load of the workers and the equipment can be the trigger that causes the insulator to rupture, endangering both the workers and the public.

Unexpected rupture of insulators is the result of degradation of the insulator core, which in many cases shows no external signs of degradation. During operation, the insulator is constantly subjected to tensile, torsional, and tension forces, and vibration. Insulators are extremely resilient and robust, but if the core develops some minor damage, e.g., due to a factory defect, deliberate damage, or improper handling, it can become more severe over time, leading to the rupture of the insulator. Partial discharges inside the insulator can also significantly weaken the core by burning the resin in the fiberglass core. Water entering the insulating sheath can also have serious consequences, as it is responsible for two different processes that can degrade the insulating core. One of these problems is the increase in leakage current [1],[2], which increases the temperature of the insulator and exposes it to increased aging. The other problem is that water entering the insulator can form acids, which damage both the sheath and the insulator core [3].

The main problem for system operators is that, although the potential faults are known, most diagnostic technologies are optical measurements (visual inspection, UV, IR cameras, hydrophobicity testing) [4],[5] which focus on identifying external damage of the insulator housing. Therefore, there is currently no diagnostic method that can effectively test the insulating core in situ, but at the same time is economically feasible.

This paper presents a method based on wave propagation analysis, which can be used to identify core damage, even in cases where the insulator exterior is intact. The idea is that in a homogeneous medium, a traveling wave propagates at a constant speed until it reaches the medium boundary, where it is reflected. The medium is usually not lossless, so the waves are continuously attenuated, but more importantly, any defect in the medium causes inhomogeneity. Such inhomogeneous parts are called discontinuity points at which the propagating wave is reflected.

In the TDR method, known in cable diagnostics, a low-voltage pulse is induced in the cable, and it is possible to identify various faults based on wave reflections. In its original form, the method is not applicable to composite insulators, but vibrations caused by mechanical excitation can be detected with a piezoelectric sensor. The sensor converts the mechanical wave energy into an electrical charge so that inhomogeneities inside the insulator, and hence, defects can theoretically be detected using an oscilloscope in a similar way to TDR.

As of the knowledge of the authors, the method has not yet been used to diagnose composite insulators, but other fields of science have had a similar approach to diagnosing different structural units.[6]–[8] The measurement procedure and initial results are presented, in the following sections.

II. Measurements

To test the method, waveforms detected on intact and damaged insulators were compared. Since detecting defects in the core of insulators is costly even under laboratory conditions, the damaged sample was not collected from the field; instead, an intact insulator was artificially damaged.

The aim of the study was to investigate the applicability of the method for the detection of damaged insulators. Therefore, we tested the method under laboratory conditions. However, we did not exclude its future application in the

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field, so we tried to design the measurement setup to be similar to field conditions. This means that the insulator under test is in a hanging position, and one of its end fittings is in a fixed position to which the piezoelectric sensor is attached to. The sensor is connected to an oscilloscope via a signal amplifier. In service, the other end fitting would support the weight of the conductor, but here we have examined three different cases. In the first case, the end fitting hangs freely; in the second case, a small weight (~7 kg) was attached to the end fitting using a rope to reduce the sway of the insulator. In the third case, a 250 kg weight was attached directly to the end fitting, and the insulator was tightened without the weight lifting off the floor.

The first two cases are more straightforward and quicker to use in the laboratory because the wave will be reflected entirely at the free end fitting, which is easy to handle. The third case represents field conditions, where the insulator is stressed by a heavy weight, and complicated wave reflection is expected at the weighted end. The sketch of the measurement setup is shown in Fig. 1.

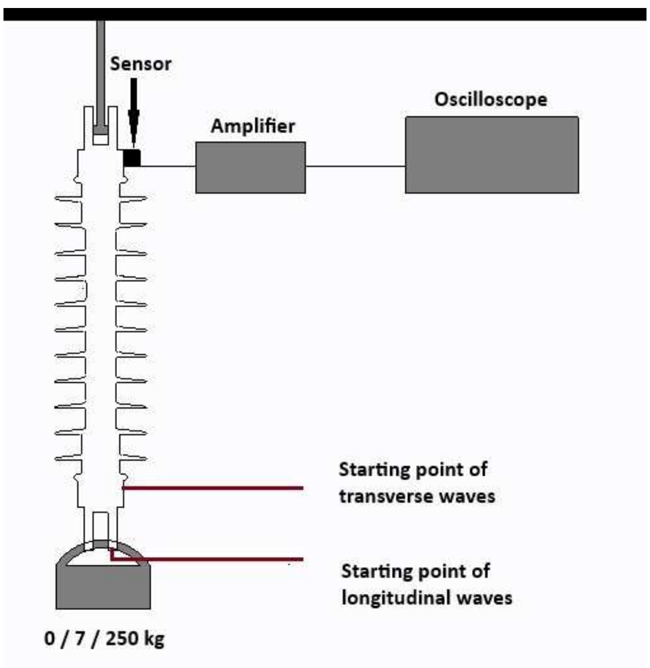

Fig. 1. Sketch of the measurement setup.

To ensure the repeatability of the results and to compare waveforms effectively, the process of mechanical wave generation had to be standardized, as the shape of the wave is strongly influenced by the location, angle and magnitude of the impact. We solved this by using a spring-loaded device to provide the excitation during the measurements. The device had two different fixed positions at the end fitting of the insulator. This was necessary because, although the preliminary assumption was that longitudinal waves would make it easier to identify the fault, we could not be sure, and it might be easier to generate transverse waves in the field. Therefore, one fixed position design was responsible for generating longitudinal waves, and the other one for generating transverse waves.

III. Results

In signal shape studies, conclusions can be drawn from multiple properties of the signal. Observable properties include the amplitudes, phases, repetition, attenuation and frequency components of the signal. There are many methods for evaluating results, but in many cases, they require some prior knowledge of the signal. Therefore, the results presented here are the results of simple observations gained from a limited number of measurements. In most cases, several differences between signals of intact and damaged insulators could be observed, but many of these did not match on repeated measurements, or the differences were not significant enough to be conclusive. The most significant differences observed are highlighted below. The results will be presented based on the load fixed to the free end fitting.

In all the following cases, the generated waves lasted for less than 20 ms. From each of the detected waveforms, 500,000 data points were taken, and using those data points, the signal was reconstructed in MATLAB for further investigation. This allowed us to compare the waveforms more easily, calculate the cumulative energy of the waves (which is calculated as the square of the deviation of each data point from 0 and summed), and analyze the waveforms in the frequency domain.

A. There is no load on the free end fitting

1) The excited wave is longitudinal to the insulator core

In this case, the amplitude of the signal associated with the damaged insulator decreased quicker than that of the intact insulator. In this case, the cumulative energy was lower in the case of the damaged insulator. The signals for both the intact (top) and damaged (bottom) insulators can be seen in Fig. 2.

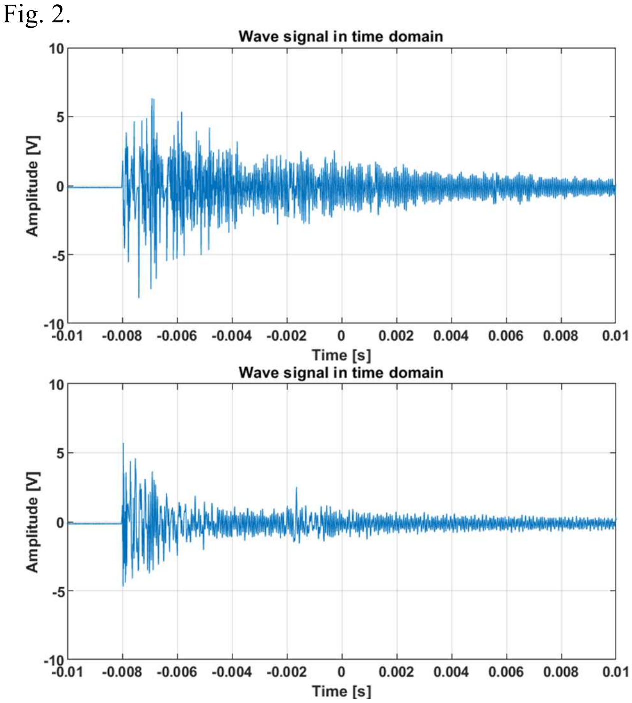

Fig. 2. Signals detected during the measurements.

In the frequency domain there is a significant difference between the signals of the intact and the damaged insulators, as the frequency component around 60 kHz is missing in the case of the damaged insulator. Wave signals in the frequency domain are shown in Fig. 3. for both intact (top) and damaged (bottom) insulators.

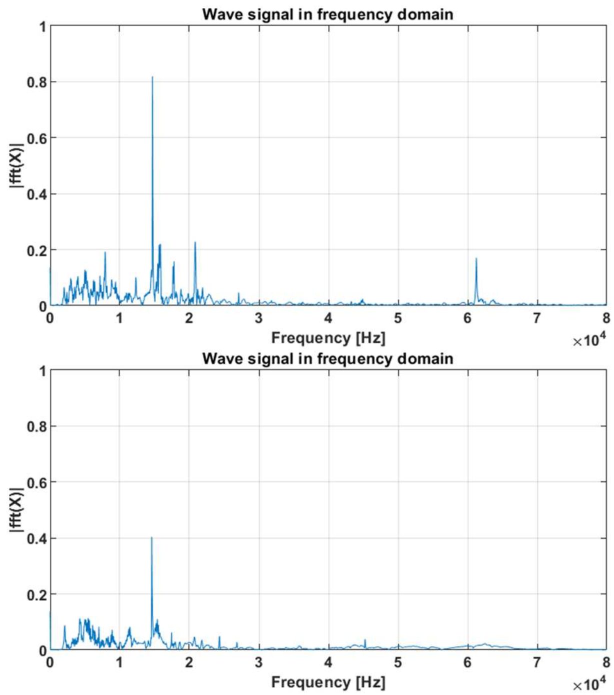

Fig. 3. Signals detected during the measurements.

2) The excited wave is transverse to the insulator core

In the case of transversal waves, the waves detected by the sensor could be easily separated in the time domain during the test of the intact insulator. Fig. 4. shows an example of the waveform. In the case of the damaged insulator such separation could not be made on the signal. The cumulative energy of the wave was higher in the case of the damaged insulator.

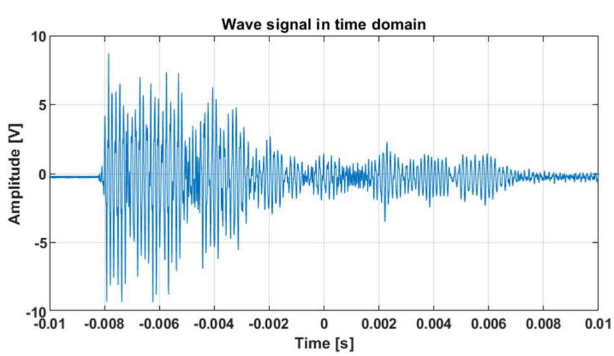

Fig. 4. Signals detected during the measurements (intact insulator).

In this case, the spectral patterns were very similar for intact and damaged insulators, with the only significant difference being the reversal in the proportion of components around 7 kHz and 18 kHz.

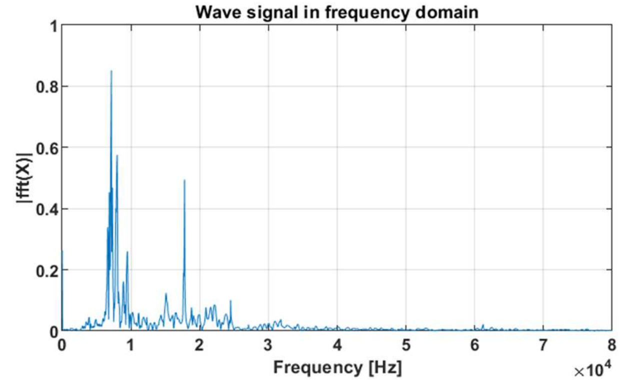

Fig. 5. Spectrum of the signal (intact insulator).

B. 7 kg load on the free end fitting

1) The excited wave is longitudinal to the insulator core

The amplitude of the detected signal associated with the damaged insulator decreased faster. In this case, the cumulative energy was higher in the case of the damaged insulator.

In the frequency domain, as in the unloaded case, we found that the frequency component around 60 kHz does not appear in the case of a damaged insulator.

2) The excited wave is transverse to the insulator core

In this case, no significant difference was found between the time-domain signals of damaged and intact insulators. The cumulative energy of the signal associated with the damaged insulator was higher.

The only dominant frequency in the spectrum of the intact insulator was around 18 kHz. In the case of damaged insulators, there were significant components at a number of frequencies.

C. 250 kg load on the free end fitting

1) The excited wave is longitudinal to the insulator core

In the case of a strained insulator, the time-domain signals are very similar for both intact and damaged insulators. The reason for this is that there is much more significant reflection at the weighted end fitting of the insulator and, therefore, more waves reach the sensor, which overlap. However, isolating several larger waves detected by the sensor is possible. Further observations could therefore be made by splitting the signal into smaller parts. In our case, however, this was prevented by the fact that the amplitude of the signal was too large for the oscilloscope, even at the lowest gain, and so it was cut off. This will require the insertion of a signal attenuator or a change in the excitation in the future. This can be observed in Fig. 6. Due to the overdrive, it is not possible to determine the cumulative energy in this case.

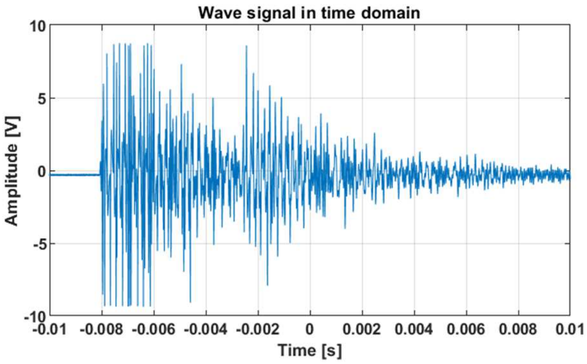

Fig. 6. – Spectrum of the signal (intact insulator).

Spectrum analysis is also much more difficult in this case. The frequency components in the intact and damaged spectra are different but not as significantly as before. Therefore, in Fig. 7, the spectra of the intact insulator (top) and the damaged insulator (bottom) are only shown up to 30 kHz, so the difference can be seen. However, repeated measurements have not yet been able to establish a definite difference.

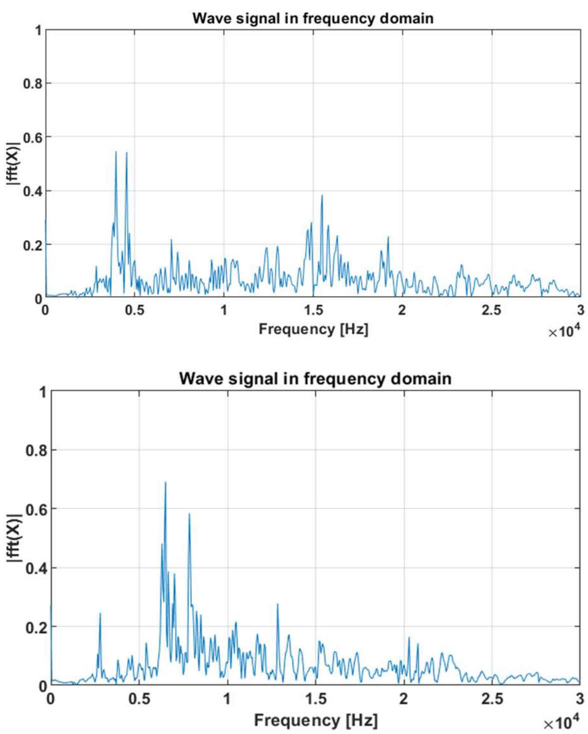

Fig. 7. – Spectra of the signal (intact insulator).

2) *The excited wave is transverse to the insulator core*

In this case, the same can be established in both time-domain and frequency-domain analysis as in the previous case.

IV. Conclusions

The wave propagation based method has not been used before for the diagnosis of composite insulators, and it is therefore essential to establish a solid basis for this research. For this reason, we have set up several scenarios for testing, among which we have found several possibilities to distinguish between damaged and intact insulators using this method. However, further studies are needed to determine the reliability of the method and the extent to which the results can be applied uniformly to different insulator types. Future work will also aim to find the most suitable time and or frequency range for the analysis. Consequently, this paper only presents the initial stages of the research and the possibility of diagnosing non-visible damage of insulators.

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