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Ehrenbergstr. 11
98693 Ilmenau
Germany

info@ilmsens.com
+49 3677 76 130 30
www.ilmsens.com

## Abstract:

A new measurement device for broadband impedance spectroscopy coupled with variable electric field strength applicable to the Device Under Test is introduced. This has a novel character in that, up to now, no meaningful measurement has been possible at high field strengths for the majority of the measurable insulating materials due to feedback effects from the measurement.

Furthermore, the current State of the Art as well as physical basics will be explained.


# 1 Introduction

Breakdown events in insulating materials of electrical devices often happen unforeseen and result in unpredictable faults / damage, such as total equipment failure. Often, minor design flaws suffice to yield to a product malfunction due to breakdown processes at some point of its lifetime. But why is it still not possible to eradicate this problem in 2022? The answer is multifaceted:

Discharges of all kinds have a statistical nature. They cannot be predicted, only the probability of their occurrence. Besides, a variety of circumstantial influence the breakdown process. These include two electrical items: One is the electric field strength the material is exposed to, which results from the prevailing voltage. The other is the frequency at which the voltage is applied. Both quantities stress electrical systems and devices by different mechanisms.

The problem is that up to now we have only been able to comprehensively consider these quantities separately from each other. This plays a very important role in the design of insulating materials, which are used in almost all electrical devices and where voltage-carrying elements must be reliably separated from the surrounding field. Knowing how they behave under which conditions is crucial for operational safety.

# 2 So, what is the Problem?

How come the sudden necessity of measuring the quantities “Field Strength” and “Frequency” altogether? Well:

Looking back to over a century of almost pure 50 Hz – alternating current technology, we find that direct current has been the exception. Hence, in general the system ran with either 50 Hz sinusoidal voltage type or direct current which doesn’t alternate in polarity. However, this changed fundamentally with the mass-introduction of power electronics in the 1990s. Today we find switched - mode power supplies in almost every application, be it chargers for phones, digital topologies, or traction inverters on electric vehicles. Voltage signals can now be shaped and shifted in magnitude almost arbitrarily with little space requirements. However, this has a downside: Switched – mode power supplies operate at switching frequencies of over 1000 Hz up to several 10 kHz. Due to their mode of operation, they also introduce a variety of high frequency – interferences which additionally stress adjacent grids and components.

And suddenly – seemingly without reason – devices equipped with switched – mode power supplies fail, break down, even though the insulating materials are supposedly designed for this.

## 3 What happens in the insulating Material?

Insulating materials have a very basic task: to separate two voltage poles from each other. This happens as the particles in the material have such strong binding forces to each other that they cannot move in an applied electric field. But that doesn't mean they don't try to align themselves with it by wiggling, twisting, compressing or stretching. This process, called polarization, causes heat in the insulating material, in turn called dielectric heating. The amount of heat generated depends on the strength of the change (= field strength) and the speed with which the particles in an alternating field try to align themselves again and again (= frequency). This means that an insulating material can itself become hot in use, even though nothing appears to be happening inside it. If it gets too hot, it fails and breaks down.

## 4 Why is it not possible to measure this at present?

Conventional measuring systems work according to a well-tried principle: the measuring bridge, e.g. according to Schering. There, a network of resistors and capacitors is adjusted around the test object at an applied test sinusoidal voltage until the circuit is balanced. This process takes time to adjust and can only work with one AC test voltage of a fixed frequency at a time. It is therefore time-consuming and involves the risk of the test specimen becoming too hot due to dielectric heating when the voltage is too high, resulting in incorrect measured values or even breakdown.

To keep the energy input into the test specimen small enough, there are either measuring bridges for 50 Hz and high voltages up to kV or large frequency ranges at low voltages. A combination of high voltage and large frequency range is technologically very difficult at the current state of the art and conventionally realized only up to 1 kV at 1000 Hz.

## 5 What do we need to measure?

Two characteristic values are usually measured: the relative permittivity $\varepsilon_r$ and the loss tangent $\tan\delta$. Both values are interlinked to one another and tell us how much the material can polarize or how much loss energy it converts in that process.

So measurement systems designed to investigate the suitability of an insulating material for its application often derive these two values from the measurement.

## 6 What do we do differently?

The current requirement for insulating materials is often defined by their use on converters. Thus, that usually means, a high DC voltage is present, which is, for example, superimposed with a ripple, i.e. fluctuates slightly but repetitively around its nominal value, or is also superimposed with additional signal residues from the voltage generation, which have not been sufficiently filtered.

Our measurement system can replicate this voltage. We first generate a high, smooth DC voltage that we can use to create a high field strength in the **M**aterial **U**nder **T**est. After a waiting time, which is needed by the material to polarize, we modulate our measurement signal onto the DC voltage - a pseudo noise.

The trick: our signal is only a few µs long, but it contains all the important frequencies from about 500 Hz to 250 kHz and can thus map the usual pulse frequencies and their harmonics in the material. Since our measurement is very fast, the risk of dielectric heating is very low. At the same time, the measurement enables us for the first time to have broadband knowledge of $\varepsilon_r$ and tanδ with simultaneously definable high voltage.

# 7 Conclusion

With the measurement system presented above it is now possible to replicate current stress situations of modern insulating materials by applying a high voltage, thus field strength, while measuring dielectric properties over a wide range of frequencies while simultaneously keeping the MUT's dielectric heating at a very low level.

This enables adequate design of dielectrics and insulating materials for e.g. e – mobility to increase safety and longevity of future products.