Mohammad Shukri HAPEEZ, Ngah Ramzi HAMZAH, Habibah HASHIM, Ahmad Farid ABIDIN, Mustafar Kamal HAMZAH

Universiti Teknologi MARA

An Algorithm for Identification of Different Types of Partial Discharge Using Harmonic Orders

***Abstract**. This study was conducted in order to classify and then to identify the different types of PD based on the characteristic of the harmonic orders. The data from the experimental work has been validated before the harmonic analysis can be commenced. Once the validation stage has been completed, the obtained data is then analysed in terms of its fundamental power frequency and the characteristic associated. The outcome of the analysis shows that each different type of PD produced a distinctive Total Harmonic Distortion (THD) level and distinguishable harmonics order. Based on the findings, a classification has been profiled and a conditional method system is proposed to be used to identify the PD types based on the harmonics order. The outcome of this study shows an accuracy of 98.33% of PD types can be identified from various types of data which have been tested based on the proposed condition.*

***Streszczenie**. W artykule przedstawiono wyniki badań dotyczących identyfikacji różnych typów wyładowań niezupełnych w oparciu o analizę harmonicznych. W badaniach wykorzystano wyniki prac eksperymentalnych. Opracowane wyniki wykazały różny wpływ poszczególnych rodzajów wyładowań na współczynnik THD. Na podstawie posiadanych danych możliwa była identyfikacja ponad 98% typów wyładowań. (**Zastosowanie analizy harmonicznych w algorytmie identyfikacji rodzajów wyładowań niezupełnych**).*

Keywords: partial discharge, harmonics, total harmonics distortion and identification.
Słowa kluczowe: wyładowanie niezupełne, harmoniczne, THD, identyfikacja.

Introduction

Partial discharge (PD) is defined as an electrical discharge that does not completely bridge the insulation between conductors, which may or may not occur adjacent to a conductor [1]. PD is a phenomenon that occurs when an insulation material of an electrical equipment gradually deteriorate after a long period of time [8-10]. Eventually, for a longer time, a complete breakdown will occur. PD can cause physical and chemical degradation of the adjacent insulation which could ultimately result in the failure of the entire insulation [8-9]. The energy released in a PD produces effects where chemical and structural changes occur in the materials and electromagnetic signals are emitted [17-18]. Other effect caused by PD is the disturbance in the power source which can cause failure to the electrical equipment. When the power quality is measured in such cases, the harmonic level might have increased and caused distortion in the supply voltage.

Harmonics are currents or voltages with frequencies that are multiples of the fundamental power frequency [20]. Harmonics can also be nonlinear currents or voltages that draw current not proportionally to voltage. Harmonic sources can come from power electronic devices, arcing devices, transformers and rotating machines [15]. Current harmonics might have an effect on the electrical equipment supplying the harmonic current to device such as transformers or conductors. Current harmonics can cause issues with distribution equipment from the utility transformer but generally does not affect other equipment connected to the electrical system [20]. Conversely, voltage harmonics increase when current harmonics are able to create sags in the voltage supply which can affect the sensitive parts of any equipment that are connected to electrical system [20].

In this study, hypotheses are made based on the idea that each type of PD has distinct harmonic characteristic. Harmonics content of the voltage waveforms of different PD types are further investigated and analysed for their harmonic characteristics, which then will be profiled and to be further used for classification. An identification system, constructed in a form of an algorithm using the information acquired from the harmonic classification, has been developed. This identification system is intended to be used to identify the PD types by only using characteristic of data of the harmonic orders. Analysis on the results is performed in order to unveil the constituent component and to validate the distinction that exist in each of the different types of data. The PD types that are involved in this study are corona discharge, internal discharge and surface discharge.

The significance of this study is that the information on harmonics of distinct characteristic can be used to identify the PD types. Another important contribution is that the identification algorithm that is used to identify the PD types is based on the harmonic orders obtained from the Total Harmonic Distortion (THD) analysis. This study on harmonics and PD can be associated with the investigation on equipment malfunction due to excessive voltage distortion could provide a convenient insight for solutions on harmonics problem and provide initial scrutiny on power quality issues.

Reviews

Reviews have been conducted on the latest and most recent publications, and it was found out that there was lack of analysis of harmonics caused by PD. Not much work was found which discuss the different types of PD based on the characteristic of harmonic orders. Most of the publications show that research was focused on the PD images that were distorted by harmonics [21, 23]. This particular research [21, 23] discussed on the phase-resolved partial discharge pattern and the image produce that is distorted due to harmonics. Furthermore, the harmonic research was conducted only on electrical treeing PD and this research involved insulator material to be studied.

Other research focused on current harmonics because voltage harmonics are usually low in nature and consequently ignored. Even though voltage harmonics are usually ignored, most of the problems that involve damaged equipment are caused by voltage harmonics [19]. On the other hand, most of the research conducted mostly focused on transmission line faults which are quite different from the PD phenomena in equipments. In the studies mentioned, no classification of PD has been made since only corona discharges were discussed to be detected in transmission lines [22].

Recurrences of Discharges

Recurrence of discharges can potentially influence the harmonics of the voltage waveform. The recurrence discharges occurrences in a cavity can be modelled as an air capacitance which is shunted by breakdown path [20]. When applied AC voltage reaches the cavity's breakdown voltage, a discharge occurs. After the discharge, the cavity is again recharged to the cavity's breakdown voltage.

This charging and recharging will occur repeatedly. The recurrence of discharges can be shown illustratively in Fig. 1, where the voltage applied across dielectric is *Va*, the voltage built across cavity is *Vc*, the voltage drop limit is *V*, the breakdown voltage is *U* and the time of the discharge occur is *t*.

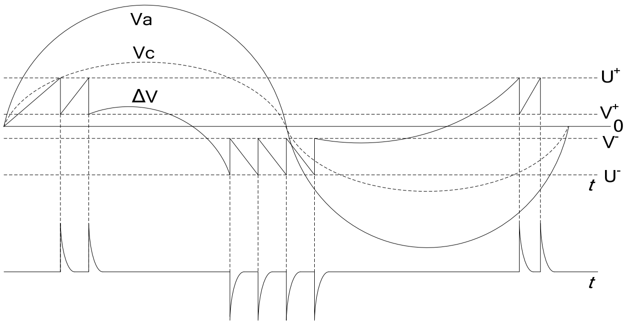

Fig.1. The recurrence of discharges in 1 AC voltage cycle

The topology of recurrence discharge can be used to describe the occurrences of the discharges that disturb the voltage output when PD occurred. The THD are potentially to be increased when the voltage output is distorted. A discharge happened in the cavity when the high voltage across *Vc* reached the voltage breakdown U^+. The voltage then drops to V^+ where the discharge abolished. The voltage drop may be expected as step function. After the discharge vanished, the voltage over the cavity increased again. When the discharges in void reach U^+, the new discharges occur. Before the new discharges occur, several times the discharges occurred when *Va* over the samples decreases and *Vc* drops to U^-. The discharges in the cavity cause impulses and it distillate in region where the voltage applied to the sample increase or decrease. With each discharge there is a charge transferred traversing the void in the cavity and denoted as transfer charge.

Associated with the discharges is discharge of energy and this is reflected in the voltage output. The fundamental power frequency might be disrupted and the harmonic constituent potentially increases. From the reappearance of discharges that occur in the voltage output because of PD, further investigation is performed on the harmonic characteristic. The outcome of the investigation is expected to discover distinctive characteristics on each harmonic profile due to the recurrence of discharges that may lead to distinguish the PD types.

Methodology

The methodology of this work is described in step by step manner for clear understanding of the implementation involved. This work is divided into several parts including apparatus arrangement and setup, experimental work procedure, validating the acquired THD data and classifying the validated THD data. Later in the subsequent section, the proposed method will be elucidated including the comparison process of the obtained results for justification purposed.

a) Apparatus Arrangement and Setup

The experimental work for this study was conducted in a high voltage laboratory using existing standards [1-6] and others well-known cited publication as references and guidelines [7-10, 12-20].

The arrangement of the apparatus for this experimental work is shown in Fig. 2. The HV transformer is connected to a PD source which is produced by a custom made apparatus. Capacitor divider is used to step down the voltage ratio before connecting the output to the oscilloscope. The initial measurement taken is the AC power supply voltage, without any PD involved. The transformer will step the voltage up to the desired voltage and measurement is taken. All types of PD were unable to withstand voltage stress exceeding than the mentioned voltage, else a complete breakdown will occur.

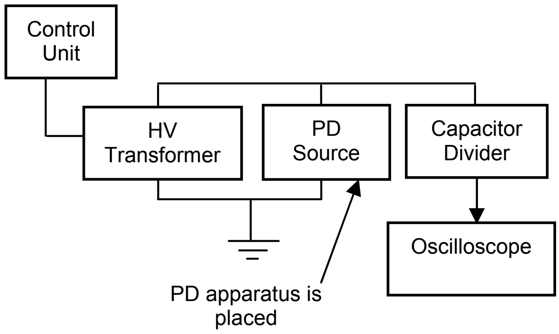

Fig.2. The apparatus setup for the experimental work. The PD source is where the different PD is generated using different apparatus.

For corona discharge, the voltage is injected up to 7 kV or until the PD is produced. As for surface and internal discharges; the voltages applied should be able to withstand the voltage stress up to 13 kV. The corona discharge was produced by using a brass needle is shown in Fig. 3. The dimension of the brass needle and the bottom electrode are illustrated in Fig. 3 (a) and (b). A brass needle at high voltage is pointed towards a grounded brass plate.

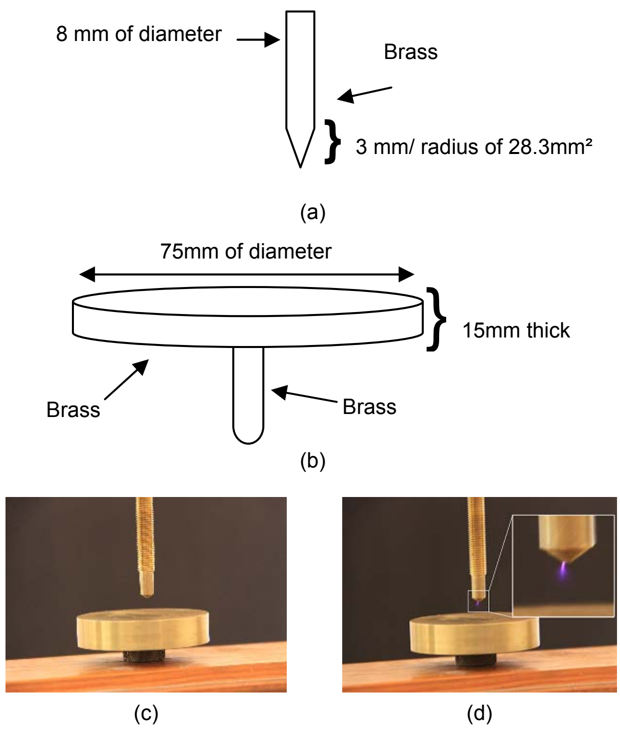

Fig.3. (a) The dimension of the brass needle prepared. (b) The dimension of the brass plate prepared. (c) The apparatus arrangement to produce corona discharge (d) The corona discharge occurrence

To produce the internal discharge, a vessel with capabilities to withstand high voltage was used as shown in Fig 4. The vessel is vacuumed at -0.4bar. In order to avoid the occurrence of corona discharge, perspex was used and placed in the middle of the electrode. The internal discharge is expected to be arcing in the vacuumed area. The dimension of the perspex, vessel and both top and bottom electrodes used are illustrated in Fig. 4 (a) and (b).

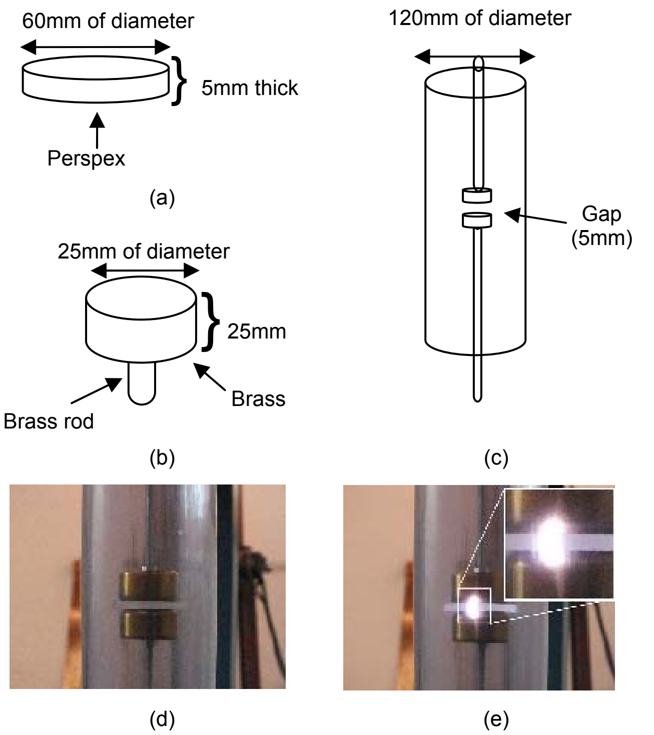

Fig.4. (a) The dimension of the perspex, (b) top and bottom electrodes of similar size and (c) the vacuum vessel (d) The apparatus arrangement to produce internal discharge (e) The internal discharge occurrence

For surface discharge, the top electrode is relatively smaller than the bottom electrode as shown in Fig. 5. The dimension of the top electrode is similar as illustrated in Fig. 4 (b) and the bottom electrode is similar as illustrated in Fig. 3 (b). Perspex is used as the insulation material that is placed in the middle of the two brass electrode. The top electrode is injected with high voltage and the bottom electrode is connected to ground. Each PD type is tested, in order to measure the recurrence voltage of the PD that affects the output voltage and subsequently produces harmonic distortion.

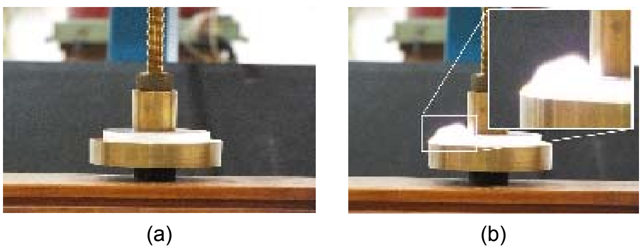

Fig.5. (a) The apparatus arrangement to produce surface discharge (b) The surface discharge occurrence

b) Experimental Procedure

The voltage output is connected to the capacitor divider before being measured using the oscilloscope, to step down the voltage ratio. The HV transformer is tested to ascertain that the voltage output and the measured voltage are similar. The measurement for the AC power supply voltage is initially taken, without any PD occurrence. The waveforms of the voltage are measured directly from the HV transformer using the capacitor divider. To produce PD, the applied voltage is increased until the PD occurs.

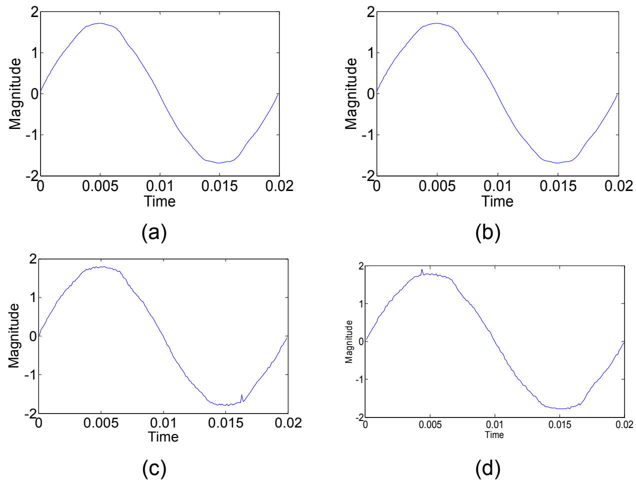

Fig.6. The voltage waveform that was measured from the HV transformer (a) Voltage waveform measured without PD. Voltage waveform measured upon the occurrence of corona discharge, (c) internal discharge and (d) surface discharge, respectively

In this work, corona discharge was able to withstand voltage up to 7 kV before complete breakdown. For surface and internal discharges, both were able to withstand the voltage stress up to 13 kV. Fig. 6 shows the obtained waveform measured from the experimental work performed.

c) THD Data Validation

Prior testing was conducted to ensure that the THD measurement were within standard limits. The HV transformer was configured to produce to a certain level of voltage. The output of the HV transformer was connected to a high voltage digital test meter. This step was taken to ensure the injected voltage is similar to the output voltage. Next, the THD level is measured from the power supply using power quality analyser. The THD level measured from the HV transformer output without PD occurrence was in the range of 1.7% to 1.8%. The THD level measured on both power supply and HV transformer outputs are similar and does not exceed the standard harmonic limit (below 5%) according to IEEE [6]. Hence, the obtained data are verified to be valid and will be used in this study.

d) Classifying the Measured Data

From the data collected, the waveform characteristics were analysed. For corona discharge, the signal waveform has ripple, mostly throughout the waveform. The corona discharge experiment was unable to be tested at the same voltage as surface and internal discharge due to its breakdown limit stress which is lower than the other two mentioned discharges. The breakdown limit for the surface discharge and internal discharge is higher than corona discharge (13 kV). The interval time of the spike occurring on the surface discharge waveform is lesser compared to the spike occurring on the internal discharge waveform. The positions of the spike appearance were also random. Therefore, it was unable to determine the variance of data obtained.

Table 1 shows the typical THD values of the various PD types. From the internal and surface discharges, it can be stated that even though the voltage level when measuring the data is similar, the THD values is different. Fig. 7 shows the comparison of the average THD values which shows that internal discharge produce less THD compared to surface and corona discharge. Even though that corona discharge was produced using lower voltage compared to internal discharge, the results show that corona discharge produces higher THD. This shows that level of harmonic distortion is dependent on the PD types. In addition, the measurement also shows that the level of applied voltage does not affect the harmonic level of the measured voltage.

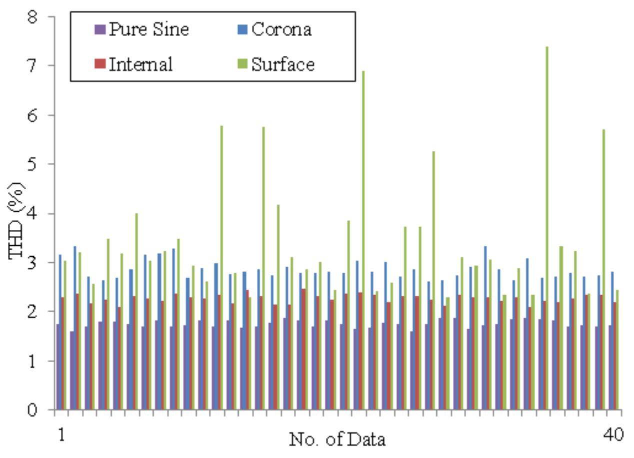

Fig.7. The forty randomly selected data of THD

After several sets of data collected from the experimental work, it can be observed that on 12th data in Fig 7, the THD values have exceed the 5% standard limit. If the average values are not taken into account, there are more than 5 datasets that produce THD values that exceed the 5% standard limit.

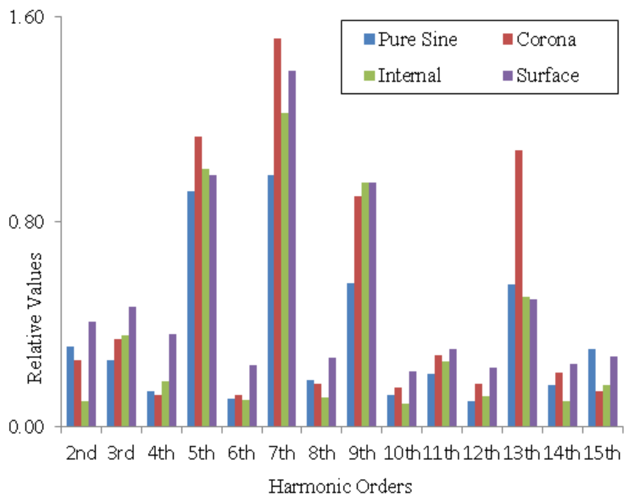

Fig.8. The average of the harmonic orders for all PD types. The figure shows the significance difference in the odd and event harmonic order between the PD types

Table 1. Randomly selected THD values on different types of PD to show the distinction in the THD values

Corona	Internal	Surface
3.15 %	2.29 %	3.04 %

Determining the pattern and classifying the level of harmonic distortion during PD occurrence can be useful in defining the THD level that is associated to the types of PD occurred.

The odd and even harmonic orders of the THD values are also taken into consideration in order to classify the characteristic of the harmonic caused by PD. From there, the harmonic order comes into play when the component of the frequency is taken into consideration. The data is extracted in order to gain information on the harmonic order. The frequency component of the THD can be translated into the harmonic order when the frequency component is presented in time-domain.

The Proposed Identification System

Based on the harmonics data obtained, the observation made has thus supported the hypotheses that the pattern of the harmonic orders varies systematically and can be used to classify the different PD types that occur. The classification method used can be based on a condition that the given data of harmonic order is caused by PD. The frequency component of the data obtained is plotted in the bar graph (Fig. 10 and 11), in which each of the bars represents the values of the harmonic order by using the fast Fourier transform.

a) Fast Fourier Transform (FFT)

FFT is a method to compute Discrete Fourier transform (DFT) fast and decompose signal to complex exponential functions of different frequencies [25] proposed by Cooley and Tukey [26]. The Fourier transform of a signal of *s(t)* can be defined by:

$$X(f)=\int_{-\infty}^{+\infty} s(t)\bullet e^{-2j\Pi ft}\,dt \quad (1)$$

where *t* and *f* are the time and frequency of the signal, respectively. *s* and *X* represents the signal in time domain and frequency domain, respectively. FFT depends on the computing of the *N*-point of DFT of a signal that can be driven into two parts, each with an *N*/2- point DFT where $N=2^r$ and r is integer as *r* = 1, 2, 3… The FFT is an effective technique to calculate transformation describes as [26]:

$$a_k=\sum_{j=0}^{n-1} x_j \exp(i2\Pi jk/n) \quad (2)$$

where, *k* = 0,1…, *n-1* and x_j and a_k are complex values. By extracting the frequency components of the signal, each fundamental frequency of the waveform can be identified.

b) Working Principle of the Algorithm in the Identification System

The 1st harmonic has been omitted since it only shows the fundamental component (working frequency of the applied voltage). The average of the odd and even harmonics order for the corona, internal and surface discharges are shown in Fig. 8. The analysis of the harmonic orders is taken up to 15th order. From the obvious differences in Fig. 8 it can be stated that the 13th order and the 7th order can be significantly useful to be used as the characteristics of the PD.

Before the classification process begin, the data have to be calculated into average values using ten sets of data. Average can be useful in consistency and reliability of data for classification purpose. The inconsistent values of the harmonic order values can cause deviation every time the data is tested. Furthermore, average is convenient in obtaining results without affecting much of the original values, if the data is randomly selected in any sequence. From the observation, internal and surface discharges have nearly similar pattern of the harmonic.

However, the similarity pattern can be distinguished by the deviance of the harmonic order values. From the observation over 100 data, the 5th, 7th and 9th harmonic's order can be used to determine the PD type, for either internal or surface discharges. For internal discharge, the average THD of the 7th order is 20% to 25% higher than those of 5th and 9th order. The 5th and 9th order have almost similar values. The 13th order is lower than the 9th order. For surface discharge, the 6th order is lower than the 4th order and the 4th order is lower than the 2nd order. The 5th and 9th order have almost similar values and the 13th order is lower than the 9th order.

The range values for certain harmonic order was also obtained. Certain harmonic order values are within particular range of values for each types of the PD. This has been taken in consideration to be as one of the characteristic of the PD types. Based on the range of harmonic order values, postulation can be made for the threshold range of the PD characteristic conditions.

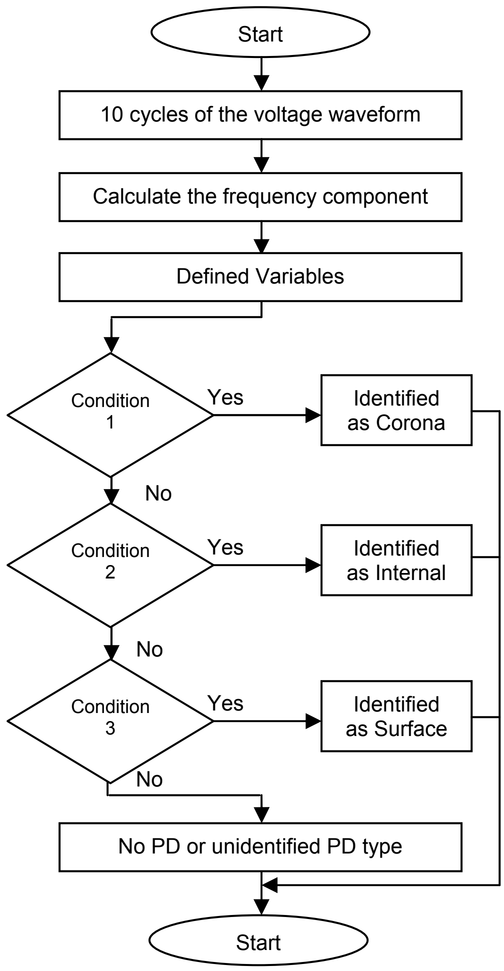

Fig.9. The flowchart diagram for the new proposed algorithm of conditional method system.

For corona discharge, the average of the 13th order is slightly higher the values of 9th order. The 5th order is 10% or slightly higher values than the 9th order. Based on this information, the identification system in algorithm form was developed to identify the PD types based on the harmonics order. The purpose of this algorithm is to simplify the identification method given that the harmonics order data are caused by PD. The flowchart of the identification system is shown in Fig. 9 and the algorithm is described in step by step as follows:

Step 1) Obtain at least 10 cycles of the waveform data

Step 2) Obtain the frequency components which represent each of the harmonic order components of certain frequency.

Step 3) Omit the 1st harmonic order and obtain the values for the 2nd to 15th harmonic orders.

Step 4) Define the variable for each harmonic order to ease the conditional methods and avoid confusion.
The variables are a = 2nd order; b = 3rd order; c = 4th order; d = 5th order; e = 6th order; f = 7th order; g = 8th order; h = 9th order; i = 10th order; j = 11th order; k = 12th order; l = 13th order; m = 14th order; n = 15th order; p = average of d and h;

Step 5) **Condition 1:**

f is within the range of 15% to 20% > p;
if l > g or l > p;
and if l > n and f > j;
identified as "Corona";
else go to Condition 2;

Condition 2:

if l < d and l < f and l < h;
f is within the range of 19% to 25% > p;
if f > p and l < p;
identified as "Internal";
else go to Condition 3;

Condition 3:

if a > c > e;
identified as "Surface";
else go to Case4;

Condition 4:

If no match go to Condition 1 or;
Declared as "Unidentified";

Step 6) If Condition 1 is fulfilled, then the data is identified as Corona. If Condition 2 is fulfilled, then the data is identified as Internal. If Condition 3 is fulfilled, then the data is identified as Surface. If none of the conditions are matched, the data is reprocessed or will be declared as no match.

c) Comparison Process

In order to prove and justify that the proposed method algorithm is superior and confirmed to be the most reliable identification method for this results validation, an alternative Goertzel algorithm has been used to replace the FFT. Goertzel algorithm is a method used to identify the frequency component of an indication taken over a short time section of a signal at a given frequency [24]. It is said to be faster than that FFT for a single frequency calculation [24]. The Goertzel algorithm using the z-domain transfer functions of:

$$H(z) = \frac{1 - e^{-j\left(\frac{2xk}{N}\right)} z^{-1}}{1 - 2\cos\left(\frac{2\pi k}{N}\right) z^{-1} + z^{-2}} \qquad (3)$$

where the description of the *N*-point of Fourier transform. The frequency resolution of the *N*-point is defined by (f_s/N) and it is implemented as

$$X(k) = \sum_{n=0}^{N-1} x(n)\, e^{-j\left(\frac{2\pi}{N}\right) nk} \qquad (4)$$

where *x[n]* is the current input of the signal, *k* is the index for a discrete frequency and *N* is the number of input signal. The result *X[k]* has a real value and imaginary value. With these both real and imaginary values, the amplitude and the phase of the frequency for each of the PD types can be acquired.

Results

Fig. 10 shows the randomly selected data from the harmonics order (obtained from the experimental works) on all PD types that will be used to test the proposed algorithm. The data is named in sequence and each of the data indicated their relative values for each of the harmonics order. The remark column in the table indicates the original data of which PD the data was selected from. The FFT and Goertzel column indicate the matched results either the randomly selected data can be identified or unidentified using the proposed algorithm. The PD type indicates that which types of PD data is identified; A is for corona discharge, B is for internal discharge and C is for surface discharge. To evaluate the performance of the new method, the system is executed and the results obtained are tabulated in Table 2.

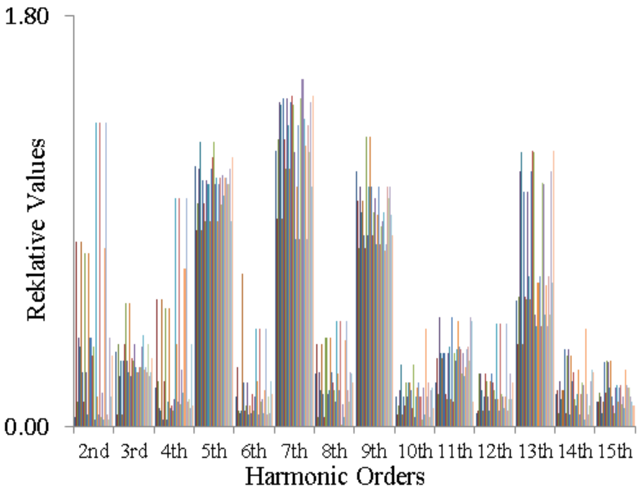

Fig.10. The first set of the randomly selected data which comprises 30 data from all PD types

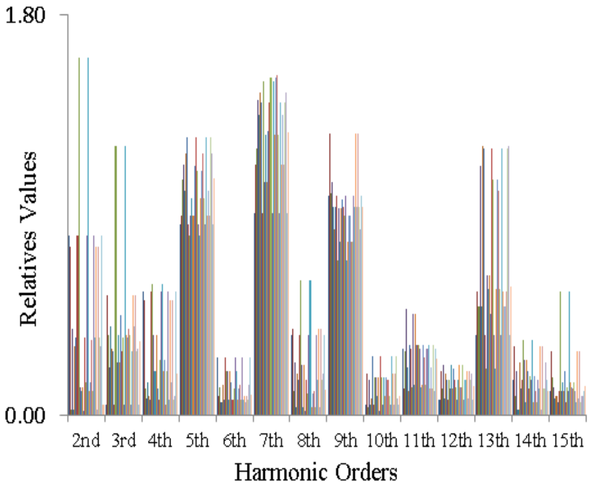

Fig.11. The second set of the randomly selected data which comprises 30 data from all PD types

To prove the result is trustworthy, the Goertzel algorithm is taken into test. The outcome shows a similar identification results with the FFT performance. In Table 2, the Data 6 that was unsuccessfully identified can be considered as an outlier. In order to ascertain the reliability of the proposed techniques, another test was carry out with another new randomly selected sets. Fig. 11 shows another randomly selected set of data, also obtained from the experimental works performed. Table 3, shows the results with total match of all the data can be identified.

Table 2. The first identifying results using the conditional method system from randomly selected data

No	Data	PD Types			FFT	Goertzel	Remark
		A	B	C			
1.	Data 1	0	1		Identified	Identified	Internal
2.	Data 2	0	0	1	Identified	Identified	Surface
3.	Data 3	0	1		Identified	Identified	Internal
4.	Data 4	1			Identified	Identified	Corona
5.	Data 5	1			Identified	Identified	Corona
6.	Data 6	0	0	0	0	0	Surface
7.	Data 7	1			Identified	Identified	Corona
8.	Data 8	0	1		Identified	Identified	Internal
9.	Data 9	0	0	1	Identified	Identified	Surface
10.	Data 10	1			Identified	Identified	Corona
11.	Data 11	0	1		Identified	Identified	Internal
12.	Data 12	0	0	1	Identified	Identified	Surface
13.	Data 13	1			Identified	Identified	Corona
14.	Data 14	1			Identified	Identified	Corona
15.	Data 15	1			Identified	Identified	Corona
16.	Data 16	0	1		Identified	Identified	Internal
17.	Data 17	0	0	1	Identified	Identified	Surface
18.	Data 18	0	1		Identified	Identified	Internal
19.	Data 19	0	1		Identified	Identified	Internal
20.	Data 20	0	0	1	Identified	Identified	Surface
21.	Data 21	1			Identified	Identified	Corona
22.	Data 22	1			Identified	Identified	Corona
23.	Data 23	0	1		Identified	Identified	Internal
24.	Data 24	0	0	1	Identified	Identified	Surface
25.	Data 25	0	0	1	Identified	Identified	Surface
26.	Data 26	0	1		Identified	Identified	Internal
27.	Data 27	0	1		Identified	Identified	Internal
28.	Data 28	1			Identified	Identified	Corona
29.	Data 29	0	0	1	Identified	Identified	Internal
30.	Data 30	1			Identified	Identified	Corona

The results were also tested with the Goertzel algorithm to prove the results were proven trustworthy. From the presented results in Table 2 and 3, it can be observed that in total of twenty-nine from thirty randomly selected data were successfully identified using the conditional method system.

Table 2. The second identifying results using the conditional method system from randomly selected data

No	Data	PD Types			FFT	Goertzel	Remark
		A	B	C			
1.	Data 1	0	1		Identified	Identified	Surface
2.	Data 2	0	0	1	Identified	Identified	Surface
3.	Data 3	0	1		Identified	Identified	Internal
4.	Data 4	1			Identified	Identified	Corona
5.	Data 5	0	1		Identified	Identified	Internal
6.	Data 6	1			Identified	Identified	Corona
7.	Data 7	1			Identified	Identified	Corona
8.	Data 8	0	0	1	Identified	Identified	Surface
9.	Data 9	0	0	1	Identified	Identified	Surface
10.	Data 10	0	1		Identified	Identified	Internal
11.	Data 11	0	1		Identified	Identified	Internal
12.	Data 12	0	1		Identified	Identified	Internal

13.	Data 13	0	1		Identified	Identified	Internal
14.	Data 14	1			Identified	Identified	Corona
15.	Data 15	1			Identified	Identified	Corona
16.	Data 16	0	0	1	Identified	Identified	Surface
17.	Data 17	0	0	1	Identified	Identified	Surface
18.	Data 18	0	1		Identified	Identified	Internal
19.	Data 19	1			Identified	Identified	Corona
20.	Data 20	1			Identified	Identified	Corona
21.	Data 21	0	1		Identified	Identified	Internal
22.	Data 22	0	0	1	Identified	Identified	Surface
23.	Data 23	1			Identified	Identified	Corona
24.	Data 24	0	0	1	Identified	Identified	Surface
25.	Data 25	0	1		Identified	Identified	Internal
26.	Data 26	0	0	1	Identified	Identified	Surface
27.	Data 27	1			Identified	Identified	Corona
28.	Data 28	1			Identified	Identified	Corona
29.	Data 29	0	0	1	Identified	Identified	Surface
30.	Data 30	0	1		Identified	Identified	Internal

Conclusions

This study investigated the harmonics present while PD occurs and the distinction of harmonic orders characteristic that can be used to classify different types of PD. The results of the THD values and harmonics order from 3rd to 15th order are presented. The new identification method is also presented and explained. This research work shows that the harmonics occurrence caused by PD has particular characteristic and can provide insight about the PD types. The characteristic of the harmonic order is distinct for every type of PD. The distinction of this harmonic order can be used to classify the PD types; given that the harmonic distortion occurred is due to PD. The study conducted shows that a total of 98.33% success rate of PD type identification from the randomly selected harmonic data shown in both Table 2 and 3. The proposed algorithm limitation at the moment is that the algorithm is only tested on three different types of PD. Some parameters may be required to be reconfigured in order for the algorithm to be adapted to certain conditions. The limitation in the algorithm can be expected to be improved in future works. At the moment, from the presented work, it can be proved that the stated hypothesis has been proven and the proposed algorithm is reliable.

Acknowledgement

Support from Universiti Teknologi MARA, Kementerian Pengajian Tinggi (KPT) Malaysia for MyBrain15-MyPHD Scholarship and ERGS Grant (600-RMI/ERGS 5/3 (20/2012)) are gratefully acknowledged and appreciated for the implementation of this project.

REFERENCES

[1] IEEE Standard, the IEEE Standard Dictionary of Electrical and Electronics Terms, *IEEE Std*. 100, Sixth Ed., IEEE, Inc., 1996

[2] IEEE Recommended Practice for the Detection Of Partial Discharge And The Measurement Of Apparent Charge In Dry-Type Transformers*, IEEE Std*., C56.124, 1992

[3] IEEE Trial-Use Guide for the Detection of Acoustic Emissions from Partial Discharges In Oil-Immersed Power Transformer – *Transformer Committee of The IEEE Power Engineering Society* – Approved: 21 Sept. 2000 – IEEE Standards Board

[4] IEC 60270:2000 Standard, *High Voltage Test Technique – Partial Discharge Measurement*, 3rd Edition, 2000

[5] *ASTM D3756-97* Standard Test Method For Evaluation To Resistance For Electrical Breakdown By Treeing In Solid Dielectric Materials Using Diverging Fields, 2010

[6] IEEE Recommended Practices and Requirements for Harmonic Control In Electr.Power Systems *IEEE Std*. 519-1992

[7] Xin Liu, Partial Discharge Detection and Analysis in Low Pressure Environments, PhD Thesis, *Ohio State University*, 2006

[8] Conti. M, Development Of Artificial Intelligence Systems For Electrical Insulation Defect Identification Through Partial Discharge Measurement, PhD Thesis, *University of Bologna, Italy*, 2003

[9] Li-Jung Chen, Whei-Min Lin, Ta-Peng Tsao, Yu-Hsun Lin, Study Of Partial Discharge Measurement In Power Equipment Using Acoustic Technique And Wavelet Transform, *IEEE Trans. Power Delivery*, Vol. 22, No. 3, July 2007

[10] Li-Jung Chen, Ta-Peng Tsao, Yu-Hsun Lin, New Diagnosis Approach To Epoxy Resin Transformer Partial Discharge Using Acoustic Technology*, IEEE Trans. Power Delivery*, Vol. 20, No. 4, October 2005

[11] Peek, F.W., Voltage And Current Harmonics Caused By Corona, Trans. *American Institute Of Electrical Engineering*, Vol. 70, No. 2, 1921

[12] Si, W.R., Li, J.H., Li, D.J., Yang, Y.G., Li, Y.M, Investigation Of A Comprehensive Identification Method Used In Acoustic Detection System For Gis, *IEEE Trans. Dielectrics And Electrical Insulation*, Vol. 17, No. 3, June 2010

[13] Sacha M. Markalous, Stefan Tenbohlen, Kurt Feser, Detection And Location Of Partial Discharge In Power Transformers Using Acoustic And Electromagnetic Signals, *IEEE Trans. Dielectrics And Electrical Insulation*, Vol. 15, No. 6, 2008

[14] Lai, K.X., Phung, B.T., Blackburn, T.R, Application Of Data Mining On Partial Discharge, Part I: Predictive Modelling Classification*, IEEE Trans. Dielectrics And Electrical Insulation*, Vol. 17, No. 3, June 2010

[15] Victoria M. Catterson, Sanjay Bahadoorsingh, Susan Rudd, Stephen D.J. Mcarthur, Simon M. Rowland, Identifying Harmonic Attributes From Online Partial Discharge Data, *IEEE Trans. Power Delivery*, Vol. 26, No. 3, July 2011

[16] Boczar, T., Borucki, S., Cichon, A., Zmarzly, D., Application Possibilities Of Artificial Neural Networks For Recognizing Partial Discharges Measured By The Acoustic Emission Method, *IEEE Trans. Dielectrics and Electrical Insulation*, Vol. 16, No. 1, February 2009

[17] Pinpart, T., Judd, M.D., Differencing Between Partial Discharge Sources Using Envelope Comparison Of Uhf Signals*, IET Science Meas. & Technology*, Vol. 4, No. 5, 2010

[18] Kreuger, F.H, Partial Discharge Detection In High-Voltage Equipment, *Butterworth & Co. Publishers Ltd*, 1989

[19] Anar M., Partial Discharge In Electronics Equipment, Phd Thesis, *Brno University Of Technology*, 2009

[20] Hearn, S.D, Basic Understanding Of Harmonics In Electrical Systems", *Hearn Engineering Tech. Report*, 2010

[21] Florkowski, M, Distortion of Partial Discharge Images Caused By High-Voltage Harmonics, *IEE Proc.-Gener. Transm. Distrib*. Vol. 153, No.2, March 2006

[22] Yangchun Cheng, Chengrong Li, Xingquan Huang: Study Of Corona Discharge Pattern On High Voltage Transmission Lines For Inspecting Faulty Porcelain Insulators*, IEEE Trans. Power Delivery*, Vol. 23, No. 2, April 2008

[23] Florkowski, M., Florkowska, B, Wavelet-Based Partial Discharge Image Denoising, *IET Gener. Trans. Distrib*., 2007, Pp 340-347

[24] Jae-Hyung Kim, Jun-Gu Kim, Young-Hyok Ji, Yong-Chae Jung, Chung-Yuen Won, An Islanding Detection Method For A Grid-Connected System Based On The Goertzel Algorithm, *IEEE Trans. On Power Elects*., Vol. 26, No. 4, April 2011

[25] Brigham, E.O., Morrow, R.E., The Fast Fourier Transform, *IEEE Spectrum*, Dec. 1967

[26] Cooley, J.W., Tukey, J.W., An Algorithm For The Machine Calculation Of Complex Fourier Series*, Math. Comp*., Vol. 19, Pp, 297-301, April 1965

***Authors**: Mohammad Shukri Hapeez, Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450, Shah Alam, Malaysia, E-mail: shukri@ieee.org; assoc. prof. dr. Ngah Ramzi Hamzah, Deputy Rector of Bertam Campus of Universiti Teknologi MARA, E-mail: ngahramzi@yahoo.com.sg; assoc. prof. dr. Habibah Hashim, Deputy Dean of Research and Industrial Linkage in Faculty of Electrical Engineering, Universiti Teknologi MARA, Shah Alam, Malaysia, E-mail: ibahhashim@gmail.com; dr. Ahmad Farid Bin Abidin, Head of Power Department, Faculty of Electrical Engineering, Universiti Teknologi MARA, 40450, Shah Alam, Malaysia, E-mail: ahmadfarid@hotmail.com; Assoc. prof. Mustafar Kamal Hamzah, Vice-Chair of IEEE Malaysia Section, Chair of IEEE Malaysia PEL/IE/IA Joint Chapter, E-mail: mustafar@ieee.org*