Technical Document

Partial Discharge vs. Radio Influence Voltage (RIV) measurement

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Current and voltage – our passion

PARTIAL DISCHARGE VS RADIO INFLUENCE VOLTAGE (RIV) MEASUREMENT

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Abstract: The purpose of this article is to support the proper understanding and setup of Radio Influence Voltage (RIV) measurements. The limitations of RIV measurements and their relation to Partial Discharge (PD) measurements are described and discussed. The given advices will ensure repeatable results, simplified comparisons and will help to detect test object failures. The main theory and principles of PD measurement are explained, followed by a short description of the PD and RIV processing blocks as well as a comparison of the calibration methods. Furthermore, the differences of RIV standards are covered. Important recommendations will be given on which fundamental parameters to be stored in the measurement records for future analysis of test objects. Those recommendations will provide a plausible overview about the potential aging effects and failure development which helps to improve final product quality management.

1 INTRODUCTION

Originally RIV measurement was simply supposed to indicate the level of a radio disturbance causing annoying interferences, and the degree of annoyance for AM radio listeners. The means to weight the measurements was the quasi-peak (QP) detector. Weighted measurements of impulsive disturbances are made to minimize the cost of filtering when radio users do not feel uncomfortable or disturbed [1]. This led to EMC standards such as NEMA, ANSI and CISPR.

Quasi-peak detection has been developed for AM modulation only. Likewise, the modern digital communication using error correcting codes and complex modulation is more sensitive to repetitive perturbations rather than to low occurrence pulses. The perturbations are then no longer pure noise but mainly ‘blank’ sound or missing data. Today the QP detector is still part of the EMC standards but new RMS-Average detectors have been introduced to better fit with digital communication but with the same intention of lowering the weight of low repetition rate pulses [2].

The QP detector is just a blind removal of low repetition events and therefore has no relation to PD measurement but only to EMC [1, 2]. QP detector is suitable for AC voltage stress with repetitive pattern but is inappropriate for DC voltage stress applications where peak detection must be used. Partial discharge (PD) measurements have been widely used starting in the 1940's. At that time sensitive radio noise meters were the only alternative for partial discharge measurements according to the NEMA 107 standard.

Later, other standardization groups such as ANSI and CISPR came up with alternative measuring principles. This resulted in two parallel paths for RIV measurement standards. Even when IEC has created a new PD measuring standard (IEC 270) it kept the QP detector. This resulted in the competition between RIV and PD (IEC 270) for corona (i.e. partial discharge) measurement.

With the advent of PD measurement NEMA/ANSI standards dealing with RIV measurement became obsolete and outdated. The CISPR EMC standard is continuously considered in RIV measurement specifications. Recently several IEC and IEEE standards have started to refer to the CISPR standard but only for EMC compatibility purposes.

2 PARTIAL DISCHARGE (PD) THEORY AND PRINCIPLES

Partial discharge measurement performed according to IEC 60270 [1] has become an essential tool for the quality assurance of HV products. The main goal of IEC 60270 is to standardize and unify PD measurement to get comparable results for tests performed at various locations, with different equipment and by different operators. To achieve that goal IEC 60270 has defined a set of processes and key parameters which have to be followed carefully.

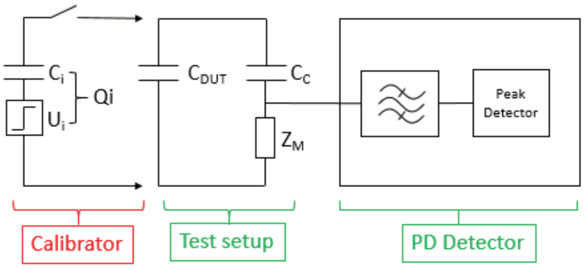

Figure 1: Simplified schematic of the PD measurement at the time of calibration

Figure 1 shows the simplified schematics of the PD measurement circuit at the time of calibration. C_i represents the injection capacitance of the calibrator and U_i is a step voltage generator, resulting in the injected charge $Qi = C_i * U_i$. C_{DUT} is the capacitance of the test object. C_c is the coupling capacitor. Z_M is the measuring impedance. The PD detector basically consist of digital filters and a peak detector. IEC 60270 describes and defines the following features, components and procedures for PD measurement:

1. Measured quantities

The most common quantity to characterize PD activity is the charge Q which is derived by an integration of the PD current pulse. Further quantities include e.g. discharge current, discharge energy, PD event rate etc.

2. Measuring circuit

The use of a coupling capacitor (common range from 500 pF to 10 nF) is defined to reach a reasonable sensitivity and Signal-to-Noise Ratio (SNR) together with a valid frequency response. The measuring impedance is defined as an RLC quadripole.

3. Measuring circuit components

The PD measurement setup and connections are precisely described. Basically, only two basic arrangements are allowed – connecting the measuring impedance in series with the coupling capacitor (90% of the cases) or in series with the test object (which is not feasible for all test objects, leads to higher risk of instrumentation damage during test object flashover but might provide better SNR). For special cases two additional setups used for noise suppression and discrimination are allowed.

4. Definition of the measuring frequency range

Wide-band and narrow-band measurement principles are defined. In practice, wide-band measurement is used predominantly due to its robustness, plausibility and the consistency and repeatability of measurement results [2]. Narrow-band measurement was promoted especially in the 1990s by Tettex due to its specific benefits of SNR optimization. However, it has been shown that narrow-band measurement suffers from several major disadvantages. Very low bandwidth limits can render correct pulse polarity recognition difficult. When the PD repetition rate exceeds the PD detector filter bandwidth the measurement is invalid. Correct filter settings are very specific and differ for each test setup, test environment and test object and require advanced knowledge and techniques for proper configuration.

5. Calibrator and calibration procedure

The calibration procedure as well as the parameters and uncertainties of the calibrator are precisely described.

2.1 Selecting PD filter frequency range

IEC 60270 [3] requires the PD pulse spectrum cut-off frequency to be higher than the upper cut-off frequency f_2 of the PD detector filters. In addition, important practical values like the error introduced in the measurement when the PD pulse spectrum cut-off frequency is close to f_2 or resonances occurring in the measuring bandwidth (BW) are needed to ensure correct measurement setup. It is important to note that the PD spectrum of interest is the one associated to the current measured by the measuring impedance Z_M as shown in [4]. The measuring impedance and analogue filters used to suppress power electronics switching noise are part of the PD detector filter and do not change the PD pulse bandwidth considered for pseudo integration.

Partial discharge measurement requires to correctly set the PD filters to ensure that the pseudo-integration of the PD pulses properly converts the measured input current into the corresponding charge in Coulombs.

The Fourier transform of the impulse response of a filter corresponds to the frequency response of the filter. Theoretically the input impulse should be a Dirac pulse whose magnitude is defined by the pulse area = amplitude * time. The peak magnitude of the filtered output signal is proportional to the Dirac pulse area. This is true as long as the spectrum of the incoming pulse extends well beyond the filter bandwidth in which case the filtered peak value is proportional to the incoming pulse area, effectively “integrating” the PD pulse.

Thus at least the PD calibration pulse spectrum should be checked to satisfy this requirement. Ideally some of the real occurring PD shall be checked as well to ensure that the measurement is valid independent of the pulse propagation path from the PD source in the test object to the measuring impedance.

When measuring PD, it is assumed that this check has been performed once when the setup was defined, without the need to redo it. This is mainly the case for equipment manufacturers which are repeatedly testing the same well-known product.

2.2 The - 6dB cut-off frequency limits

PD measurement is very similar to spectrum analyzer measurements in EMC testing where the bandwidth is commonly defined by the -6 dB frequency limits when testing continuous wave (CW) signals. However, the response of a filter to a broadband pulse is best characterized by its impulse bandwidth (IBW). A detailed discussion of IBW goes beyond the scope of this paper. More detailed information on the definition of BW and IBW can be found in [5] which explain the importance of recording not only the -6 dB limits but also the overall frequency response. IBW is defined as an ideal rectangular filter which has the same voltage response as the considered filter under test. This is equivalent to defining a reference filter mask. The corresponding measurement methods can be found in [5]. The main difference between spectrum measurements for EMC testing and PD measurements is that PD is calibrated by a PD calibrator injecting a defined charge prior to each measurement whereas spectrum analyzers are calibrated at manufacturing time using techniques such as reference impulse generators [5].

3 RIV THEORY AND PRINCIPLES

Today, RIV measurement still appears in IEC standards and is referred to in the latest CISPR technical report [6].

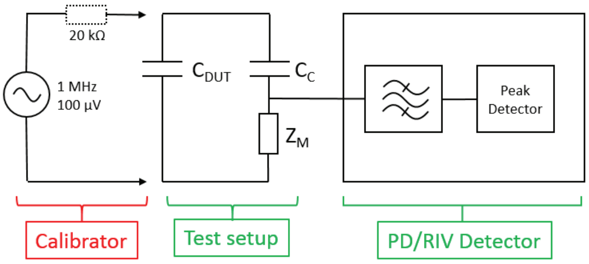

Figure 2: Simplified schematic of the RIV measurement at the time of calibration.

Figure 2 shows the simplified schematics of the RIV measurement circuit at the time of calibration. In case of NEMA-ANSI a sinewave generator with a given frequency and amplitude is used, typically 1 MHz and 100 µV. A 20 kΩ resistor is connected in series with the sinewave generator in order to inject a current signal according to the CISPR standard. C_{DUT} is the capacitance of the test object. C_c is the coupling capacitor. Z_M is the measuring impedance. The PD/RIV detector basically consist of digital filters and a peak detector.

3.1 NEMA-ANSI: A voltage calibration

It is often assumed that the impedance value of the measuring impedance directly influences the RIV measurement (in µV). This is true for the reading of the instrument but with calibration according to NEMA the RIV reading is corrected by the circuit RIV factor, which is the ratio of the reading of the instrument to the voltage at the terminal of the test sample. Therefore, the calculated "true" value is independent of the measuring impedance.

3.2 CISPR: A current calibration for a voltage measurement

In contrast to the calibration of the measuring circuit by voltage comparison (NEMA-ANSI, Section 3.1) the size of the measuring impedance directly influences the measuring result when applying current calibration according to CISPR. Provided the whole current of the radio frequency generator (or pulse generator) passes through the measuring impedance (direct series connection), the instrument reading is proportional to the value of the measuring impedance. But if the measuring impedance is in series with the coupling capacitor (or test sample), the current distribution of the measuring circuit is altered by a change of the measuring impedance and therefore the current through the measuring impedance is altered too. The deviation will be relatively small though, and the circuit RIV factor will change only slightly. But the instrument reading increases with increasing measuring impedance, so that the calculated "true" value increases too. Therefore, RIV measurement with calibration by current comparison is dependent on the measuring impedance.

3.3 NEMA-ANSI and CISPR discussion

The limitations of voltage calibration according to NEMA-ANSI were partially rectified by the CISPR definition of current calibration. At the same time, however, a certain confusion arose due to the current calibration of a voltage measurement. CISPR also defines a rather complex measuring circuit with a defined relation between the coupling capacitor and the measuring impedance characteristic. In addition, an elaborate calibration procedure is required. But in practice most requirements are ignored because some are too difficult or impossible to fulfil.

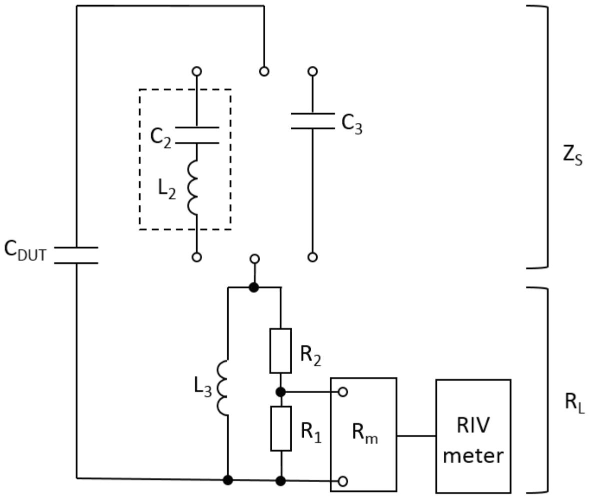

Figure 3: CISPR measuring circuit diagram.

In Figure 3 according to [6] the total impedance $Z_s + R_L$ shall be 300 Ω +/- 40 Ω with a maximum phase angle of 20° at the measuring frequency. If only a single capacitor is to be used, then C_3 must be five times the overall stray capacitance to ground, which is difficult to measure or verify. C_3 is recommended to be 1 nF or L_2 = 200 µH and C_2 = 50 to 100 pF with the resonance corresponding to the measuring frequency. The measuring impedance shall consist of R_2 = 275 Ω, R_1 = 50 Ω (same as detector impedance) and L_1 = 1 mH. Calibration with a 50 µA current (1 V / 20 kΩ) is recommended.

Generally, the recommended value of 1 nF for a coupling capacitor typically used for PD measurements does not meet the CISPR requirement of 300 Ω +/- 40 Ω with a phase angle less than 20°. A 3 nF is required to match the 300 Ω impedance at 500 kHz and 1 MHz (recommended measurement frequencies).

It can be concluded that quite a complicated setup is required with parameters that are difficult to test or measure. In addition, those requirements do not ensure correct, stable, plausible and repeatable results as demonstrated in Section 5. This has been confirmed also in study [7].

Many users have collected a large amount of RIV measurement results using those RIV measurement as an indicator for PD activity and hence requiring retrospective comparison with this historical measurement database. A major issue when comparing the NEMA-ANSI and CISPR standards is the difference of the peak detection response with respect to the pulse repetition frequency (PRF, see Figure 4). Especially for PRF ≥ 100 Hz the characteristic responses differ significantly. More detailed information can be found in [8]. For this reason, an inter-comparison of PD/RIV measurements is virtually impossible.

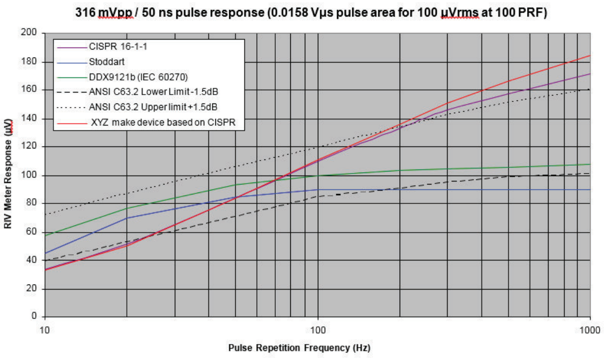

Figure 4: Peak detector response of NEMA (Stoddart), ANSI, CISPR and IEC 60270 as a function of the pulse repetition frequency [8].

In addition, RIV reading errors can be large. The total error can be up to 12 dB corresponding to a factor of 4 between the readings [9].

4 PD AND RIV - DIFFERENCES AND SIMILARITIES

Comparison of Figures 1 and 2 implies that RIV and PD measurements are similar because they are based on the same measuring circuit and share a very similar architecture (bandpass filter, quasi-peak detector). The differences are partly in the filter and peak detector characteristics but mainly in the calibration method. CISPR 18-2 is more similar to PD measurement than NEMA-ANSI RIV measurement because the calibration is performed by injecting a current instead of applying a voltage.

RIV according to CIPSR 18-2 is very similar to a narrow-band PD measurement with a filter bandwidth of 9 kHz. The most apparent difference is the displayed value which is shown in µV instead of pC. All limitations that apply to the narrow-band measurement apply as well to the CISPR measurement. However, the major difference is that the CISPR calibration method is much more complicated with stringent requirements on the measuring impedance and coupling capacitor. As a result, finding the correct setup for measurement and calibration is not easy. The measurement may be very difficult to interpret and therefore it is not possible to assess the condition of the test sample unambiguously. The quasi-peak detection might hide valuable information. As well as for the PD measurement the most valuable information is given by the peak value.

5 PRACTICAL MEASUREMENT AND COMPARISON OF PD AND RIV MEASUREMENT

The CISPR 18-2 standard provide an example for a “burst of corona pulses”. It is important to note that real corona does not emerge as two equal clusters (i.e. same amplitude and same repetition rate) for each half cycle of the sinewave. Two clusters in the same cycle can be observed only at the final stage of corona (“pre-breakdown stage”). However, those two clusters differ radically both in the magnitude and the repetition rate of the pulses. More details about the corona behavior (including its development stages and frequency spectrum of the burst signals) can be found in [10]. To demonstrate the suitability, plausibility and repeatability of RIV and PD measurements an artificial “burst of corona pulses” was injected to a PD/RIV detector. The PRF was varied from 100 Hz (close to the corona inception voltage) up to several kHz (real corona can even reach PRF above 1 MHz) synchronized to a sinewave voltage. A corona pulse burst sequence is characterized by a typical so-called comb spectrum with local maxima (peaks) and local minima spaced at the burst frequency. With increasing PRF the local maxima and minima of the spectrum are further pronounced. These local maxima and minima depend not only on the PRF (i.e. number of pulses per second) but primarily on the burst frequency (i.e. time spacing between the pulses).

In the following section two test cases are shown illustrating the reading differences between wide-band PD measurement (center frequency = 300 kHz and bandwidth = 400 kHz) and RIV measurement (center frequency = 1 MHz, bandwidth = 4.5 kHz (NEMA-ANSI) and 9 kHz (CISPR) respectively). Pulse clusters of various PRF and a burst frequency around 19 kHz have been used for both test cases.

5.1 Case 1 – Increase of RIV reading for increasing PRF

Figure 5 depicts the flat spectrum of a corona burst with PRF = 100 Hz. The higher PRF together with the given burst frequency result in a peak of the spectrum at the measuring frequency of 1 MHz as shown in Figure 6. This effect causes an increase of the RIV reading for an increase of the PRF as indicated in Figure 7. In contrast to the RIV reading the PD reading (wide-band) remains stable and is not affected by a change of the PRF.

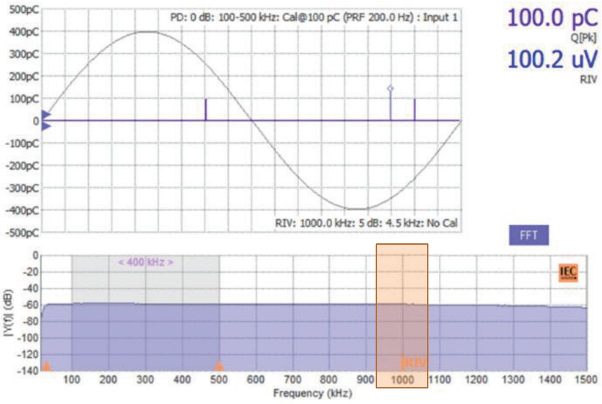

Figure 5: Case 1 – Corona burst spectrum for PRF = 100 Hz.

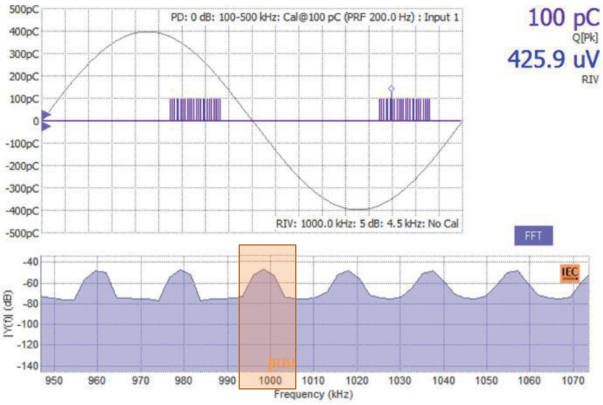

Figure 6: Case 1 - Corona burst spectrum for PRF = 2400 Hz.

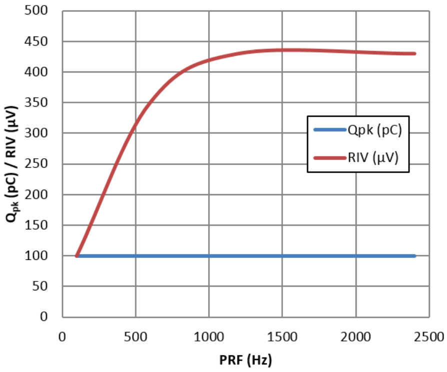

Figure 7: Case 1 – PD and RIV measurement response in dependence of PRF.

5.2 Case 2 – Decrease of RIV reading for increasing PRF

Corona (and PD behavior in general) changes both its PRF and the burst frequency (over time and voltage). Figure 8 shows the pulse burst spectrum with a local minimum at the 1 MHz center frequency of the measurement. In comparison to case 1 (Section 5.1) this corona burst leads to a decrease of the RIV reading as shown in Figure 9. The difference of the spectrum compared to case 1 is caused by a slightly different burst frequency which is a typical behavior of corona discharges (and in general for any PD activity).

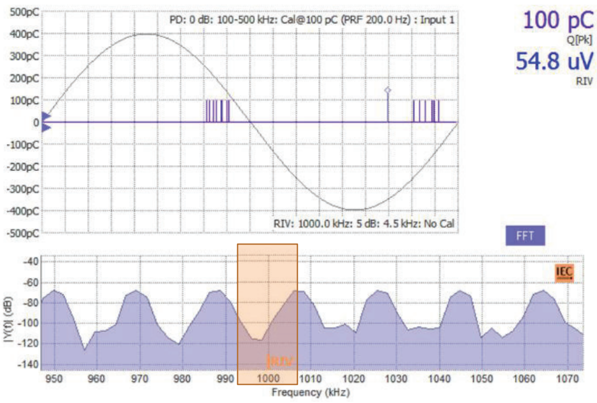

Figure 8: Case 2 - Corona burst spectrum for PRF = 2400 Hz.

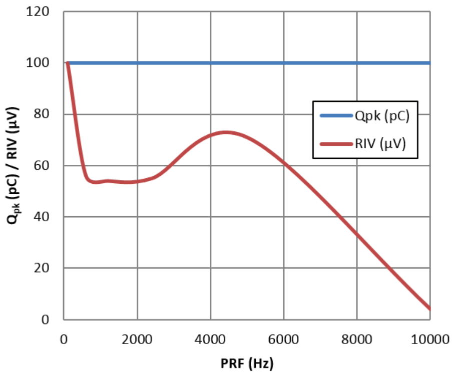

Figure 9: Case 2 – PD and RIV measurement response in dependence of PRF.

6 DISCUSSIONS

Partial discharge measurement according to IEC 60270 is capable of providing correct, stable, plausible and repeatable results (peak measurement) without excessive, complicated and partially ambiguous requirements as in case of RIV measurements according to NEMA/ANSI or CISPR.

Initially RIV measurement was used exclusively for AM interference measurement. However, by finding that those measured High Frequency (HF) disturbances are caused by partial discharges, RIV was also used for PD measurement, especially in North America. Nevertheless, RIV was replaced in the 1960s by PD measurement according to IEC 270 which became a well-established measuring technique that has been proven successful over the decades. In the 2000s RIV measurement has almost disappeared but later CISPR has updated their technical report TR 18-2 and several international standards including IEC (as e.g. [11, 12, 13]) have adopted this measuring technique not for PD measurement but for EMC (Electromagnetic Compatibility) tests which was the original purpose of RIV measurement.

7 CONCLUSIONS

Charge Q_{pk} (pC) provides the maximum value of the reading and is independent of the pulse repetition frequency (PRF) and/or the time spacing between the pulses.

RIV (µV) reading provides a value which is not always stable and can increase or decrease during the measurement depending on the PRF of the PD pulses and the time spacing between the pulses.

The characteristic behavior of real corona is demonstrated in Section 5. The PRF and spacing between the pulses varies in dependence of the time and the applied voltage.

If not required by any applicable standard for a user specific application, we recommend replacing RIV measurement by PD measurement since the test setup and test procedure is almost identical and in fact both techniques measure the same physical phenomena, but PD measurement overcomes the technical limitations of RIV measurement. If RIV measurement is explicitly required, we recommend performing an additional (simultaneous) PD measurement to avoid losing important information like e.g. phase resolved PD patterns. Based on the mentioned issues EMC standard committees might reconsider the narrow-band filter, QP detector, measuring circuit definition and calibration procedure for RIV measurement or replace it by the PD measuring technique.

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