

## EFFECT OF INTEGRATION ERROR ON PARTIAL DISCHARGE MEASUREMENTS ON CAST RESIN TRANSFORMERS

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**Abstract**-Partial discharge measurements are routinely used for quality assurance of medium voltage resin encapsulated transformers. Instrumentation and procedures are covered by international Standards whereas the limit for the apparent charge is presently specified at a 10 pC level. Despite common difficulties in industrial testing bays due often to electromagnetic interference, measurements are in general reliable and reproducible and the way in which the measurand is obtained is substantially robust. The paper intends to discuss the problems encountered during a series of tests which apparently gave origin to very controversial results and measurement inconsistencies, thus making impossible a definite statement of the actual PD level of the equipment under test.

### I. Introduction

Partial discharge (PD) measurement is considered a very reliable tool for quality assurance of industrial equipment because it can prove that there are no weak points in the insulation system due to incorrect design or construction defects.

The technique is extensively used both for HV and MV equipment; in this latter voltage range it has proven to be essential in all the cases where the main insulation consists of cast or extruded resin, namely dry type transformers and cables.

Product related Standards give usually maximum PD values which can be tolerated and therefore provide a criterion for acceptance or rejection of the apparatus under consideration; apart from the physical meaning of the potential danger associated to the PD activity, from an industrial point of view the correct determination of PD magnitude is essential to avoid misjudgements of the test results.

Cast resin power transformers are now widely used; the insulation between turns or layers is provided by a combination of plastic materials which can easily deteriorate in presence of partial discharges: their measurement is therefore required as a routine test with a specified limit which has been lowered over the years, being now fixed at a level of 10 pC.

Circuit layout and characteristics of measuring instruments are well specified and covered by [1,2]; basically, the charge associated to the pulses is provided to the object under test by a coupling capacitor and passes through a measuring impedance connected to an amplifier which carries out a pseudo-integration of the current signal.

Traditional Wide Band Partial Discharge Detectors have a low pass frequency bandwidth, with a lower limit in the range of 30 ÷ 100 kHz and an upper limit frequency of the order of 500 kHz; partial discharge current pulses, having rise times of the order of few ns and overall duration of few hundreds ns have a very wide harmonic content which is substantially constant up to several MHz.

When such a pulse is detected from a wide band partial discharge detector, the output will be the impulse response of the measuring system with an amplitude of the peak proportional to the signal integral.

Under these assumptions, the actual band over which the measuring instrument operates is not critical: however, if the harmonic content of the input signal PD is not flat over the measuring range, the PD detector output waveform is no longer corresponding to the impulse response and the relation between peak value and current integral is lost. It is difficult to determine when such situation arises giving origin to a so called integration error [3,4], which can hardly be predicted.

An indication can be derived from the fact that, under these circumstances, the readings of different PD detectors or, more commonly, of the same detector operating with different frequency bands, can be substantially different thus making measurements not reproducible. This problem can be of some importance in case of measurements on cast resin transformers.

As shown in Fig. 1, in cast resin transformer technology, transformer windings are wound in sections composed by wires or by strips, depending on current values. Both techniques give origin to stray capacitances which form a rather complex network due to the numerous possible combinations (turn to

turn, layer to layer, layer to earth etc) [5,6] which interact with the inductive couplings of the coil: as a result the frequency response of the coils have, typically, a series of resonances in the range between 10 and 200 kHz. Their specific value can hardly be predicted as this would require a detailed investigation of the stray parameters and a study of the equivalent circuit which goes far beyond usual requirements in the design phase.

Some examples of frequency response for different types of winding layout are given in Figure 2. Commercially available wide band PD detectors often allow a certain degree of freedom for the positioning of the measurement bandwidth; the work has mainly been focused on possible discrepancies being experienced when using two different types of measuring systems in the same situation.

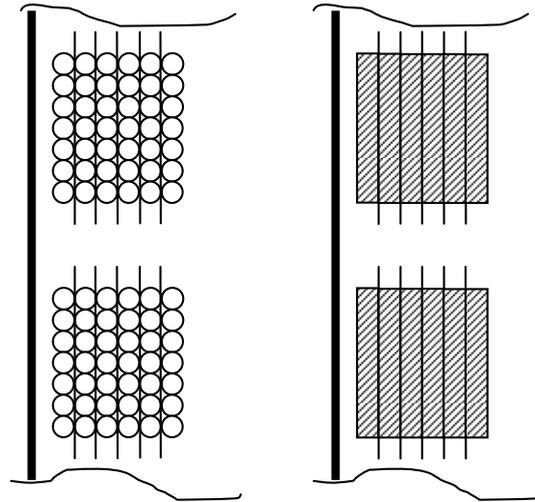


Figure 1. Typical MV winding layout of cast resin transformers

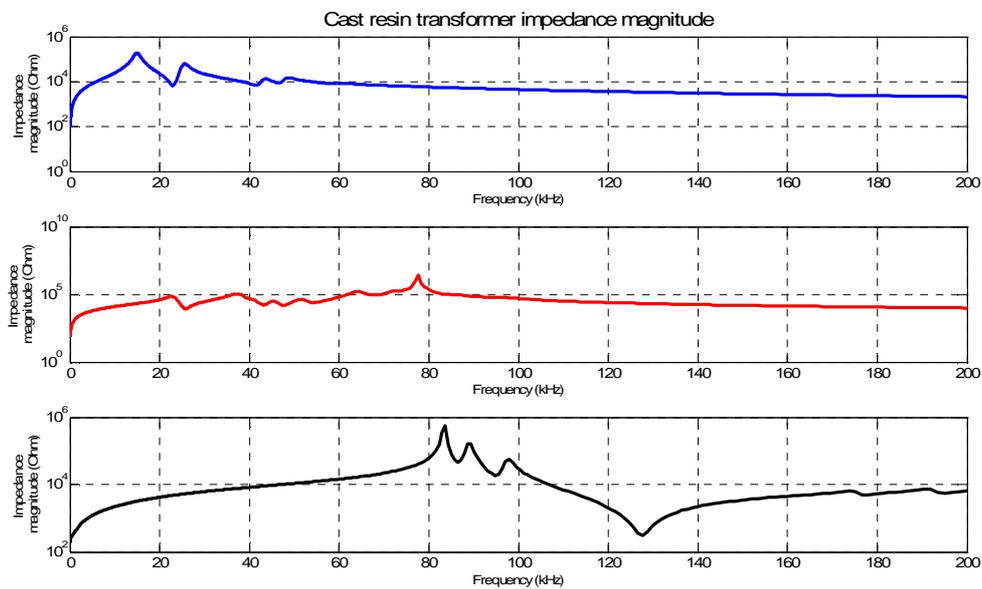


Figure 2. Examples of frequency response of MV transformer windings

## II. Circuit layout for PD measurements

Measurement of PD magnitude on transformers is performed with IEC circuit and the only points to which the coupling capacitor can be connected to the object under test are the coil terminals: the circuit calibration is therefore carried out by injecting a current pulse with a known associated charge value in this same position. If during the actual test a PD current pulse is originated in their vicinity, the

coupling to the external circuit is straight and therefore the effect can be thought to be practically the same as for the calibration whereas, if the defect is inside the coil, the signal has to propagate along the line to reach the terminal. The shape of the resultant pulse will therefore be seen as the convolution between the original pulse waveform and the coil transfer function: in presence of coil resonances, the shape could exhibit specific frequencies which could fall inside the measuring bandwidth of the PD detector.

In Fig. 3 a typical response of a wide band PD detector to a calibration pulse is reported: it can be seen that the correct adjustment of the parameters of the measuring impedance results in an optimally damped oscillation which has an overall duration of the order of 50  $\mu$ s. Fig. 4 shows a partial discharge recorded in the same circuit during the transformer test: the shape is completely different and a long lasting oscillation appears. The response settles after a time which is longer than the previous one by an order of magnitude thus reducing also dramatically the time resolution of subsequent pulses and giving possibly origin also to superposition errors.

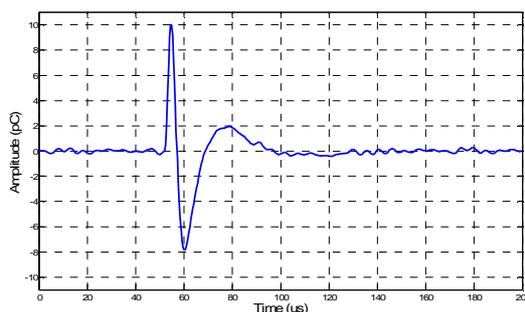


Figure 3. PD detector # 2 - Response to a calibration pulse

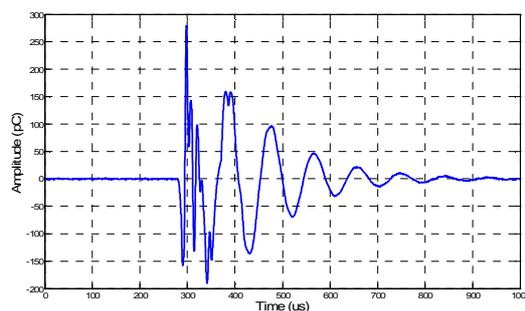


Figure 4. PD detector # 2 - Response to a PD pulse originating near the tap changer position

### III. Instrumentation behaviour

To investigate the reproducibility of the measurement during an industrial test, two different types of instruments were used on the same transformer which exhibited an appreciable PD activity. In all the cases the calibration was carried out following the usual procedures but in addition calibration pulses were also injected in the middle section of the winding between taps; this operation can be performed easily for this kind of transformers which have the tap changer readily accessible.

As it can be seen from Fig. 5, the responses being obtained in this latter configuration can differ widely from those associated to the charge injection at the winding terminals; apart from the heavy attenuation which is always experienced, responses are always oscillating for long periods and the maximum does not occur at the same time with respect to the origin. In any case the shape of the signal associated to the partial discharges is more similar to that of the calibration carried out between tap-changer taps. The time pattern of the response of the measuring system upon which the peak detector operates to extract the PD value is completely different from that resulting from the calibration at the coil terminal: as a result, the PD values which could be obtained for the transformer under the same test conditions were differing appreciably by 40 ÷ 50 % ; the use of the second measuring instrument gave origin again to results which were different to an extent which could not be attributed to the measurement uncertainties; also in this case a marked oscillation is present (Lower trace - Fig. 6) which makes the response completely different from that of the calibration.

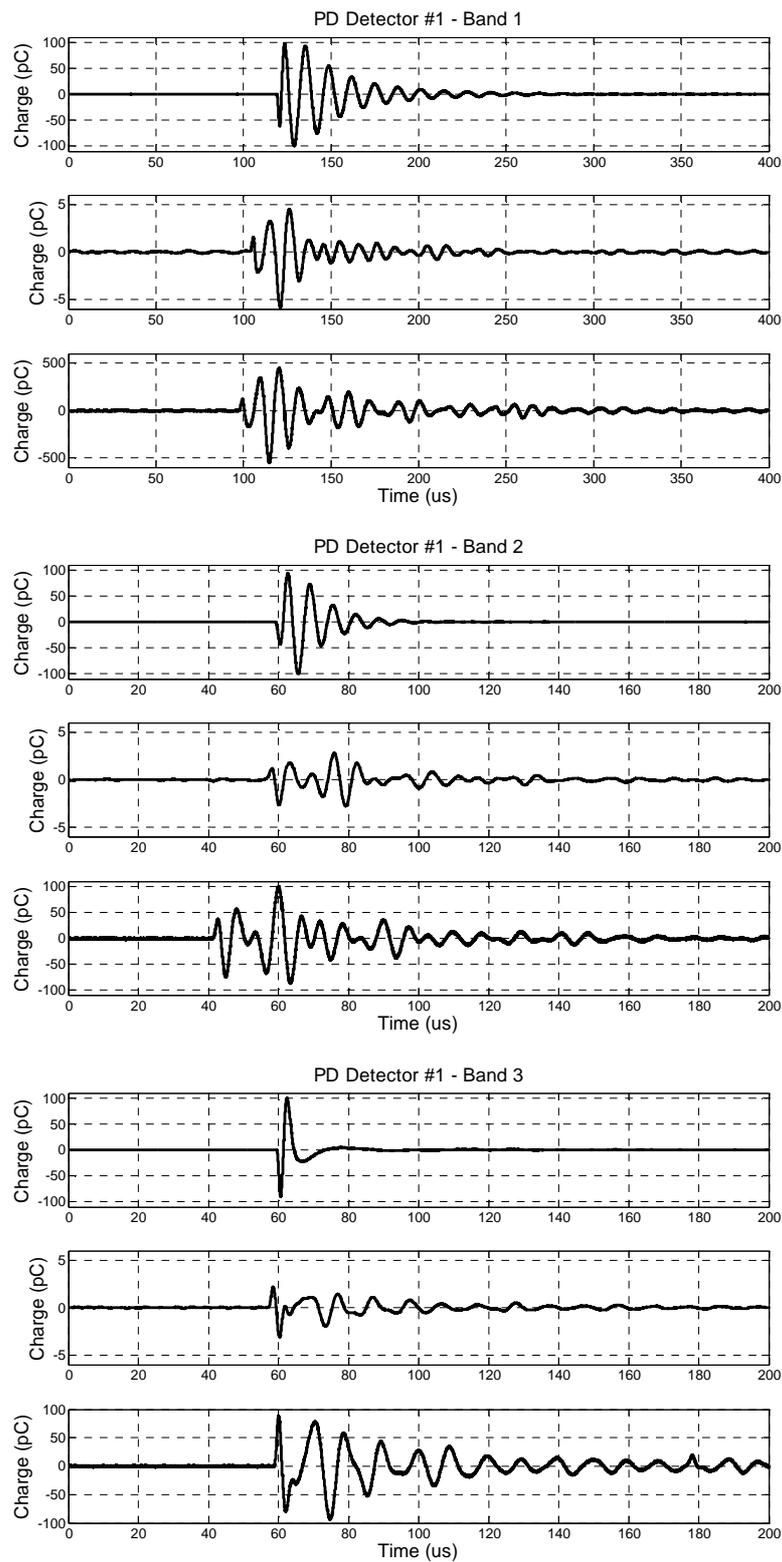


Fig. 5. Instrument #1

- Upper trace: response to a calibration pulse
- Medium trace: response to the same pulse injected between taps in the middle section of the winding
- Lower trace : response to a PD pulse originating in the central part of the transformer coils

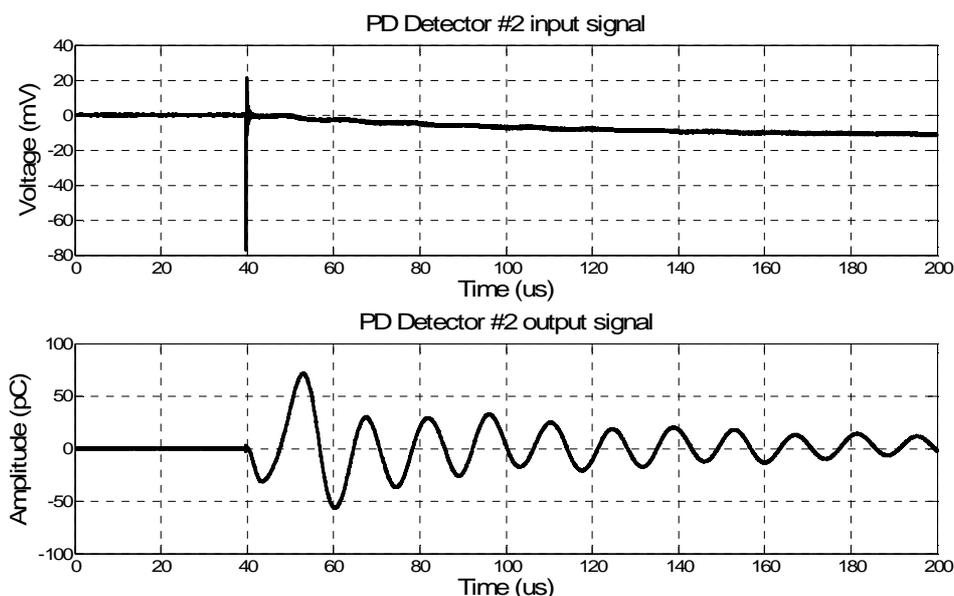


Figure 6. PD detector # 2 - Simultaneous record of input and output signal

To investigate the reason for such behaviour, the input signal was recorded and compared with the output of the amplifier coupled to the measuring impedance: as it can be seen from the upper trace of Fig. 6 there is an initial spike associated most likely to the charge transfer through the capacitive couplings of the winding followed by a long lasting tail which has a superimposed small amplitude oscillation: comparison with the output signal backed also by an FFT analysis indicates that the frequency is the same for both signals. It is therefore the influence of a possible resonance frequency of the transformer which determines and control the final shape of the response in case of a partial discharge taking place far away from the terminal.

The situation arising in this kind of circuit has been simulated by considering a second order system performing the pseudo-integration as in the real operating conditions. In presence of an input signal having the shape of the pulse being detected as shown in Fig. 7, the oscillation is strongly amplified and even if its amplitude is kept low in respect to the impulse peak it can be seen (Fig. 8) that not only the tail is dominated by its presence but also the peak is affected: the contribution to the first maximum and therefore the error being introduced with reference to a calibration carried out without the oscillating tail is almost twice the amplitude of the oscillation itself.

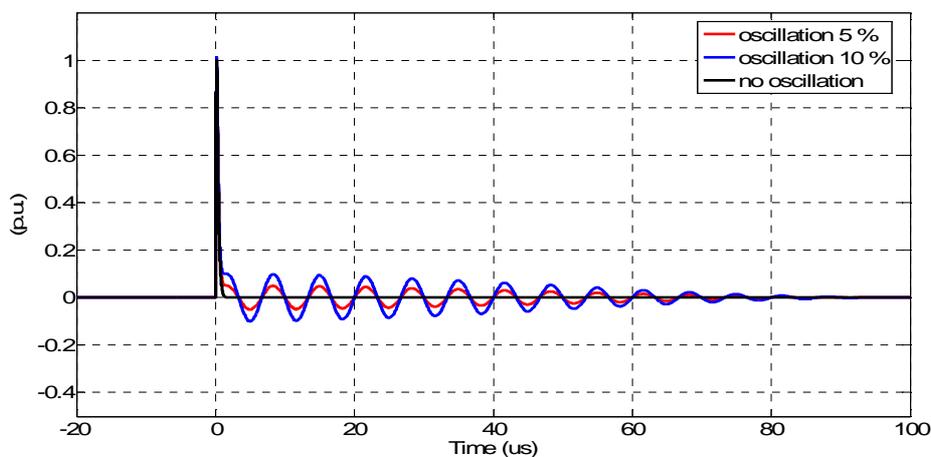


Figure 7. Simulated input signals

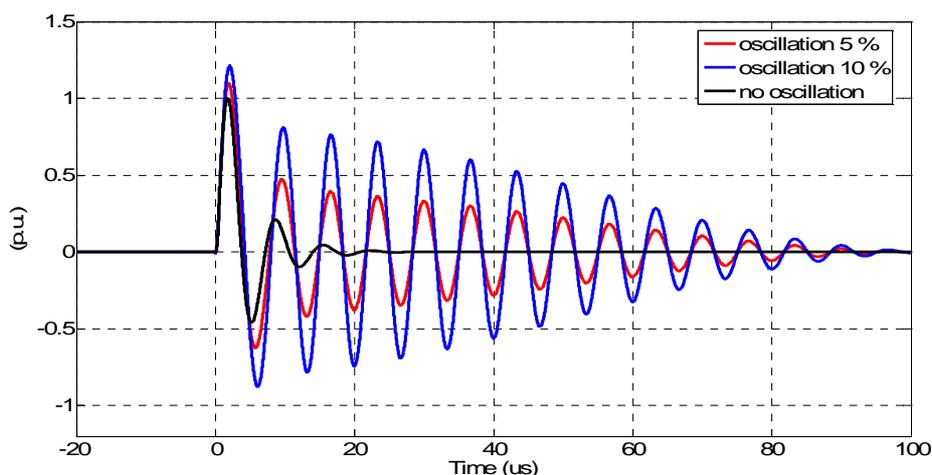


Figure 8. Calculated responses in presence of oscillations

#### IV. Conclusions

A comparison between different types of wide band PD detectors has been performed under conditions in which integration errors are experienced.

It has been proved that when a PD pulse origin is located inside the MV coil of cast resin transformer, the propagation of the pulse towards the terminals can cause a marked distortion: detected pulse frequency spectrum typically contains specific frequencies that have been amplified by the winding resonances.

The pulse harmonic content therefore cannot be flat in the frequency measurement range of wide band PD detectors and consequently the hypothesis upon which the pseudointegration principle is based is no longer valid.

In normal industrial measurements on transformers, where typically PD detector pulse response is not controlled, this systematic measurement error can bring to very high errors in PD charge evaluation.

Since this error depends also upon instrument bandwidth, the obtained results will depend upon factors such as instrumentation bandwidths and frequency ranges, thus making measurements hardly reproducible.

Of course, if the PD level is well below the contractual limit, the result could still be acceptable but in other cases it might cause a false interpretation of the test outcome.

#### V. References

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- [3] W.S. Zaengl, P. Osvath H.J. Weber, "Correlation between the bandwidth of PD-detectors and its inherent integration errors" 1986 *IEEE International Symposium on Electrical Insulation*, Washington, D.C./U.S.A., June, 1986, pp. 115-121.
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