

QUALIFICATION OF ANALOG PD MEASURING INSTRUMENTS ACCORDING TO IEC 60270 STANDARD

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Abstract – The contribution presents the results of a complete set of tests carried out on PD measuring instruments in view of their qualification according to IEC Standard 60270. The difficulties encountered and the calibration facilities which are necessary for the operation are discussed.

The investigation covers several types of instruments, based on various operating principles ranging from traditional wide and narrow band till more recent equipment using an active integrator.

Keywords: PD Measurements, PD Instruments.

1. INTRODUCTION

Partial Discharge (PD) measurements are carried out routinely since a long time with difficulties of different origins, due mainly to the stochastic nature of the phenomena, to the electrical environmental noise and to the characteristics of the electrical quantities being involved.

It is therefore difficult to obtain repeatable values for the same objects and also to have traceable measurements.

The newly established IEC 60270 Standard [1] has put requirements both on the calibration procedure and on the characteristics of the instruments, namely calibrators and measuring systems, in order to overcome these difficulties.

Calibrators have been thoroughly investigated; there are primary standards already available, for which the charge being delivered is related directly to DC voltage and capacitance, with overall uncertainties below 1% even for low charge values. Compatibility has been investigated by means of national and international round robin tests [2-5].

Experience with instruments is much less frequent [6] and therefore also the possibility to fully analyse their behaviour is more difficult. The qualification requires the availability of calibrators or pulse generators which are not common in industrial laboratories; new type of instruments which use electronic integration in the time domain are now available and this can pose new problems as far as their qualification is concerned.

According to the requirements of the above mentioned IEC Standard, periodical performance checks and performance tests of PD measuring systems should be carried out, with the aim to define and maintain the metrological requirements of the instruments.

This aspect is relatively new and while the most difficult task would be fulfilled by the manufacturer for new

instruments, it has to be established by the user for apparatus already in use.

The contribution presents the results which have been obtained for different types of instruments and it focuses on the difficulties which can be encountered in performing the tests. Digital PD instruments have not taken into consideration but the conclusions which will be presented apply in any case to their analog processing stage.

The procedure has been carried out for:

- I. Wide-band Biddle Type 66-2J.
- II. Narrow-band, Messwandler-Bau - (MWB), TEM77 option: E1.9 1981, with AKV coupling quadripole.
- III. Active integrator wide-band LDIC, type LDD-5 1999, with LDM-5/U active coupling quadripole.

The first two instruments are rather old but still in use: aim of the work was also to establish to which extent they could comply with the new requirements of the Standard.

For all instruments the following points have been examined in detail:

1. Determination of the transfer impedance $Z(f)$ and lower and upper limit frequencies f_1 and f_2 .
2. Determination of scale factor k and verification of linearity.
3. Evaluation of the pulse resolution time T_r of the measuring system.
4. Verification of the variation of the reading of the apparent charge q with pulse repetition frequency N of the calibration pulses.

In addition, for a more thorough analysis, the following items have also been included:

5. Evaluation of the polarity effect.
6. Evaluation of the integration error.

2. RESULTS OF THE TESTS

To perform a substantial part of the tests required for the qualification of the PD measuring instrument it is essential to use a calibrator having capabilities far beyond those commonly provided by commercial instruments. It has been assembled by using an arbitrary function generator (Analogic Data Precision Model 2020 or HP33120A) coupled through a low value precision capacitor to the input of the instrument. In this way it is possible to generate a sequence of current pulses having specified characteristics, in particular different amplitude, polarity and time interval between subsequent pulses.

2.1. Transfer impedance $Z(f)$ and limit frequencies

The shape of the transfer impedance $Z(f)$ has to be determined and checked at regular time intervals. It has to be pointed out that this quantity has a meaning only in relative terms because, for a fixed input current, the voltage output can vary depending on the amplifier gain which usually is neither known nor fixed.

IEC 60270 specifies the injection of a sinusoidal current of a known amplitude and the reading of the corresponding indication of the PD Meter.

In principle, the current could be obtained from a calibrator but, apart from its availability in an industrial laboratory, it is very difficult in any case to find a device with the possibility to go up in frequency into the MHz range. Such performance can be needed when testing a narrow band PD Instrument, which easily exhibits a midband frequency between 500 kHz at 2 MHz.

A practical solution is to use the same function generator having specified overall uncertainties for the voltage output (including frequency flatness) with a resistor of known value connected in series. It can be easily shown that the current needed to obtain a deflection corresponding to an ordinary charge value (tentatively 100 pC) corresponds to few tens of μA ; being the input impedance of the measuring system relatively low (usually from 50 Ω to about 1 k Ω) it is sufficient to use a resistor of some hundreds k Ω to obtain a current generator of adequate characteristics.

Typical examples of the results being obtained are reported in Fig. 1, 3 and 5 which refer respectively to instruments type I (with two different input settings resulting in different bandwidths) and type II.

A substantial point associated with this aspect is the impedance check which could be carried out, in principle, at one specific frequency: however it is obvious that the comparison with previous data might be useless if the amplifier gain drifts or it is not known. To overcome the point, an alternative approach has been implemented starting from the consideration that, in any case, when dealing with PD measurements, a charge calibrator must be available. If its current pulse is fed directly to the input, the response of the PD measuring system will in fact contain the same information. Starting from the digital record of the output pulses as shown for example in Fig. 2, 4 and 6 the straightforward FFT transform will provide the pattern of the transfer impedance under the sole condition that the input current pulse is so narrow that it resembles, for practical purposes, an ideal pulse having a white uniform spectrum.

Comparison with results obtained previously shows a very good agreement under very different conditions, which include narrow and wide band traditional systems. This kind of technique would not require additional apparatus and it would provide a calibrated input: in addition, the result would include the whole $Z(f)$ and therefore make comparison easier.

Care has to be taken in any case to avoid the saturation of the input amplifier, because it can cause an important non linearity with substantial change of the $Z(f)$ pattern.

A detailed knowledge of the internal block diagram is useful, in particular when applying the second method: in

fact, the FFT is carried out on a signal which corresponds to that driving the meter peak detector only if the output buffers behave linearly.

Extensive analysis carried out in this respect has shown that the condition is fulfilled so that the shape being derived for $Z(f)$ is independent upon the voltage output being considered.

The method can be implemented very quickly to spot possible damages intervening in the input stages or drift of the electronics components which represent the most sensitive part of a PD measuring instrument.

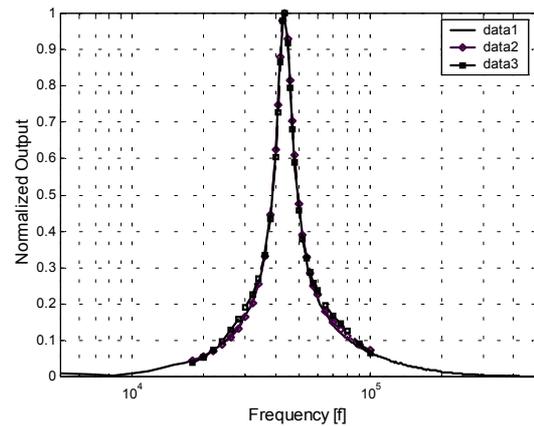


Fig. 1. Transfer Impedance $Z(f)$ for meter type I – slow response
Data1: FFT of the record of Fig. 2.
Data2: Experimental points derived from lin out.
Data3: Experimental points derived from log out.

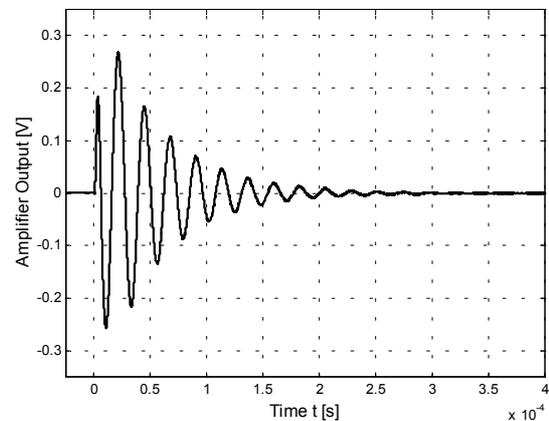


Fig. 2. Voltage output from input amplifier
Meter type I - slow response

Similar investigations have been performed on instruments type II and III. The MWB is a PD detection system of Quasi Integrator Narrow Band type with a narrow bandwidth (about 20 kHz, - 6 dB), and a midband frequency F_0 which can be tuned at 1.9 MHz \pm 10%.

Available outputs correspond respectively to the voltage signal coming from the Intermediate Frequency amplifier (I.F. about 450 kHz) and to the signal for the external recorder; this latter does not provide information on the impulse response but is simply proportional to the meter reading.

The shape of normalised $Z(f)$ obtained by the two techniques already discussed is presented in Fig. 5, while the record of the output voltage of the I.F. amplifier is given in Fig.6. There is indication of a slight saturation or non linearity for the negative part of the sine wave output, but for practical purposes the effect is not so important because only the positive value is considered in the evaluation.

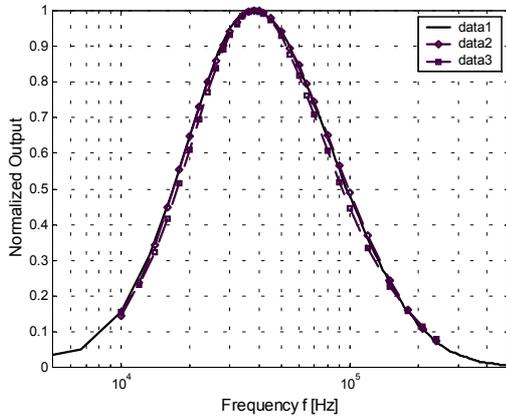


Fig. 3. Transfer Impedance $Z(f)$ for meter type I – medium response
 Data1: FFT of the record of Fig. 4.
 Data2: Experimental points derived from lin. out.
 Data3: Experimental points derived from log. out.

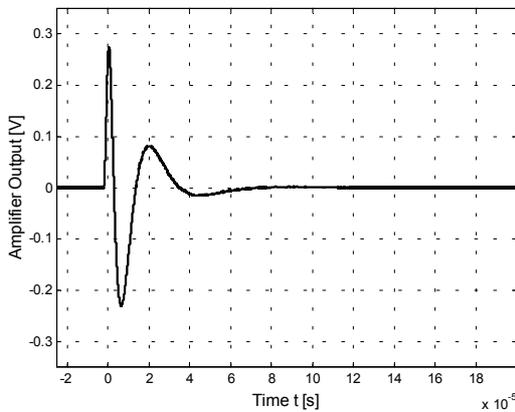


Fig. 4. Voltage output from input amplifier Meter type I - medium response

When considering the FFT transform it has to be considered that, having access only to the IF stage, the information associated to the midband frequency is lost. Therefore, to make comparison with the data obtained by the IEC procedure, it is necessary to shift the amplitude spectrum to take into account the difference.

LDIC LDD-5, on the contrary, is a wide band PD detection system based on an active integrator; the bandwidth is fixed. The general structure is quite different from that of the instruments described because there a wide band quadripole coupled to an amplifier with similar band-pass characteristics with the result that the current signal passing through is only slightly distorted; the integration is then carried out by means of an electronic circuit.

The coupling quadripole is a passive crossover filter for the separation of the PD voltage signal from AC voltage for the device under test; its frequency response is shown in Fig. 7 and together with the input amplifier it determines the actual bandwidth of the system.

There are several available signals corresponding respectively to the output of the wide band amplifier, to the signal to drive the recorder and the CHARGE output (Fig. 8) which appears to be connected to the PD meter reading.

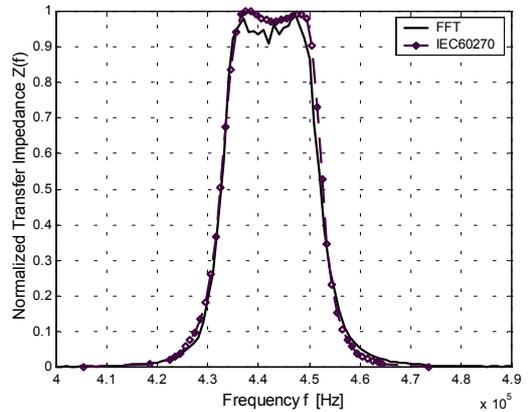


Fig. 5. Transfer Impedance $Z(f)$ for meter type II - narrow band
 FFT of the record of Fig. 6
 Experimental points according to IEC 60270

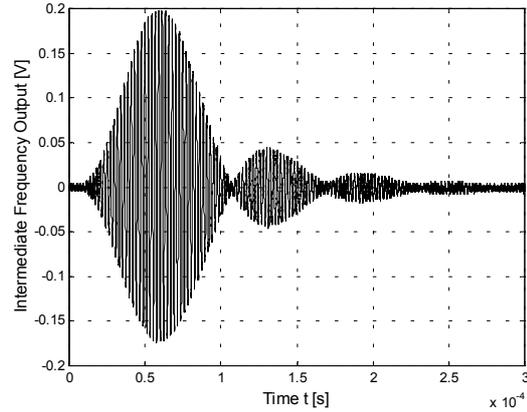


Fig. 6. Voltage output from Intermediate Frequency stage Meter type II - narrow bandwidth



Fig. 7. Frequency Response of the LDD-5 Quadripole (frequency axis grid scaled according to : 1,2,4,6,8,10).

In this case it can be easily noticed that the shape of the pulse is no longer related to the frequency response of the system but it depends only upon the time constant which has been chosen for the integrator.

Therefore, for this kind of instruments, the shape of normalized transfer impedance $Z(f)$ can be obtained only by direct injection of an AC current because the available voltage waveform does not represent a characteristic of the input stage.

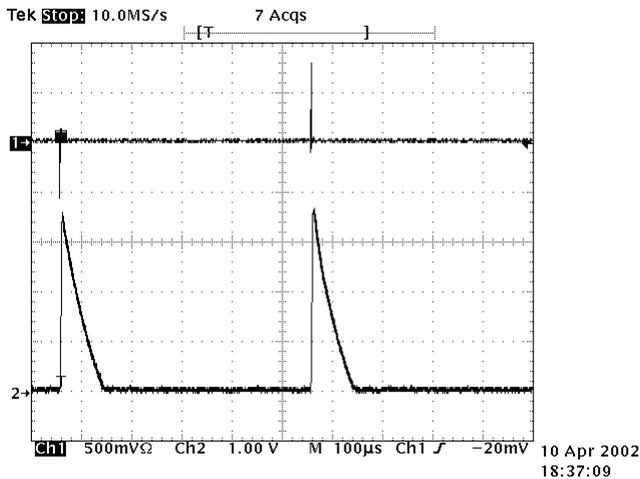


Fig. 8. Ch1: Amplifier Output
Ch2: Charge Output LDD-5,
Applied Input : bipolar impulses of equal amplitude

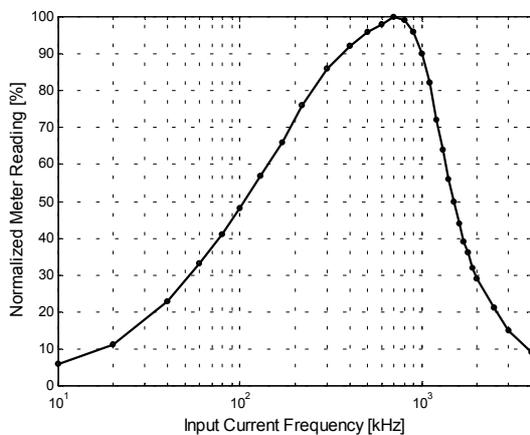


Fig. 9. Transfer Impedance $Z(f)$ for meter type III
Procedure according to IEC 60270

The result which has been obtained is shown in Fig. 9 and indicates a bandwidth of around 1.6 MHz, with a lower limit frequency around 100 kHz.

2.2. Scale factor k and linearity

According to the Standard, there are different requirements to be fulfilled in case of type or performance test. For the former the determination of the scale factor k of the measuring system shall be made at least at three different charge magnitudes ranging from 10 % to 100 % of the full scale (f.s.), at a repetition rate of about 100 Hz whereas, for the latter, the scale factor k has to be verified from 50 % of

the lowest to 200 % of the highest specified PD magnitude to be measured. Variation of factor k shall be less than $\pm 5\%$ in order to prove the linearity of the measuring system.

Maximum deviation from linearity (positive impulses - 100Hz repetition rate)		
Biddle	MWB	LDIC LDD-5
< 5 % of the calibration point	< 5 % of the f.s.	< 2 % of the f.s.

The implementation of the procedure requires only a flexible variable calibrator with a suitable number of charge steps. The results of these tests are reported in the Table. New generation equipment stay easily within permitted limits but also dated systems proved to perform satisfactorily in this respect.

2.3. Pulse Resolution Time T_r

For this test it is sufficient to generate a double step voltage with an adjustable variable time by means of the arbitrary function generator. The voltage is always coupled to the instrument with a low value precision capacitor. The pulse repetition rate was chosen equal to 100 Hz.

According to IEC 60270 it is sufficient to carry out the test only with unipolar impulses. Due to the substantial linearity of instruments based on quasi-integration method, it is possible to foresee with good accuracy the error resulting from superposition by simply adding the responses to two subsequent impulses [7] and for instrument type I and II this proved to be true. On the contrary, for instrument type III, the effect of the active integrator and possibly of auxiliary connected circuits makes this approach completely useless and the results for T_r are completely unpredictable.

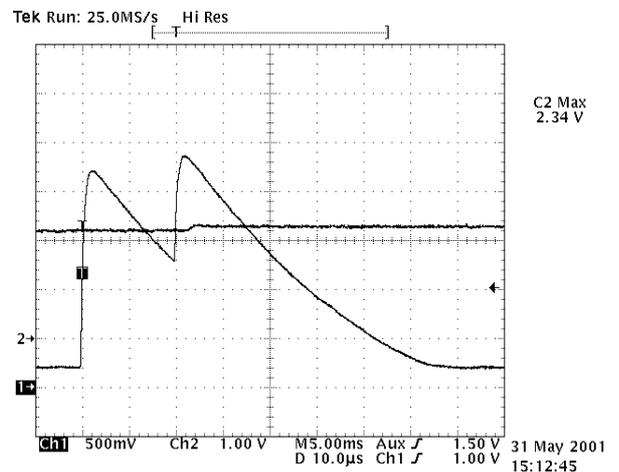


Fig. 10. Ch1: Charge Output LDD-5,
Ch2: Recorder Output LDD-5
Input LDD-5: two positive equal impulses with $T_r=20\mu s$.

As an example, Fig. 10 shows the response to a sequence of two pulses of equal amplitude and it can be seen that the second one contributes only marginally to the resulting voltage output.

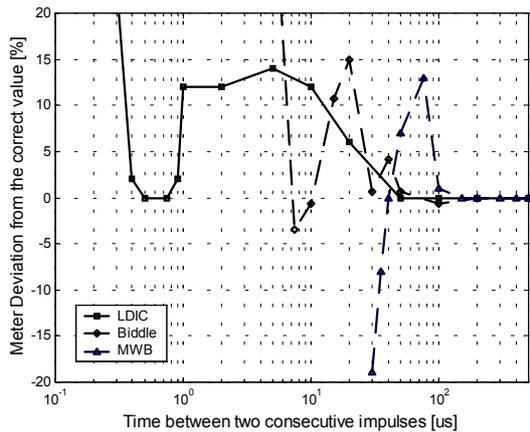


Fig. 11. Resolution Time for different instruments.

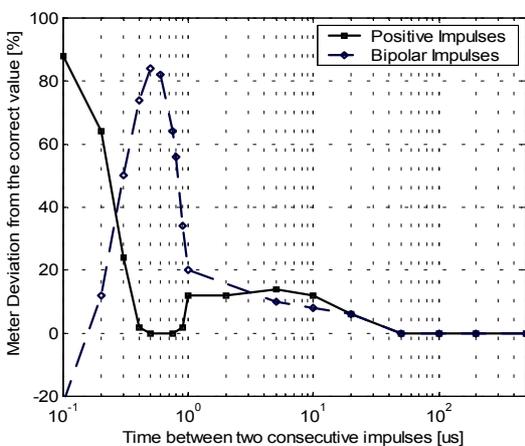


Fig. 12. Resolution Time

Results for type III instrument in case of positive and bipolar impulses

Detailed analysis for the various instruments results in the patterns presented in Fig. 11 and 12. As expected, the time resolution is in general varying inversely with the bandwidth of the measuring system. For active integrator type instrument this parameter can be very small for both unipolar and bipolar impulses.

At the lower time limit, narrow band instrument can provide indications which are misleading because the superposition of the two pulses causes a significant subtractive effect resulting in false charge indication.

2.4. Effect of the pulse repetition frequency N

To check the instrument performance in this respect it is sufficient to generate a sequence of impulses with a specified repetition frequency. The relation which has been obtained experimentally is presented in Fig. 13 for all instrument types. It has been found that in the low frequency range compliance with IEC 60270 requirements can hardly be met, although meters of recent development are certainly performing quite satisfactorily.

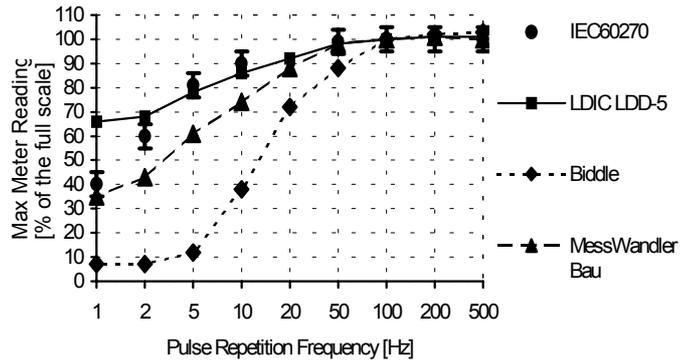


Fig. 13. Pulse train response and Pulse train response limit (●) according to IEC60270

Some care has to be taken in the evaluation of the voltage output intended to drive a recorder; an example is reported in Fig. 14. The performance of the recorder, under these conditions, will depend primarily on the mechanical features of the assembly and therefore cannot be evaluated only on the basis of the electrical signal.

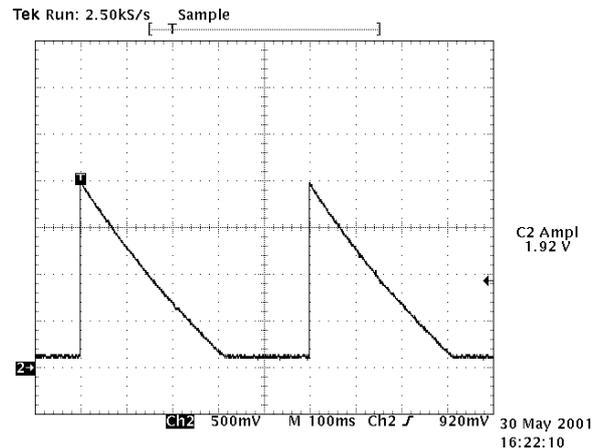


Fig. 14. Ch2: Recorder Output LDD-5, Input LDD-5: unipolar impulses with repetition rate of 2 Hz

2.5. Polarity effect

The polarity effect is not taken into consideration explicitly in the Standard, but this aspect is worth consideration due to the internal structure of the instruments which can include absolute value circuit as in case I and III, while for type II only a positive peak circuit detection is present. For this test the possibilities of the arbitrary function generator have been again exploited, by generating pulses of opposite polarities. Instrument type I proved to be particularly affected by the polarity effect, while for the other instruments the detection worked correctly.

Maximum Polarity Error for all operational condition (repetition rate: 100Hz)		
Biddle	LDIC LDD-5	MWB
< 10 % of the reading	< 2 % of the reading	< 1 % of the reading

2.6 Integration Error

This test is not included in IEC60270 standard but it might be relevant for systems having a wide bandwidth or a high midband frequency.

The integration error can arise as a consequence of the finite duration of the current pulse which results in an amplitude spectrum which is not uniform in the frequency band of the measuring system.

The effect has been investigated by varying the slope of the square wave, thus resulting in current impulses of equal charge and different time duration. This relation can be seen in Fig.15 for all instruments taken into consideration.

In any case, if the impulse duration is less than 60 ns (as required by the Standard) thus giving origin to a spectrum with constant amplitude up to several MHz the meter reading is constant, but for longer impulse duration, the error can be significant. This aspect can be controlled in the calibration phase but practical implications in the measuring circuits can hardly be evaluated, due to the lack of knowledge of the shape of the current pulses.

It appears that this factor is very important for the wide band instruments and for the narrow band instruments with a midband frequency F_0 higher than 500 kHz.

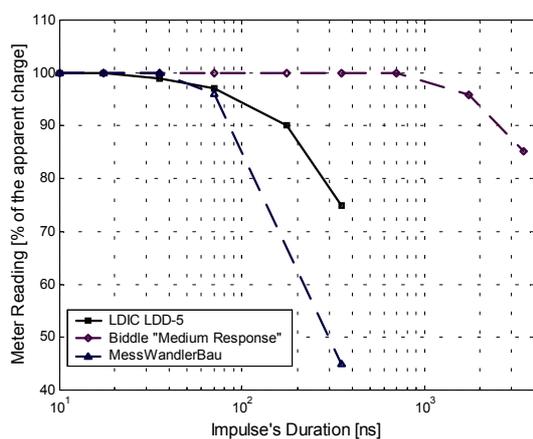


Fig. 15. Integration error for different types of instrument

3. CONCLUSIONS

The complete qualification of PD measuring systems can be performed but, in general, due to the variety of situations which can arise, it can be hardly carried out by an industrial user. In any case a programmable calibrator is needed and this piece of equipment is not readily available.

The results obtained for various types of instruments proved to be generally in compliance with the requirements of the new Standard, even when they were dating back in time.

Application of new procedures based on signal analysis could help the system identification and give reliable and repeatable results, by simply using the calibrator associated to the measuring instrument; however correct application requires a detailed knowledge of the internal diagram and a substantial equivalence of the different paths over which the PD signal is routed.

In general, measuring systems based on traditional concepts exhibit a behaviour which can be easily interpreted whereas it has been found more difficult the approach to new equipment which incorporate active electronic integrators.

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