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Time and frequency domain analysis of partial discharges using electrical method

Abstract

Partial discharge (PD) measurement results with particular consideration of time domain and frequency domain analysis of pulses generated by PD model sources are presented in the paper. Three different PD generation model sources are selected for the research: surface type, point to point and multi-point to plate. All measurements are proceeded under laboratory conditions using electrical method of a PD detection, according to the IEC60270 standard. Various amplitude and power density spectrum descriptors are proposed, as well as PD source type identification abilities on grounds of the selected descriptors are considerated. Electrical power transformers on-line PD detection and evaluation systems improvement and development are the main purpose of the presented research. Laboratory experiment results gives a solid base for further research focused on verification of the proposed methodology on a real life apparatus.

Keywords: partial discharges, electrical method, IEC 60270, frequency domain, time domain.

1. Introduction

Nowadays a PD phenomenon is a very common and negative aspect strictly related with a high voltage insulation systems degradation. A significant share of all electrical power distribution system serious faults or blackouts are recognized as indirectly or directly PD connected (Fig. 1) [1]. Any repair, overhaul, supersede or cut-off process of such primary apparatus in electrical power system as transformers or generators need to be planed and proceeded with particular consideration of costs as well as energy consumers nuisances. An early detection and recognition of any insulation faults of primary apparatus has been a priority for contemporary electrical power providers. Such an attitude to the approached problem not only allows to provide a reliable electrical power delivery but also may reduce some potentially costs related with uncontrolled failures of an infrastructure.

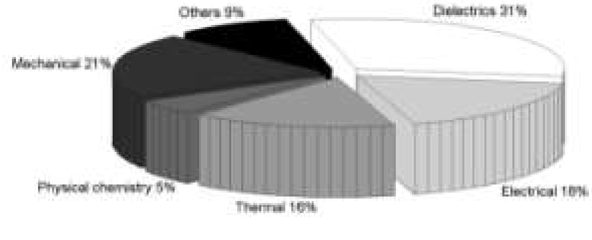


Fig. 1. Percentage share of the most common highest voltage power transformers fault causes [1]

Many different PD detection and analysis methods based on a different physical phenomena accompanying a PD are presently known and applied for apparatus diagnostics. The most commonly applied are inter alia: acoustic emission (AE) method [2-3], based on a sound wave generation during a PD activity, spectrophotometry method based on a light emission [4], thermovision method [5], based on a heat emission, dissolved gas analysis (DGA) method, based on chemical reactions results [6], electrical method, so-called a conventional method, based on an electrical capacitance changes [7-8], transient earth voltage (TEV), based on an electromagnetic radiation in high frequency range [9], and ultra-high frequency (UHF) method, based on a radio frequency radiation [10]. From among all of those techniques only an electrical method is a PD direct measurement method, which means it delivers exact information about testing phenomena, i.e. an apparent charge value [11]. All other mentioned methods, so-called unconventional, are indirect measurement techniques, so measured physical quantities are proportional for the measuring phenomena properties. Thereunder all unconventional methods application supports PD intensity and apparent charge value survey estimation only [12].

An electrical method is the only non-destructive one that has been normalized (apart from a DGA analysis) so far. A measurement methodology has been described in IEC 60270 standard. A phase resolved PD pattern (PRPD) has been widely known as an essential tool for a PD analysis provided by this method [7]. Measured apparent charge values and phase angle of the power voltage cycle correlation have been supported by the PRPD. Highest effectiveness as well as analysis capabilities of the measured phenomena are delivered by a PRPD pattern tool. A stochastic nature of a PD phenomena has been the highest challenge for all of PD measurement methods so far. Most of the physical quantities values registered during a measurement tightly depend on the PD source nature as well as on environment conditions. Any modification of the environment or the PD generation conditions radically affect the final measurement results. Thereunder in order to provide an adequate measurement results interpretation an objective comparison of achieved data with representative database need to be supported [9]. In most cases an individual, relative measurement result is not an explicit and its interpretation may differ with reference to different apparatus or environment conditions.

In addition to a PRPD pattern tool a time domain PD pulse registration has been also provided by contemporary electrical method measuring systems [8]. A frequency domain analysis including amplitude or energy information extraction may be easily applied on grounds of pulses time runs. Furthermore it is possible to apply a fast Fourier transform (FFT) or any other frequency domain analysis tool with no need of using expensive professional PD measurement systems, which require a high voltage direct access. A high frequency current transformer (e.g. Rogowski coil) and an oscilloscope can be used for a PD pulse registration instead [13].

Application capabilities of PD pulse time and frequency domain analysis for PD detection and assessment process support have been announced in the paper. Authors have proposed some PD pulse descriptors as well as a voltage level influence on descriptors values has also been indicated. A measuring methodology with detail consideration of a contemporary PD detection methods complementation has been described as well.

2. Research methodology

The presented research have been proceeded under laboratory conditions in the high voltage techniques laboratory of Electrical Power and Renewable Energy institute at the Opole University of Technology. Three following spark gap configurations for a PD source modeling of a common power transformers insulation faults have been picked for the measurements: point to point – a PD generated by a single insulation fault of two neighboring turns of windings, multi-point to plate – a PD generated between multi-point winding insulation faults and a grounded flat surface (tank, shielding), surface type – a PD generated on a boundary of a solid and liquid dielectrics (paper – oil).

A PD model source has been immersed in steel tank filed with a mineral insulation oil, commonly used for paper-oil insulation systems in contemporary electrical power transformers. A high voltage (HV) has been supplied by the test transformer with a ratio 220/110000 V/V. A HV level has been adjusted using the automatic voltage control unit, connected to the primary winding of the test transformer (Fig. 2). In the event of the surface type spark gap as well as the multi-point to plate spark gap a plate electrode has been grounded. For every selected spark gap configuration an inception voltage and a breakdown voltage (U_b) levels have been experimentally defined, for further research voltage ranges selection. Apparent charge and voltage level dependency curves have been used for the inception voltage appointments, whereas breakdown voltage levels have been defined after sequence of every spark gap breakdown tests, according to IEC60156. Measurements have been performed using the MPD600 system from Omicron. The measuring setup have consisted of a coupling capacitor MCC210 with 1 nF of capacity, a quadripole CPL542A with 30 µF of capacity (used for measuring impedance also), a MPD600 module with battery power supply and a MCU504 control unit. A MPD software equipped with a virtual oscilloscope has been used for PD pulse curves acquisition. An oscilloscope sampling frequency has been set to 64 MHz and a window width has been set to 32 µs and those have been constant during all measurements. All PD data have been acquired by a PC in order to further post-measurement analysis. In view of a noise free laboratory environment no supplementary filtering has been applied during measurements.

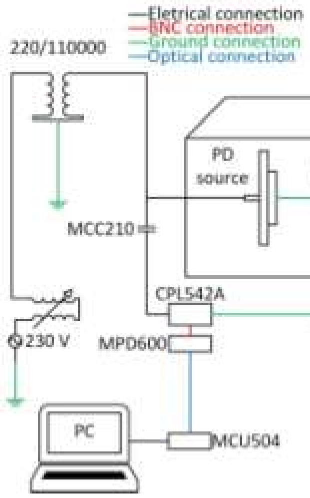


Fig. 2. Measuring set-up

70 time runs of PD pulses have been acquired for every spark gap configuration as well as for every voltage level (which is over 1200 samples total). Post-measurement gathered data analysis based on Matlab software, including approximation, statistic methods and time and time-frequency domain analysis have been applied afterwards. The fast Fourier transform (FFT) has been used for frequency domain analysis, including amplitude spectrum and power density spectrum. Further statistical analysis of the achieved spectrums has been proceeded with selected descriptors of field intensity:

a) maximum value $E_{\max}$ of the spectrum,
b) root mean square value (RMS) E_{rms} of the spectrum:

$$E_{\text{rms}} = \sqrt{\int_{f_1}^{f_2} E^2\,(f)\mathrm{d}f \,/\, \int_{f_1}^{f_2} \mathrm{d}f}, \tag{1}$$

c) peak factor

$$W_{\text{p}}\{E(f)\} = \frac{E_{\max}}{E_{\text{rms}}}, \tag{2}$$

where: $E(f)$ – amplitude spectrum or power density spectrum, $E_{\max}$ – maximum value in spectrum, E_{rms} – RMS value in the spectrum.

d) shape coefficient

$$W_{\text{S}}\{E(f)\} = \frac{E_{\text{rms}}}{E_{\text{avg}}}, \tag{3}$$

where: E_{avg} – mean value in the spectrum.

Every descriptor described above have been calculated for every registered PD pulse sample. For further analysis calculated mean descriptors values have been gathered for every selected model PD source configuration and presented as a function of voltage supply levels.

3. Results and discussion

Characteristic parameters evaluation for achieved PD time runs has been the first stage of the analysis. According to a point to point spark gap configuration a similar share of positive and negative polarization pulses has been observed, and PD pulse parameters have not depended on its polarization. PD pulse rise times and duration times have amounted about 0.2 µs and 2 µs respectively, and have been hardly related with supply voltage adjustment. Exemplary PD pulse time runs for a point to point spark gap have been presented in Figure 3.

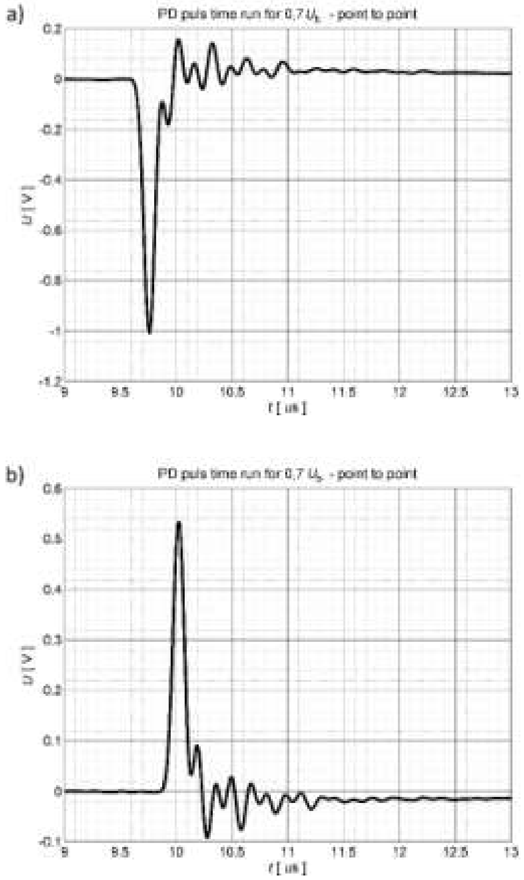


Fig. 3. Exemplary time runs of PD pulses generated by point to point source for 0.7 U_b: a) negative polarization, b) positive polarization

A high amplitude variability of captured signals has been noticed. Peak to peak PD pulse levels have varied between 0.2 V and 1 V no matter what supply voltage level has been set. Such observation seems to confirm a commonly known stochastic nature of PD generated signals. On grounds of time runs amplitude and power density spectrums have been assigned for all acquired pulse samples (Fig. 4)

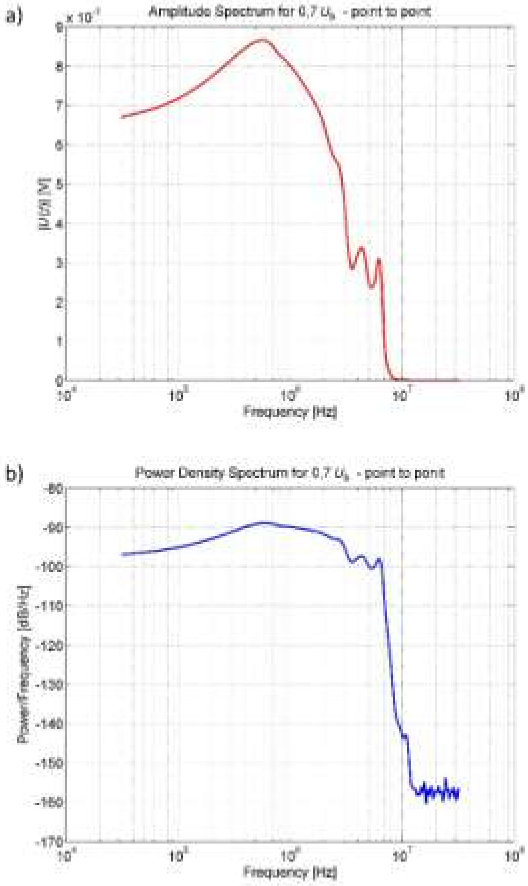
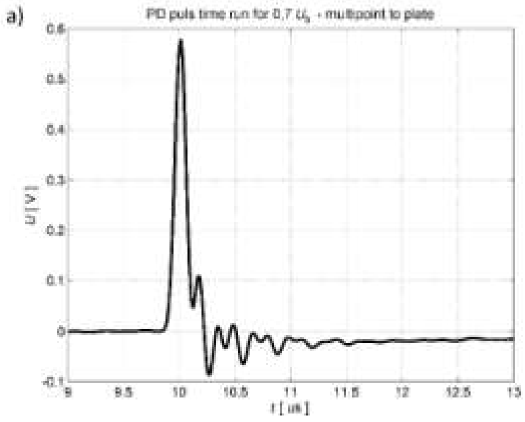


Fig. 4. Exemplary spectrums of PD pulses generated by point to point source for 0.7 U_b: a) amplitude spectrum, b) power density spectrum

Frequencies between 100 kHz and 2 MHz have been found as the most dominant. Furthermore, supplementary activity bands have been noticed at the frequencies of 4 MHz and 6 MHz.

The next research issue has been a multipoint to plate spark gap configuration measurements. PD pulse shapes as well as peak to peak amplitudes have been found similar to previous spark gap results. PD pulse rise times and duration times have amounted about 0.2 µs and 2 µs respectively, while peak to peak amplitudes have varied between 0.4 V and 2.5 V and also no supply voltage level relation has been observed. Exemplary PD pulse time runs for a multipoint to plate spark gap have been presented in Figure 5.



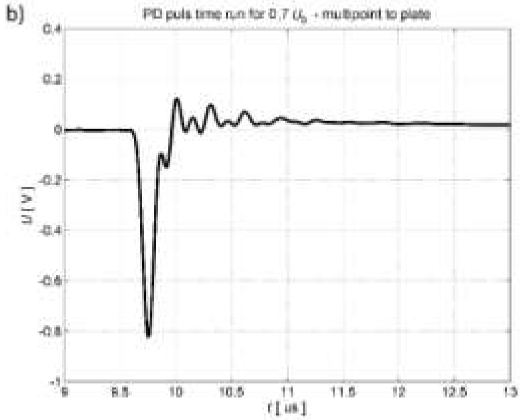


Fig. 5. Exemplary time runs of PD pulses generated by multipoint to plate source for 0.7 U_b: a) positive polarization, b) negative polarization

Figure 6 shows exemplary amplitude and power density spectrums assigned on grounds of PD pulse time runs captured for multipoint to plate spark gap configuration.

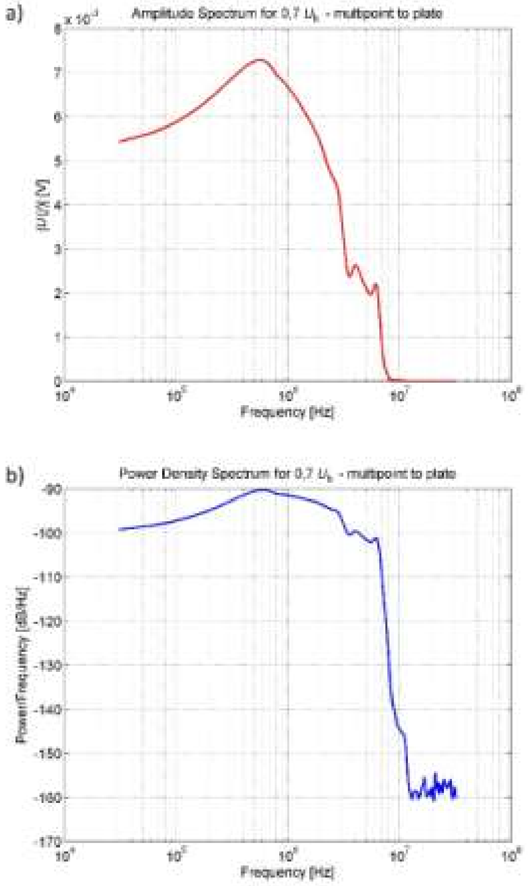


Fig. 6. Exemplary spectrums of PD pulses generated by multipoint to plate source for 0.7 U_b: a) amplitude spectrum, b) power density spectrum

Individual frequency bands energy share has been found similar to previous spark gap results. Strong domination of frequencies between 100 kHz and 2 MHz have been observed as well as noticeable increased activity for 4 MHz and 6 MHz.

The last research issue has been a study on a surface type spark gap configuration. Exemplary PD pulse time runs for surface type spark gap have been presented in Figure 7.

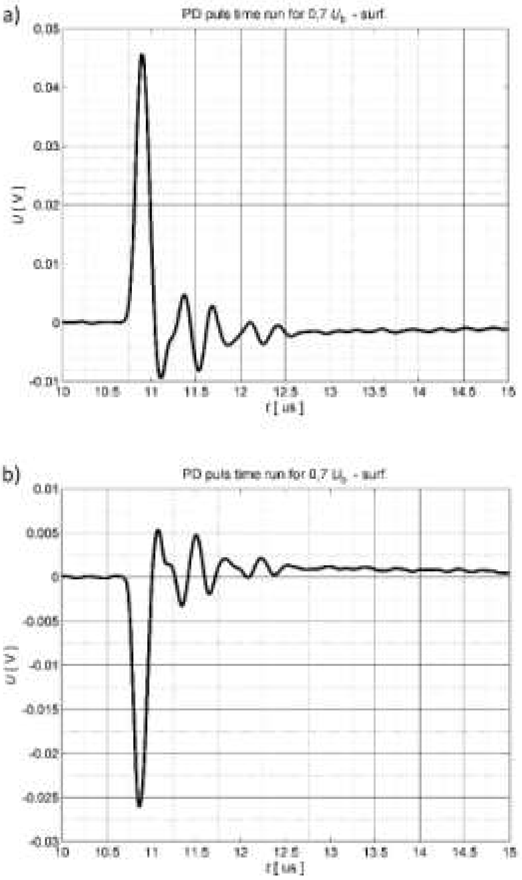
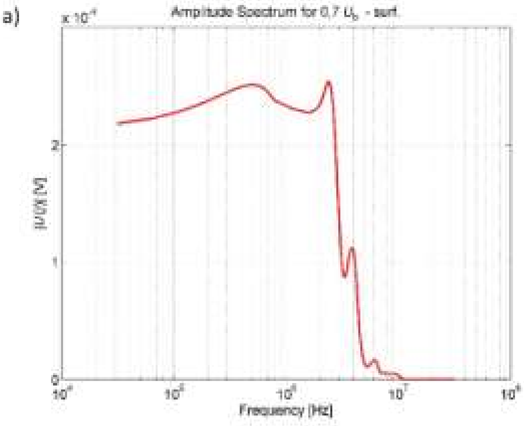


Fig. 7. Exemplary time runs of PD pulses generated by surface type source for 0.7 U_b: a) positive polarization, b) negative polarization

Acquired PD pulses time domain comparison with previous results has not showed any essential differences, however some significant signals amplitude decrease compared with point to point and multipoint to plate configurations have been observed. According to a surface type PD source maximum peak to peak amplitudes have not exceed 0.1 V for all applied supply voltage levels. PD pulse rise times and duration times have been found similar to previous results. Another significant differences might have been observed in frequency domain. Figure 8 presents amplitude and power density spectrum of PD pulses generated by surface type spark gap.



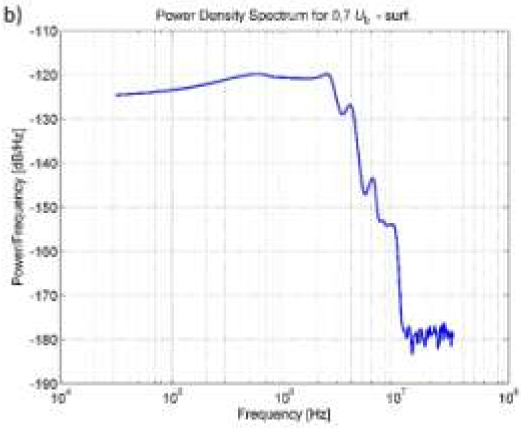
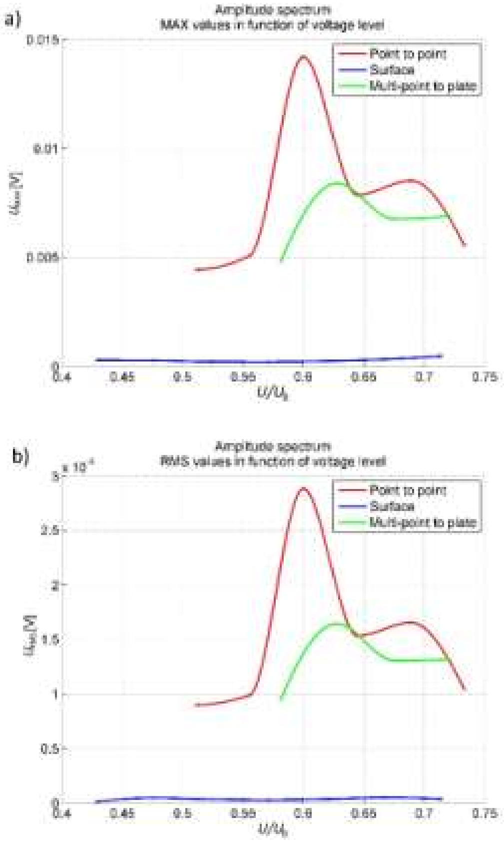


Fig. 8. Exemplary spectrums of PD pulses generated by surface type source for 0.7 U_b: a) amplitude spectrum, b) power density spectrum

A relatively flat spectrum run may be observed below 2.5 MHz, which means that energy share related with those bands is constant and similar. Furthermore, three supplementary activity bands have been noticed at the frequencies of 2.5 MHz, 4 MHz and 6 MHz, while activity rise at 2.5 MHz has not been noticed so far, according to previous results.

However, a main purpose of the proceeded research has been a spectrum descriptors analysis, assigned with statistical analysis of acquired measurement results. Four descriptors of each spectrum have been selected for further analysis: peak factor, shape coefficient, maximum value and RMS value. A final gathered comparison of the selected amplitude spectrum descriptors has been presents in Figure 9.



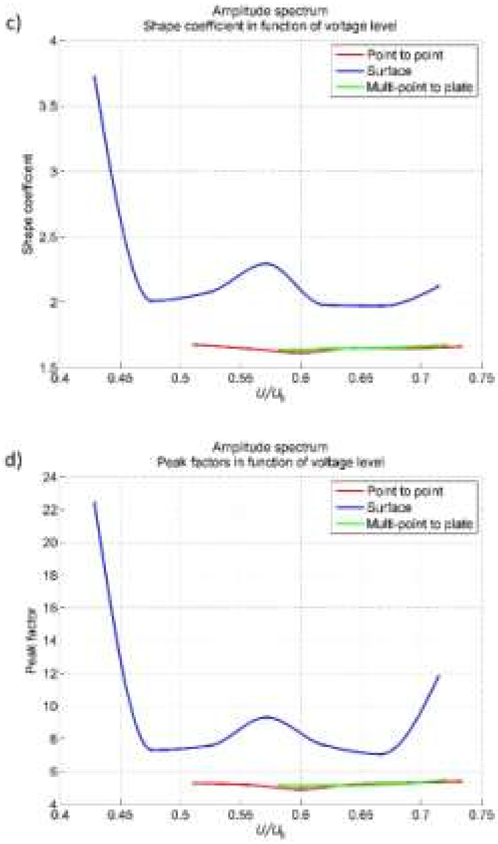
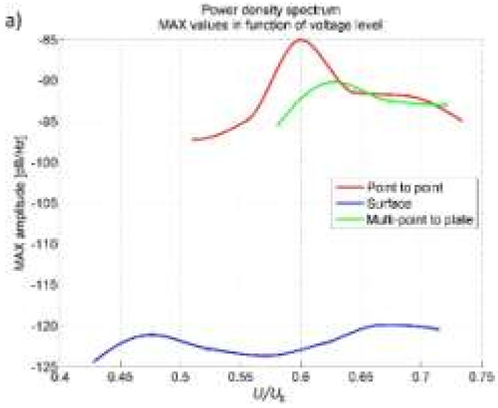


Fig. 9. General results of PD pulse amplitude spectrum descriptors analysis: a) maximum amplitude in spectrum, b) RMS in spectrum, c) shape coefficient, d) peak factor

Some significant differences in analyzed amplitudes spectrum descriptors runs have been discovered especially when surface type spark gap results have been compared with other configurations results. According to peak factor and shape coefficient results have been found generally equal either for point to point issue or multipoint to plate one. Some individual aspects have also been noticed for amplitude spectrum maximum as well as RMS values descriptors, however differences have not been found so obvious as with previous descriptors.

Similar to the amplitude spectrum descriptors analysis surface type spark gap configuration results have also proved highest individualities of power density spectrum descriptors runs (Fig. 10). Any differences of descriptors runs have been hardly observed for other spark gap configurations, mainly when supply voltage level have exceeded 0.63 U_b.



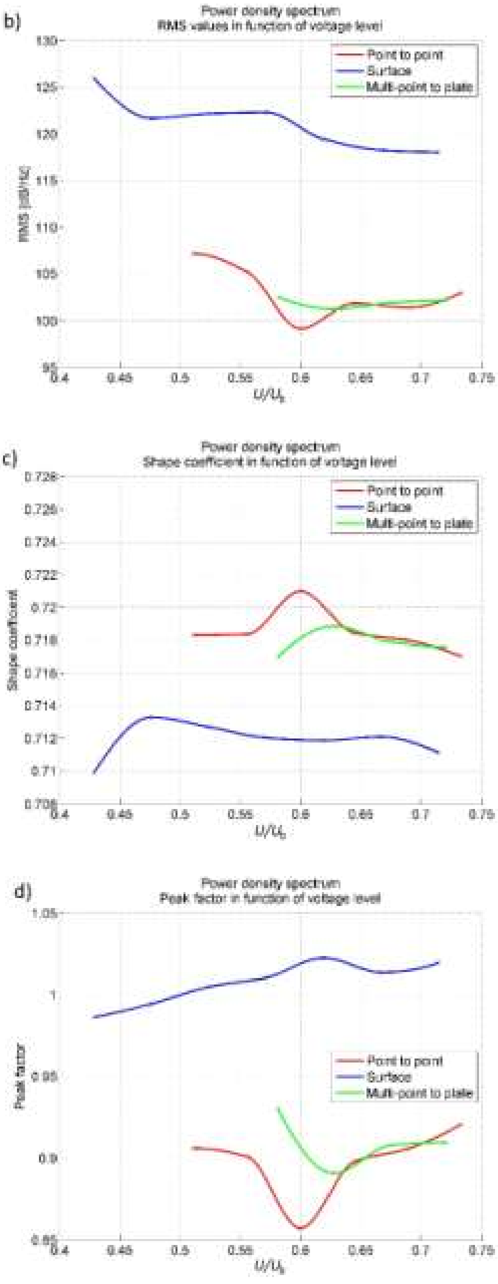


Fig. 10. General results of PD pulse power density spectrum descriptors analysis: a) maximum amplitude in spectrum, b) RMS in spectrum, c) shape coefficient, d) peak factor

It has been worth appointing that high results coherence and reproducibility have been observed according to every spark gap configuration PD pulse time and frequency analysis as well as a descriptors analysis. Relative deviations have not been exceeded 10% for every supply voltage levels and every PD model measurement series. Despite such a high reproducibility level, generally an explicit PD model source identification using proposed methodology has seemed to be not achieved, however there may be indicated some supply voltage levels that allow a PD source identification.

4. Conclusions

Nowadays PD diagnostics for sure has been found one of the crucial nexus of electrical power distribution systems. Despite there are various commonly known and widespread PD testing methods an improvement of every of them has still been a current issue, especially in the aspects of measurement results interpretation as well as a testing methodology simplifying and, above all, an on-site application during an apparatus normal service. Furthermore, advanced PD testing tools purchase costs need also to be cosiderated. Relatively easy detection and initial PD activity rate have been delivered with the proposed PD measurement methodology. Various exemplary representative measurement results have been presented as well as results analysis and interpretation patterns. As a result of the proceeded research some objective descriptors of the selected PD model sources have been assigned. Despite it has been proved that presented methodology has not allowed an explicit PD model source identification, according to above results it may be applied for the complementation of a PD detection process. Furthermore, it has been completely justified that presented methodology is an adequate indicator of a PD activity and may be freely applied for early survey PD detection process. A measurement conducting as per the previous method does not require any expensive or sophisticated testing systems as well as results interpretation may be proceeded almost directly after a measurement. As soon as a direct high voltage access is still not required the presented method seems to be a relatively safe. For example, since it has been increasingly often installed as an apparatus monitoring kit a high frequency testing transformer may be applied for a measurement conducting according to the proposed methodology.

On the grounds of the presented conclusion proposed method on-site verification as well as a noise resistance in industrial environment tests seem to be the next aim of the research that are to be proceeded by authors as a further study and development on the issue.

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