

A Literature Review of methods used for Partial Discharge Type Detection and its Improvised Techniques

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ABSTRACT: Partial discharge (PD) detection, measurement and classification constitute an important tool for quality assessment of insulation systems utilized in HV power apparatus and cables. The patterns obtained with PD detectors contain characteristic features of the source/class of the respective partial discharge process involved. The recognition of the source from the data represents the classification stage. Usually, this stage consists of a two-step procedure, i.e., extraction of feature vector from the data followed by classification/ recognition of the corresponding source. The various techniques available for achieving the foregoing task are examined and analyzed; while limited success has been achieved in the identification of simple PD sources, recognition and classification of complex PD patterns associated with practical insulating systems continue to pose appreciable difficulty.

KEYWORDS: Partial discharge, PD pulse, PD detector, pattern classification.

I. INTRODUCTION

I. I. MEANING OF PARTIAL DISCHARGE (PD):

Partial Discharge is a very common phenomenon occurring in electrical engineering insulation systems under high voltage (HV) stress. It is caused due to localized dielectric breakdown bridging the gap between the conductor and insulation when the electrical field around is higher than the breakdown field of an insulating medium. PD is the fundamental reason for the ageing of electrical insulation and breakdown of electrical-mechanical assembly functioning at high voltage. This can even lead to a complete failure of the supply system as a whole. Hence, it cannot be ignored. Partial discharge can be prevented starting with suitable material selection and a thorough design. It is recommended that all the equipments are tested in the manufacturing stage itself. It is mandatory to have periodical checkups of the high voltage equipments to avoid long term failures for reliable operation. Thorough monitoring of Bushes is also very important in case of large power transformers as problems in bushing can easily pass undetected and occur unexpectedly.

Partial discharges can be of different gravities. Some discharges are relatively harmless like the corona into the air from outdoor cable setting ends. Whereas some discharges are extremely dangerous causing a great deal of damage to the health of the insulation system like the discharges within polymeric cables and accessories. During testing, a professional engineer determines the exact type of discharge and its origin so as to notify the potential risks involved. Various methods have been developed for detection of partial discharge in order to prevent complete system failure and have been fully acknowledged early in the last century. PD sensors can be used at places suggested during testing to get the relevant data for any high voltage equipment, which can then be verified for type of discharge or classification of discharge type.

Two vital conditions cause partial discharge between conductor and insulation as well as in insulation:

1. Presence of an initial electron to initiate an avalanche.
2. When the on line electrical field is higher than the original ionization field of the insulating medium.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 8, Issue 8, August 2019

Thus, PDs are mainly concerned with dielectric materials utilized and connecting electrodes between which the voltage is applied. The insulation may comprise of solid, liquid, or gaseous materials, or any blend of them. Various wellsprings of PD give diverse impact on insulation performance. The occurrence of sparks, flashes, arcs and electrical discharges are certain indications of existence of insulation problems. Subsequently, PD classification aims at the recognition of discharges of obscure origin and is significant to assess the level of the caused destruction.

II. CLASSIFICATION OF PD TYPES

Initially, the PD classification was done by examining its patterns by naked eyes using the well known ellipse, on an oscilloscope screen. However, it has been proved to be a crude method by latest research. In current scenario, the published research distinguishes the types of PD sources by using intelligent techniques like artificial neural networks, fuzzy logic, and acoustic emission. With these sophisticated digital processing techniques, we gain exclusively new insight into the physical and chemical properties of PD phenomena and can characterize PD 'patterns' as:

1. Void indicated by a peak point,
2. Surface being all over the surface and
3. Corona being crown shaped.

These patterns in return enable the identification of the characteristics of the insulation 'defects' created by the PDs. Hence, this research enables to characterize the type of PD, though varying in its gravity, so as to remove particular insulation defects and avoid total supply failure.

The three distinct classifications of PD pulse data patterns gathered from the digital PD detectors during the experiments are -- phase-resolved data, time-resolved data and data having neither phase nor time information.

1. The phase-resolved data consists of three-dimensional discharge epoch, ϕ charge transfer, q discharge rate, n patterns ($\phi\sim q$, $q\sim n$ and $\phi\sim n$ patterns) at some specific test voltage.
2. The time-resolved data constitute the individual discharge pulse magnitudes over some interval of time, i.e., $q\sim t$ data pattern.
3. The third classification of information comprises of variations in discharge pulse magnitudes against the amplitude of the test voltage V (for both increasing and decreasing levels), i.e., $q\sim V$ data.

Out of these three classifications, phase resolved data method is used in this research work for all methods since it is drawing 2D patterns from raw data showing variations between either phase angle and charge, phase angle and number of pulses or number of pulses and charge and then comparison of these patterns amongst themselves will result in improved accuracy of the outputs.

At present, in any industry, just the source of PD is notified by using a buzzer. However, the buzzer indicates only the place of its occurrence and not the type of discharge, which is very essential for removal of insulation defects. The various techniques suggested in this research enable to know the type of the PD accurately so that the insulation defects can be removed from any high voltage equipment by specific techniques to avoid chances of supply failure.

III. CURRENT METHODS USED FOR DETECTION OF TYPE OF PD

Currently, the type of discharge is identified by Signal processing tools, Wavelet transform, Image processing tools or Distance classifiers and many more. The drawbacks of these methods are –

1. **Signal processing tool** extracts the PD patterns only with respect to frequency and not with respect to time. Hence, an effort is made to characterize the PD patterns/types directly in time domain for quick removal of insulation defects.
2. **Wavelet transform (WT)** has been applied to carry out time-frequency analysis in a number of problems. A continuous wavelet transform is generally used to obtain the time-varying information of the patterns by measuring similarity between the signal and a set of fast-decaying and oscillating functions called as *wavelets*. However, the time required by this method is much more to detect the type of discharge. Hence, an effort is

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 8, Issue 8, August 2019

made to apply two methods viz: Support vector machine method and Neural network method to quicken the detection of the PD.

- 3. In Image processing tool**, the phase-resolved three-dimensional ϕ -q-n pattern is regarded as an image and many modern image processing algorithms are used to extract the distinguishing features of the image. However, this image as an input to the distance classifiers will not give accurate result about the PD pattern clusters and hence the insulation defects. This is because the distance classifier assigns the pattern to the class to which it is matching with the closest minimum distance but cannot compare with known patterns for sure shot results.

IV. IMPROVED METHODS USED FOR DETECTION OF TYPE OF PD IN THIS RESEARCH:

This research improves all the above methods. Firstly, we need to find statistical parameters using Statistical method and give them as an input for various methods such as Back propagation and Self organizing map (SOM) methods of Artificial Neural network (ANN) method, Random Forest (RF) method and Support Vector Machine (SVM) method for accurate identification of discharge type, comparable with known patterns.

The sequence of the methods applied in my research for detecting the type of PD is –

1. Statistical methods applied for phase-resolved data patterns obtained from raw data use standard univariate statistical analysis for the computation of several statistical parameters characterizing the univariate distributions, ϕ -q, ϕ -n and n-q. These univariate parameters ϕ , q, n at some specific test voltage V constitute the feature vector. The five parameters obtained as a result of Statistical Analysis i.e. mean, standard deviation, variance, skewness and kurtosis for n-q and skewness and kurtosis for ϕ -q and ϕ -n are given as input for all four methods discussed below.

Paper [1] is the survey paper in which only various methods are listed for PD type identification, out of which Statistical method for detecting type of PD has been chosen in this research as first method. Paper [6, 7], explain methodology applied for the same. Paper [6] has listed several statistical indexes which can be used for PD type identification. Paper [7] explained about different statistical parameters and hitting patterns used for the identification of PD type of ac rotating machines. However, Hitting patterns follow conventional method of classification depending on “Recognition Rate.” The bar graphs called as Hitting Patterns obtained using statistical parameters cannot differentiate two different patterns of the same type of discharges having same recognition rate though from different physical conditions. Hence, to overcome this limitation this research uses same statistical parameters such as mean, standard deviation, variance, skewness and kurtosis for phase resolved partial discharge patterns between (ϕ -q, ϕ -n and n-q) in which the recognition rate cannot be same due to the plotting of two variant quantities [14][15][16]. Accuracy achieved by using this method is 85 %. To try to improve the accuracy of detecting the type of PD, a few more methods have been tried.

2. Back Propagation method of Artificial neural network (ANN) classifiers has the advantages of high robustness to ambiguous patterns. Whenever any insulation fault occurs in Alternators or other high voltage equipments, ANN are useful in recognizing the type of PD from PRPD patterns of raw data given by PD sensors. The application of neural network to system identification and pattern recognition has become a major trend in the fault diagnosis. Although the speed of neural networks allows real-time operation with comparable accuracy, the training process of multilayer neural networks is often very slow. This limitation can be overcome if the training data is sufficiently large and compatible. As the data collected by PD sensor is a big data, multilayer neural networks can be applied for training to increase the accuracy.

The introduction and approach towards automation for PD recognition was broadly discussed by Krivda [8]. Fractal Analysis is proposed as a tool for analyzing 3D patterns of PD as explained in paper [9]. Weibull distribution is used for identification of type of sources of PD [10, 11]. Use of Weibull distribution for PD detection along with fractal analysis followed by PD classification using Neural Network is also attempted in [12, 13]. These papers guided me to do the work on Back Propagation method of ANN.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

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Vol. 8, Issue 8, August 2019

In paper [13], both the combination of Weibull distribution and Neural network was used to detect type of PD. In these papers, Weibull distribution results were given as an input to ANN by using time resolved classification. Time resolved classification considers only variation of q with respect to time, which is very high for noticing accurately in chosen time interval. However, phase resolved partial discharge patterns (ϕ - q , ϕ - n and n - q) consider not only q but also ϕ & n variations and hence obtain more accurate statistical parameters to be given as an input to ANN to detect the type of PD. Neural Networks have an advantage that once they are trained for one sample of data, they can predict the desired results for next data. Further artificial neural networks allow modelling of nonlinear processes also and hence accepted as a very popular and useful tool for solving many problems of classification, clustering, regression, pattern recognition, dimension reduction, structured prediction, machine translation, anomaly detection, decision making etc. Hence, this research tried BPM of ANN as a new method having an advantage that it goes on executing till the error in iterations between n versus q , ϕ versus q and ϕ versus n becomes zero [17]. It was tried in both software i.e. Matlab and Python and gave a better accuracy of 89% in both the software. This encouraged me to try another method of ANN i.e. SOM.

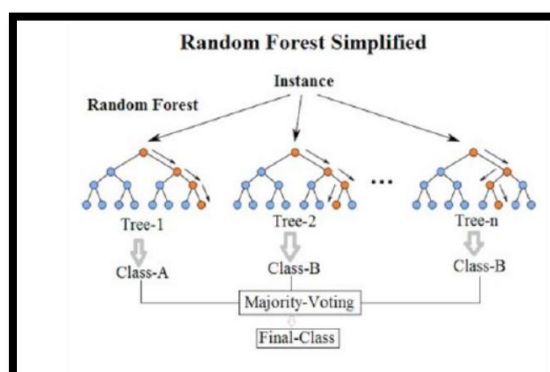
3. The Self Organizing Map (SOM) of Artificial neural network (ANN):

The idea of using SOM was from different IEEE papers as in [2, 3]. They executed self organizing map for different high voltage equipments i.e transformer, cable etc in which they have plotted phase resolved patterns of PD separately for each discharge. In this research, We applied the method for alternator data by introducing google colab of Python to display the heat map directly for all known and unknown data of discharges merged together. The output i.e type of discharge from heat map shown in results below, indicate improved accuracy, even more than that of BPM using both software.

Hence, a further effort is made to try Random Forest Method described in a book, it is new method in this research because it is not used by anyone and Support Vector Machine Method as per IEEE papers [4, 5] to check their performance for detecting type of PD.

4. Random Forest (RF) Method:

It is a popular supervised machine learning algorithm. This technique can be used for classification tasks more effectively. As the name suggests, Random Forest technique considers multiple decision trees before giving an output. So, it is basically an ensemble of decision trees. This technique is based on the belief that more number of trees would converge to the right decision. For classification, it uses a voting system and then decides the class. As it works well with large data sets having high dimensionality, it is felt that more number of decision trees can be found out for the particular type of data available from PD sensors to further improve the resulting accuracy for PD type identification. Again Random Forest method belongs to Artificial Intelligence only as listed in textbook of High Voltage Engineering by C. L. Wadhwa, F. H. Kreuger. They have explained the procedure of using RF method to detect the type of PD in any high voltage equipment. In this research, the same procedure is simplified in Python software using google colab as yet another method to verify for a better accuracy. The advantage of google colab in Python is that it executes the program step by step indicating the value of the reduced error persisting compared to other programming languages, say Matlab. Matlab indicates the error value after running the whole program and hence cannot be removed easily. The Python program is available in Open source library and can be used for coding purposes.



5. Support Vector Machine (SVM) using Python learning is chosen as next method for partial discharge classification, where data input has been found to be very important.

Papers [4, 5] deal with the PD type classification by using wavelet analysis to pre-process measurement data from PD sensor and cluster the discharges into different groups using correlation techniques. Then they applied SVM techniques to identify the type of different PD discharges. However, it was concluded by them that the technique over identified the void discharge being mixed with internal cavity discharge and hence, the exact segregation was shifted to their future scope to get the output with full clarity.

This research replaced the input data of wavelet analysis i.e decomposed data through high pass and low pass filters by statistical method data input consisting of separate files for mean, standard deviation, variance, skewness, kurtosis. This processed data is then given as an input for training in google colaboratory of Python.

The input of five parameters of feature vector derived in Statistical method always gave different patterns in an effective way. Hence, after verifying the results for three different data of Alternators (or possible for any high voltage equipment), this method has been found to be more suitable for PD type classification as shown in results below.

A support vector machine (SVM) is a type of deep learning algorithm that performs supervised learning for classification or regression of data groups. It can be used to sort two data groups by like classification. The algorithms draw lines called hyperplanes to separate the groups according to patterns. It is a discriminative classifier formally defined by a separating hyperplane. In other words, given labeled training data for supervised learning, the algorithm outputs an optimal hyperplane which categorizes new examples. Hence, in this research, hyperplane will be plotted for three known discharges i.e void, surface and corona, given for supervision. This method is therefore known as supervised learning and the resulting hyperplane predicts the type of discharge.

The accuracy from BPM method of ANN is 89%, from RF method, it is 95% and from SVM method, it is 100 %.

Hence, SVM can be considered as best method.

6. Correlation of Insulation Defects with Discharge Patterns or Characteristics:

The continuous impact of PDs may reduce the remaining lifetime of high voltage (HV) equipment. In order to ensure reliable operation of HV equipment, it is important to identify the type of defect and monitor its activity within the insulation system framework for qualitative protection. Hence, next step is to know the correlation between discharge patterns and the kind of insulation defect caused by it, as each defect has its own particular degradation mechanism.

Partial discharge measurement is a common method for diagnostics and monitoring of high voltage equipments such as power transformers and it can detect insulation malfunctions before they lead to failure. The PD activity can be recorded both in the time domain and phase domain. Analysing the PD activity and extracting different parameters from the measured PD it is possible to identify the PD source and investigate possible defects caused by harmful PDs in power transformers. The defects include corona in oil, a void in pressboard, a metal object at floating potential, surface discharge in oil, a free bubble in oil and small free metallic particles in oil. These defects can be correlated to corona in air, surface discharge in air, and discharge from an unearthed object near to the test setup. Hence, accurate PD type identification becomes essential.

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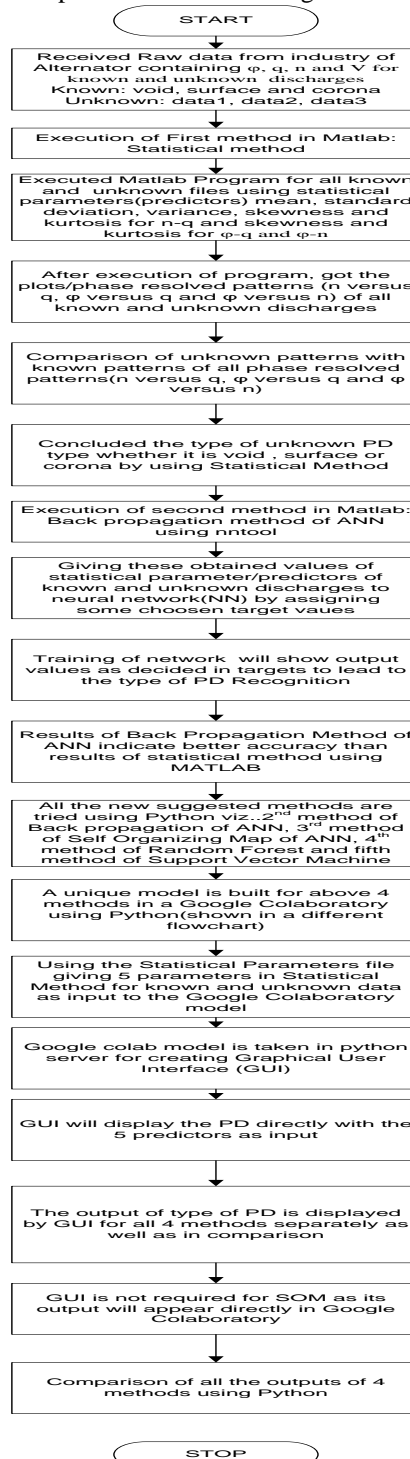
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Vol. 8, Issue 8, August 2019

V. FLOWCHART

The flowchart below will explain the overall procedure followed to get the results of this research:



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VI. CONCLUSION

All the three different types of PD data patterns used in practice have been discussed. A Comprehensive picture of the methods used by other researches for recognition of PD type and their improvised techniques used by this research already presented in papers [14][15][16][17] and some more yet to publish has been discussed in this paper. SVM is considered as best method since it give 100 % accurate results.

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