Abstimmbares Mediumband- und Breitband-UHF-TE-Messsystem für GIS

Tuned Medium Band and Wideband UHF PD Measurement System for GIS

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Kurzfassung

Als Ersatz für die Blitzstoßprüfung während der Inbetriebnahme oder für eine regelmäßige Überprüfung ist bei Vor-Ort-Messung an GIS eine sehr empfindliche und störungsrobuste TE-Messung erforderlich. Das empfindlichste UHF-TE-Messverfahren besteht aus rauscharmen Breitbandverstärkern nahe der UHF TE-Sensoren und die manuelle Auswahl der Messfrequenz zur Abdeckung möglicher Resonanzfrequenzen. Weiterhin führt eine Korrelation der detektierten Impulse mit der Prüfspannung zu einer phasenaufgelösten Signaldarstellung. Der Nachteil schmalbandiger Messsysteme ist die zeitaufwändige sequentielle Überprüfung der Mittenfrequenz im Vergleich zu breitbandigen Systemen. Die breitbandige Systemauslegung mit einem Detektionsband von oft mehr als 1 GHz hat den Nachteil einer deutlich reduzierten Messempfindlichkeit, sobald sich Störfrequenzen innerhalb der Messbandbreite befinden.

Das hier gezeigte abgestimmte Mediumband-UHF-TE-Messsystem besteht aus einem manuell abgestimmten Bandpassfilter mit einer Bandbreite von 80 MHz, in einem Frequenzbereich von ca. 0,1 bis 2 GHz. Die Bandbreite von 80 MHz ist deutlich größer als die typischerweise durchstimmbaren schmalbandigen Messsysteme. Die Auswahl der Mittenfrequenzen sollte sich in erster Linie an den individuellen Systemresonanzfrequenzen orientieren, die durch den CIGRE-Empfindlichkeitscheck (CIGRE Technical Brochure 654) [1] vor Ort an der GIS ermittelt werden. Aufgrund der größeren Bandbreite bei der Mediumband Messung, ist die Wahrscheinlichkeit, nicht bei einer geeigneten Resonanzfrequenz zu messen, viel geringer als bei der Schmalbandtechnik, die typischerweise nur eine Bandbreite von etwa 3 MHz oder weniger aufweist. Die an den TE-Sensor messbaren individuellen Resonanzfrequenzen eines TE-Signals, können sich gegeben falls durch Variation der Signalquellposition gegenüber den Empfindlichkeitscheck verschoben haben. Eine frühere Auswertung [9] von Messungen in verschiedenen Umgebungen und verschiedenen GIS-Typen zeigte eine hohe Wahrscheinlichkeit, dass dieses Mediumband immer noch schmal genug ist, um Festfrequenzstörungen durch die Verwendung einer passenden Mittenfrequenz zu vermeiden. Dies führt zu einem optimierten Systemdesign für TE-Messungen für Vor-Ort-Tests und Monitoring an GIS und zu einer hohen Empfindlichkeit der Messung auch in schwierigen Situationen durch die Kombination verschiedener Methoden und Einstellungen.

Abstract

In order to replace the lightning impulse test during commissioning procedure or for a regular check, a very sensitive and resilient PD-measurement is required for onsite tests of GIS. The most sensitive UHF-PD-measurement method consists of low-noise broadband amplifiers applied close to the PD-sensors and the manual selection of the measurement frequency to cover possible resonant frequencies. Further a correlation of detected pulses with the test voltage will lead to phase resolved signal display. The disadvantage of narrowband measurement systems are the time consuming sequential check of the centre frequency compared to broadband systems. The broadband system design with a detection band of often more than 1 GHz, has the disadvantage of significantly reduced measurement sensitivity as soon as interfering frequencies are located within the measurement bandwidth.

The here shown tuned medium band UHF PD measuring system design consists of a manually tuned band-pass filters with a bandwidth of 80 MHz applied in a frequency range of approx. 0.1 to 2 GHz. The 80 MHz bandwidth is significant wider that typically tunable narrowband measurement systems. The selection of the center frequencies should be primarily based on the individual resonant frequencies of the PD-sensors determined by the CIGRE sensitivity check (CIGRE Technical Brochure 654) [1] on site. The medium bandwidth allows to integrate the individually shifted resonant frequencies of a PD-signal at a PD-sensor within the measurement band, caused by different PD locations. Due to the wider bandwidth the probability of missing resonant frequency at a specific centre frequency is much lower than with the narrow band technique which typically have just a bandwidth of around 3 MHz or less. An earlier evaluation of measurement at different environment and different types of GIS [9] showed a high possibility that a medium bandwidth is still narrow enough to avoid fix frequency disturbances by the use of a sufficient centre frequency. This result in an optimized system design for PD-measurements at on site tests of GIS and monitoring purposes and therefore in a high sensitivity of the measurement even in difficult situations due to interfering frequencies by making use of the combination of different methods and settings.

1 Introduction

The measurement of partial discharges is a world¬wide accepted method for quality control in the factory and for on-site commissioning of high voltage (HV) insulation systems [2]. Partial discharges are local electrical discharges which lead to a partial breakdown of the HV insulation [3]. Especially in gas insulated systems (GIS) with SF_6 insulation, they generate electromagnetic waves in a very broad frequency spectrum due to their short rise time [4]. Protrusions and particles on insulators may generate low-level partial discharges but are easy detectable with lightning impulse tests. In order to replace the lightning impulse test, a very sensitive PD measurement is required for on-site tests of GIS [5]. Generally, the method of PD measurement in the UHF frequency range is also used at other assets, like e.g. Power Transformer [6].
Due to the usually significantly increased interference signal levels on site (compared to the optimized factory and laboratory environment), the PD measurement at GIS on-site is usually carried out in the UHF frequency band. The common bandwidth of the UHF PD measurement method is approx. 100 MHz to 2 GHz. For the most common defect (moving particles) a high sensitivity is achieved. Especially with the variable narrow-band method, it is possible to specifically select frequency windows free of interference. The CIGRE recommends a sensitivity check which verifies the number of UHF PD sensors in a GIS necessary to achieve a minimum sensitivity of 5 pC for a certain type of defect [1]. Details of the implementation of the sensitivity check are discussed in the CIGRE Technical Brochure 654. For on-site commissioning testing of GIS, the UHF method has established itself as the standard method for PD measurements.

2 UHF Measurement Application

2.1 Signal Transmission

The super-fast rise times of PD signals in GIS result in frequency spectra that extend to very high frequencies. Rise times down to 35 ps of PD signals generated by protrusions, corresponding to frequencies up to 10 GHz, have been verified some years ago [7].

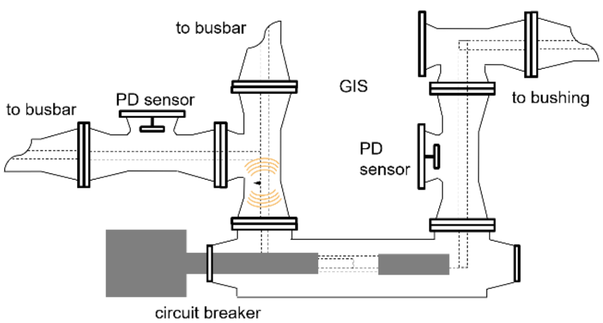

Figure 1: Subsection of exemplary GIS with a PD source as protrusion on HV

For these higher frequencies, the conductive structure increasingly acts as an electromagnetic waveguide. The cut-off frequencies limit depends on the dimensions and the internal structure of the GIS. In addition to the basic TEM signal propagation mode, higher order modes (TE and TM modes) can propagate depending on the geometry. The higher-order modes propagate only above their cut-off frequency ($f_{cut-off}$). Figure 2 shows the cut-off frequencies of the first wave modes for three different diameters and different GIS types (base on their typical diameter).

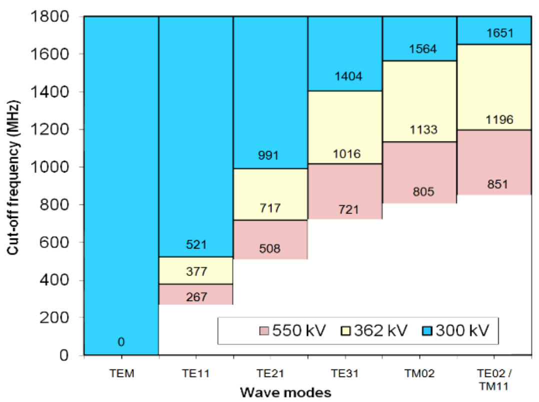

Figure 2: Cut-off frequencies ($f_{cut-off}$) within a GIS for 300 kV, 362 kV and 550 kV [8]

Each of these higher order modes is reflected and refracted at discontinuities like e.g. T-pieces, disconnector or circuit breaker in its own way. The propagation speed for the mode is around cut-of frequency strongly frequency-dependent. Signal propagation is dampened by refraction and absorption such as skin effect and lossy dielectric material. What is finally picked up at the broadband UHF PD sensor (installed in the GIS) is the complex superimposition of different modes, which is reflected in the frequency spectrum with different resonances and cancellations which are dependent on the source location.

In radio frequency engineering terminology, the GIS can be described as a heavily overmoded waveguide.

2.2 UHF Measurement

Several types of UHF methods are applied [9]:

- Tuned UHF narrowband measurement with variable center frequency
- UHF broadband measurement with fixed bandwidth
- UHF narrowband measurement with fixed frequency (or several fixed frequencies)
- Tuned UHF medium band measurement

In the following the tuned narrowband, broadband and tuned Mediumband methods will be explained and discussed.

2.2.1 Narrowband

Figure 3 shows the principle of the tuned UHF narrowband measurement with variable center frequency.

A low noise preamplifier (PreAmp) is connected close to the UHF sensor in order to prevent loss of sensitivity. Fur-

ther its shown the tunable narrowband filter and the exemplary quasi peak (QP) detector arrangement which feed the phase-resolved partial discharge (PRPD) visualization module.
The frequency window in which PD can be measured sensitively depends on the combination of the defect, the propagation path, and the employed sensor. Ideally, a suitable measurement frequency window can be identified by simple observation of the input frequency spectrum in which a high signal-to-noise ratio (SNR) results in high measurement sensitivity [5]. Something, that can be additionally evaluated during the recommended CIGRE sensitivity check [1].

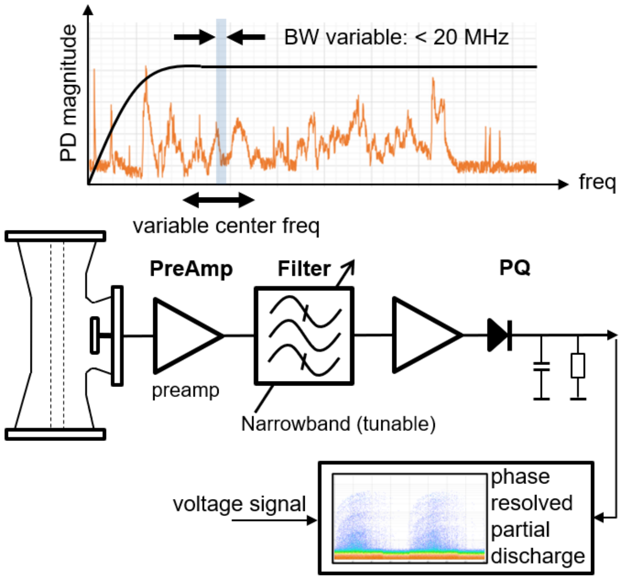

Figure 3: Schematic setup of a narrowband system

Once such a window is found, the center frequency of the narrowband filter is centered on it (blue bar in the spectrum in figure 3), the bandwidth is set to e.g. 2 MHz. The result is that the time-domain PD signal is coupled out at a measurement frequency in the UHF range with a high SNR.
Such a signal can then be displayed on a module for a phase-resolved partial discharge (PRPD) measurement, which is synchronized to the high-voltage test waveform.
Once a phase-correlated pattern can be observed (like in figure 3), it means a PD source synchronous to the test voltage is active and should be further investigated. If no phase-correlated pattern can be found, it is probable that the signal is an uncorrelated external interference which is irrelevant for the asset assessment. Even under difficult conditions with high levels of ambient interference, with some practice suitable frequency windows with good SNR can be found.

2.2.2 Wideband

Broadband UHF measurement with fixed bandwidth is widely used especially for monitoring systems. A schematic diagram of the PD signal spectrum measured across a bandwidth of several hundred MHz is shown in figure 4.

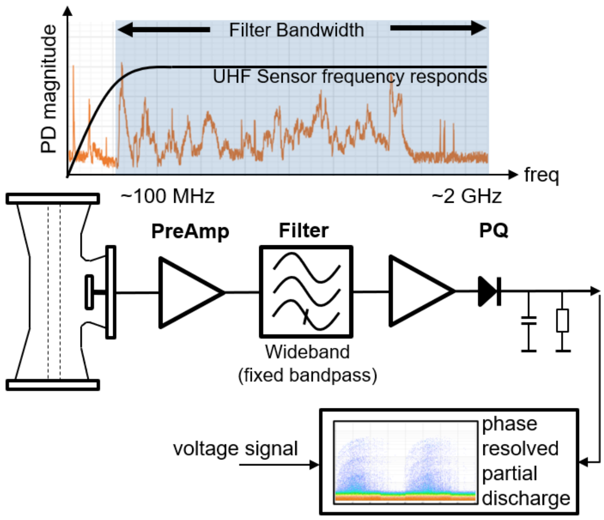

Figure 4: Schematic setup of a wideband system

Also here, a low noise preamplifier (PreAmp) is connected close to the UHF sensor in order to prevent loss of sensitivity. It's followed by a fixed broadband bandpass. The broadband frequency spectrum is directly processed in the following QP detector. The resulting signal is shown exemplary in figure 5 and reflecting roughly the envelope of the input signal.

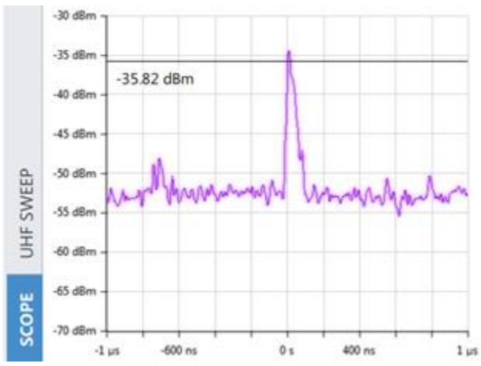

Figure 5: QP output of broadband signal as power signal (dBm) vs. time

The maximum of the signal pulses are displayed directly in phase-resolved PD pattern format by synchronizing it to the test voltage.

2.2.3 Mediumband

The tuned medium-band UHF PD method combines the advantages of simultaneous measurements on many sensors, due to less effort for measurement frequency evaluation, but with the individual optimizing of the signal to noise ratio (and noise reduction) at each PD sensor.
The tuned medium-band UHF PD measuring system design consists of tuned band-pass filters with a bandwidth of 50 to 150 MHz applied in a frequency range of approx. 100 to 2000 MHz. The selection of the center frequencies performed before the HV test should be based on the individual resonant frequencies of the PD sensors, which were determined by the on-site part of CIGRE sensitivity test. The medium bandwidth allows integrating the individually

shifted resonant frequencies of a PD signal at a PD sensor within the wider measurement bandwidth compared to the narrowband method [8].

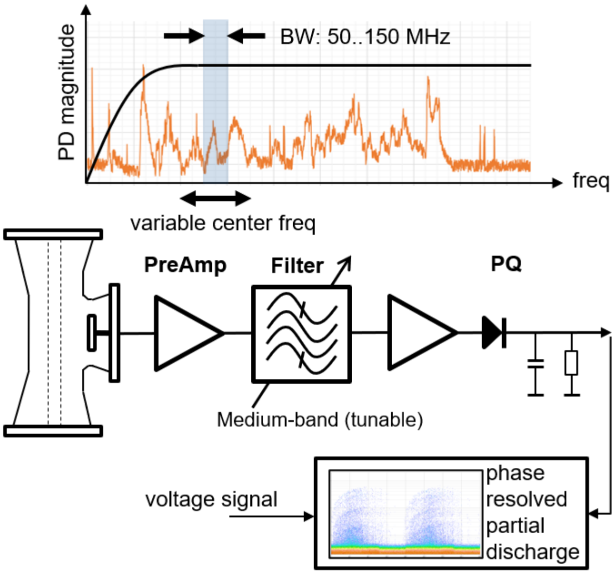

Figure 6: Schematic setup of a Mediumband system

Also here, a low noise preamplifier (PreAmp) is connected close to the UHF sensor. The filter frequency spectrum of the tunable Medium-band filter is directly processed in the QP. The resulting signal is shown exemplary in figure 7 and reflecting roughly the envelope of the filter output signal.

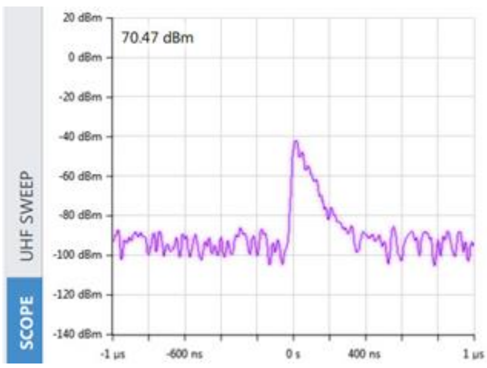

Figure 7: QP output of medium band signal as power signal (dBm) vs. time

Like the other filter concept, the maximum of the signal pulses are displayed directly in phase-resolved PD pattern format by synchronizing it to the test voltage.

3 Example

The following exemplary measurement show the different of a medium measurement and wideband measurement of the same setup. The source of the PD pulses is a surface discharge.

The used measurement system [10] is able to switch between different measurement modes, respectively different measurement bandwidth and center frequencies like shown in figure 8.

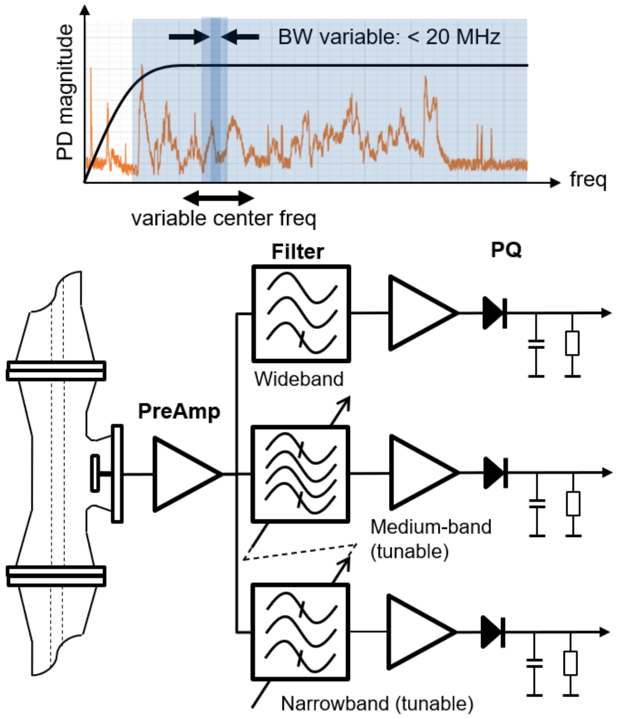

Figure 8: Schematic setup for a multi-bandwidth system

The wideband measurement show a in the SCOPE-tab a very fast responds (very rapid increase and rapid decrease) on the signal due to the short impulses and the broadband filter characteristic (see figure 5). The PRPD show a noise level which is picked up over the hole frequency range of about 2 GHz with a value of about 1.5 mV. The PD pulses are in the ranger up to 7 mV (figure 9).

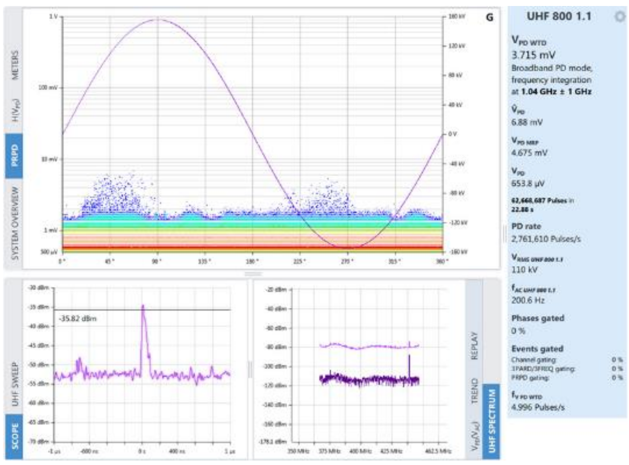

Figure 9: Wideband measurement

By choosing a more limited bandwidth with the Mediumband Mode some of the disturbances are excluded from the measurement which results in a lower noise level (~300 µV) by comparable level of the PD impulses (see figure 10). For this measurement the frequency range 80 MHz around 300 MHz is selected. The SCOPE-tab show again a very rapid increase and a comparable slower decrease as a respond on the signal due to the short impulses and the filter characteristic of the more limited bandwidth filter (figure 7).

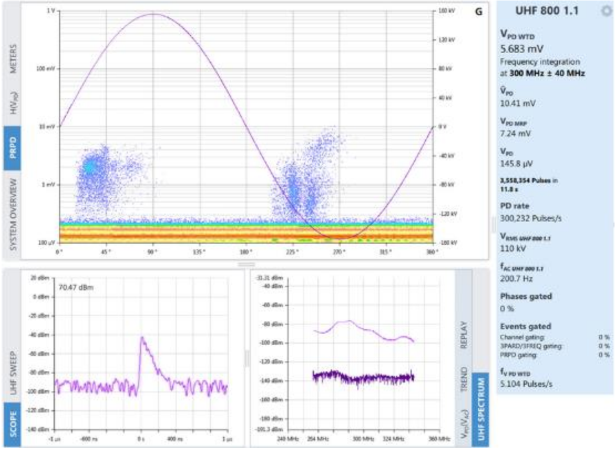

Figure 10: Mediumband measurement at 300 MHz with a bandwidth of 80 MHz.

4 Conclusion

Among the present UHF methods, the narrowband method with visual selection of the measurement frequency together with a broadband preamplifier directly mounted at the PD sensor allows the most sensitive measurements. Due to the frequency window selection process, the effort and the need of experience to practice this method is high. The proposed tuned medium-band UHF method offers the possibility to selectively avoid interfering frequencies but also not to miss resonant frequencies at a specific PD sensor (which are interdependent on the defect and its location) due to sufficient bandwidth. A pre-tuning of each individual sensor location based on the second step of the CIGRE sensitivity check on site allows simultaneous measurements of many sensor locations with optimized settings. The SCOPE view shows the expected responds on the fast input impulses and the further signal shape is explainable by the filter characteristic of the used filter respectively the filter bandwidth.

5 Literature

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