CHAPTER 1

INTRODUCTION

1.1 PREAMBLE

The quality of electrical insulation plays a vital role in the normal operation of any high voltage power equipment since high voltage would often lead to the failure of the electrical insulation. The quality of electrical insulation of high voltage apparatus is checked using non-destructive tests wherein the test object is not damaged. A successfully passed test shall guarantee operation under service conditions without damage or interruption. It is the skill of economical, technological and ecological design and production to extend all efforts just to the point where the necessary safety in service is adequate. Accordingly design and test engineers as well as the end user must be aware of certain facts: How a damage caused by a test can be discovered, even if it is only a slight weakening of the insulation and what amount of change in the quality of the insulation can be tolerated depending on whether the change is temporary or permanent. Such a means of check without doing harm by its application is the partial discharge (PD) measurement. The gradual increase in transmission line voltages has resulted in higher levels of operating stresses which in turn led to the search for newer insulating materials with superior properties, viz., cast resins, cross-linked polyethylene (XLPE), etc. Despite great care and quality control during manufacture, the occurrence of minor defects such as surface irregularities, presence of foreign particles etc. has become inevitable. The presence of these deceptively harmless defects will lead to the occurrence of partial discharges even at normal operating voltages, owing to local field enhancement at the sites of defects. The cumulative
effect of PD has been well recognised to be detrimental to the insulation system in the long run. In this regard, PD measurement has gained worldwide acceptance as a diagnostic tool with the capability to assess and monitor insulation systems for their integrity and design deficiencies, both during manufacture and while in service.

Since the partial discharge activity caused by insulation system defects indicates the degree of electrical insulation deterioration, which reduces the reliability of the equipment, both PD detection and recognition have become important tools for the evaluation of insulating constructions. The introduction of improved measuring techniques with effective methods for noise suppression aided by the application of modern computer technology offers new prospects for future practical applications. In practice, PD measurements are used only for acceptance tests with arbitrarily defined permissible values for individual apparatus. In modern PD technology, fault diagnosis (highly reliable identification of defects) as well as condition monitoring are of particular interest in order to assess the state of the insulation system. Classification of partial discharge patterns has an important role in manufacturing quality assurance and service life assessment of high voltage equipment. Recent application of digital signal processing to PD measurements and the availability of associated hardware make the PC-based PD measurement system a standard tool for quality assurance in high voltage laboratories. This enables the rapid acquisition of quantitative PD data which is necessary for the application of artificial intelligence for automatic identification of PD sources.

1.2 PD PROCESS AND PROBLEM IDENTIFICATION

Most of the insulating materials whether natural or synthetic, are non-homogeneous. They frequently contain voids or cavities containing gas (usually air) at low pressure, due to the vacuum processes to which the
electrical products are subjected. When an electrical stress is applied across such an insulation, the voltage across the void may be sufficiently high to ionise the gas inside the cavity; a PD then takes place. Partial discharge is a sudden local displacement of electrons and ions in an insulator under the influence of a sufficiently strong electric field. The charge displacement is believed to be the result of an electric field induced ionisation process due to defects, namely, discharges in gases and at gas-insulator surfaces, discharges in liquids and at liquid-solid interfaces and discharges in solids. PD is generally referred to as a discharge process in which the gap between two electrodes is only partially bridged. PDs can originate directly at one of the electrodes or occur without electrodes in a cavity of the dielectric. The various defects are broadly categorised into the following three groups in this work:

♦ Internal discharges
♦ Surface discharges
♦ Corona discharges

The defects are due to defective insulation, bad contacts, dielectrically overstressed areas and geometry of the system, namely, sharp electrodes or corners. Partial discharges in insulation systems comprise a large variety of physical phenomena, ranging from low intensity to high intensity phenomena. Low intensity phenomena are charge carrier emission from surfaces and leakage currents along insulator surfaces, glow discharges, sub-critical avalanching and charge carrier injection into liquids and solids. Electric treeing and streamers are of medium intensity type. Leaders, sparks and partial arcs are of high intensity type. Most of the discharges contribute to insulation degradation and some of them may trigger a breakdown. If the partial discharges are continuous at working voltage, they may lead to ultimate failure of the insulation and a catastrophic breakdown could occur. The primary partial discharge event is a very rapid discharge,
detection of which provides direct information about the discharge. Electrical partial discharge measures or any form of energy exchanges offer only indirect information on the primary discharge and on various reactions at the partial discharge site (Kelen 1995). Understanding the mechanism of PD phenomena, therefore, has become a major field of research and is being implemented as an important tool for the interpretation of the PD measurements with regard to the identification of discharge sources, their characterisation and the assessment of the risk of failure they comport. The discharges can occur in solids, liquids and gases which will not affect the breakdown voltage during a high voltage 'proof' test. Yet PD will cause failure and the PD-induced current in an external circuit is a complex function of the nature of the discharge-inducing defect and the geometry of the system.

In the early days of electrical engineering, the quality of insulation arrangement was judged purely by its insulation resistance and its dielectric strength. Today, partial discharge measurements are standardised and applied for quality control of high voltage equipment. In commercial quality assurance applications, a connection has been established between the presence of the highest level of partial discharge and a reduction in service life. Standards on PD measurements have evolved. Discharge detection has gradually become an indispensable tool for the evaluation of modern insulating constructions (IEC standard 270, 1981). Detection of charge displacement is the most frequently chosen measurement method.

The PD phenomenon is inherently random and inconsistent. PD measurements are very much influenced by the nature of insulation, amount of ageing, interval of voltage application, amplitude of voltage etc. The discharges are generally characterised by the discharge pulse amplitude which is proportional to the apparent charge 'q' and the time of occurrence or discharge epoch. These two characteristics have been combined into the
well-known display of discharges on the power frequency ellipse. The utility of these elliptical display has been found to be a very useful tool to indicate the origin of discharges and a set of rules for interpreting them has been published (CIGRE SG 21 WG03 1969). Correct interpretation of PD data is subjective as it is dependent on the experience and skill of the observer. Hence the reliability is limited. Assessment of insulation needs further study of discharges on applied voltage and time. Measurements are highly dependent on the measuring circuit and test specimen. Although reproducibility of measurement in the area of PD detection in electrical apparatus and cables is diligently strived for, it is extremely difficult to attain, even when measurements are made on same test specimen with equipment having identical specified sensitivities. Moreover, the PD measurements may be corrupted by interference and noise. When the noise level is appreciable and close to the discharge magnitude, even the experts experience difficulty in rating the discharge behaviour. Thus the patterns emerging are quite complex and also the subsequent patterns, arising due to the same PD fault, resemble each other only in a broad sense. Interpretation of discharge patterns can lead to evaluation of the cause of PD. Classification of PD patterns using pattern discrimination and recognition is the core of this thesis. In addition, every measurable PD signal is influenced by a statistical scatter of magnitude and direction linked to a complex time behaviour of PD sequence (Van Brunt 1991). Hence an attempt has been made to make use of digital methods (Ward 1992) which quantify and characterise the main features of discharges, their detectability in technical equipment and the assessment of the risk of failure they comport for identification of discharge sources. The specific approach undertaken in this thesis for characterisation of the PD defects makes use of statistical approaches. Statistical operators form the feature vector and drastically reduce the data base enabling easy training of the popular artificial neural networks (ANN). The steps involved starting from
the recording of the PD data till the classification of PD are delineated in the flow diagram shown in figure 1.1.

The diagnosis of insulation by partial discharge analysis finds considerable support from stochastic processing of partial discharge data. Stochastic approaches for partial discharge processing provide additional information on the partial discharge behaviour (Kreuger et al. 1993). It is well recognised that PD phenomena represent stochastic processes (Van Brunt 1991) since their initiation is evidently conditional on the availability of a first electron to initiate the ionisation avalanche. The time required for the appearance of the initial electron is statistically variable and is dependent upon a number of factors. The statistical operators of the stochastic PD processes are also influenced by the amplitude and shape of the test voltage since the latter initiates and sustains the PD sequence. Increased cognisance of the statistical nature of the discharge phenomena has impelled the development of computer systems capable of recording the PD activity for a certain number of cycles of applied AC voltage and then retaining the information for further analysis. Also a necessity arises to obtain as much data as feasible on the intricacies of the PD behaviour as a function of time to gain more information on the life expectancy dependence on PD onset. Therefore efforts are made towards an automated discharge recognition. These efforts show that statistical methods are useful to extract information from distributions forming a small data base enabling easy training of artificial neural network for the classification of PD faults.

Artificial neural networks prevail over other traditional classifiers in their ability to adapt themselves to different statistical distributions (Houzmi et al. 1992 Suzuki 1992 Kranz 1993 Satish and Zaengel 1994). Houzmi and Mazroua classified the PD sources based on the shape analysis. The discharge distributions were used to classify the PD patterns
FIGURE 1.1 APPROACH FLOW DIAGRAM
based on the shape quantifiers namely, apparent charge, rise time, fall time and area and satisfactory discrimination was reported. Various methods have been proposed for identification of defects using ANN through phase resolved analysis (Gulski and Krivda 1994, Mazroua and Salama 1993, Mazroua et al 1994) and time resolved analysis (Oyama 1994) which differ mostly in the representation of the PD data and classification methods. All these methods attempted to learn and identify the 'correlation' that exists between a PD defect and its distribution pattern. Techniques used to build the ANN structure were based on trial and error. The pre-processing methods utilised were of off-line; application to practical situations was not feasible demanding more computer memory and computation time (Suzuki 1992, Sathish and Zaengl 1994).

In this work, **optimisation of the network structure is obtained by the application of the genetic algorithm (GA)**. Genetic algorithm based ANN never lands into stagnation unlike the gradient-descent learning algorithms. Gradient-descent learning algorithms modify the network parameters following the gradient of an error function and have difficulties in learning the topology of the network whose weight distribution they optimise (Yao 1992). In this work, different paradigms are tried out. Perceptron, Widrow-Hoff, Simple Back Propagation, Improved Back Propagation with adaptive learning and momentum, Improved Back Propagation with Levenberg-Marquardt approximation, Probabilistic neural network and Generalised regression neural networks are the networks trained to identify the PD defects.

Misidentification of dielectric cavities and electrode bounded cavities (Gulski and Krivda 1994) is avoided by the inclusion of few of the quantifiers based on the average current distribution. Thus enhancement of the discrimination strength towards PD classification defects is assured. Monitoring and diagnosis of insulation comprise a sequence of two essential
activities namely experimentation and interpretation of the results. Classification of partial discharges based on the shape analysis of the **phase resolved signals** has been tried out. **Detection of the partial discharges with new generation of electronic circuitry and data collection and analysis are done using VXI based computer driven system.** This sophisticated instrumentation is a virtual one supporting visual engineering environment with graphical programming for monitoring and control of PD signals and test voltages. In addition to the computer driven display, real time processing of PD signals making use of direct displays and meter displays is also carried out for reliable identification and validation of the PD defects.

### 1.3 LITERATURE SURVEY

A large number of papers have been published on the subject of PDs. The occurrence of PD in electrical equipment had been recognised as early as the beginning of the century by Petersen (1912). As it became clear that PD might substantially reduce the life of insulation (Mason 1951) and some of them may even trigger a breakdown, much effort was spent on investigating this phenomenon (Kreuger 1989, Devins 1984 and Mc.Mahon 1968). A very clear introduction was given by Kelen (1967). An extensive synthesis was presented in the first book of Bartnikas and Mc.Mahon (1979) consisting of numerous relevant references. The measurement and location of PD phenomena have been of interest since at least the early 1940's. The apparatus and techniques used in the early days of PD investigations were very primitive and went unrecorded, though the industry is aware of the facts. For example, portable radios with extendable antenna were used as 'electronic sniffers' to provide crude location of externally generated PD or corona. The early days of PD research included studies of PD in gas-filled cavities in oil-impregnated paper insulation (Schmidt 1963), in high voltage
apparatus (Cavallius, 1963), dielectric materials (Viale 1968) and in turbine
generator insulation systems (Wood et al 1973).

1.3.1 Development of PD Test Techniques

With increasing appreciation of PD as a diagnostic tool by
electrical industries, a very wide range of materials and systems were
investigated, including:

♦ PD in polymeric materials (Tanaka et al 1978), polyethylene
  (Mayoux 1976) and porcelain (Jolley 1964).
♦ PD in high voltage apparatus with solid and liquid dielectrics
  whose PD characteristics are known from previous material
  studies. Such apparatus included PVC cables (Starr 1963),
  oil-impregnated bushings (Constandinou 1969) and oil-
  insulated transformers (IEEE WG 31).

Measurement and recording of PD in dielectrics and high voltage
apparatus was much more straightforward than providing a useful
interpretation of the recorded data (Dakin and Lim 1957). Early
investigations indicated that PD phenomena can be affected by cavity size
and shape, temperature, pressure and electrical stress. Over the years,
many methods of PD analysis were studied. In 1968, Kanoun studied PD
amplitude spectra and in 1976 Austin and James presented an interesting
study of an on-line digital computer system for measurement of PD.

Location of PD is as important as measurement and interpretation,
as location is often required before corrective action can be undertaken.
Research on PD location was undertaken as early as 1949 (Mason 1949).
Various approaches were included namely:

PD location using x-rays (Electrical review 1968 Mole 1967).

Ultrasonic vector PD location, which was demonstrated for transformers (Harrold 1971).

Many industries and manufacturers after constant work have come up with various ultrasonic methods for PD detection and location in order to advance the technology (CEGB 1969, ETC 1995).

1.3.2 Development of test apparatus

Early investigations were based on limited commercial test apparatus such as oscilloscopes of very limited bandwidth. In addition, amplifiers, counters, etc. had to be designed and constructed to meet experimental requirements. Manufacturers in need of routine PD test apparatus participated in the development of test procedures, standards and commercially available equipment capable of complying with such standards.

One of the earliest instruments was a RIV (radio interference voltage) meter. This was a modified version of a variable high frequency (MHz) radio receiver in use by telephone companies, radio stations and the military. The version developed for PD measurement provided an analog meter scaled in dB and µV and a built-in speaker for listening to the sound pattern of the radio interference. Using an extendable antenna that was available as an accessory, external noise present in the test area could be monitored. Displaying the PD patterns on a cathode ray oscilloscope has proven to be an indispensable aid in practical tests. Other techniques were developed to suit specific types of insulation systems. For example, the DLA
(dielectric loss analyser), basically a capacitive bridge capable of measuring dielectric loss consisting of an oscilloscope for dielectric 'loop' display (Simons 1950, Dakin and Malinaric 1960) was well suited for testing systems designed to operate in the presence of PD or corona. Development of PD calibration apparatus followed the development of PD measuring apparatus. A spark gap (Kreuger 1964) was among the early calibration standards. Eventually, electronic calibrators were developed. The estimation of errors in circuit calibration (Praehauser 1975) was given special attention and guidelines were established for circuit calibration (IEEE 31). PD system calibration takes into account the electrical coupling between a PD source within an apparatus and the electrical terminals of the apparatus. The purpose of PD system calibration is to assure that PD measurements (Praehauser 1972) on similar apparatus carried out in various laboratories will give similar data. However measurements at the terminal of the apparatus reveal little about actual PD related charge flow within the apparatus.

1.3.3 Standards

When looking back to the history of the IEC (International Electrotechnical Commission) Recommendations on PD measurements, we neither have to consider a long period nor to examine a large number of documents; the first edition of publication IEC 270 is dated 1968 and has been followed only by a revision in 1981 and 1994. The lengthy delay inspite of the realisation that PD has been recognised as an important source of ageing and deterioration of solid insulation since the beginning of the 1920's is attributed to the intrinsic difficulties of measuring PD by the technologies then available and of correlating the results of these measurements with the physical phenomena taking place during the life of a dielectric. The measurement techniques and the testing procedures that are in the IEC documents are based on 'instrument defined quantities'. All the measuring
systems were seriously affected by internal noise and external disturbances, so that the detection of low levels of PD was extremely difficult and subject to large variations according to the test environment, the size of the test object, etc. The test procedures most affected by the problem of disturbances included the important tests for determining the PD inception or extinction voltages, which were based on the appearance or disappearance of PD of a specified low intensity generally marked by an abrupt change in this intensity.

The recommendations considered only tests with alternating voltages and gave little information about the discharge behaviour in windings and cables; thus it was left to the relevant Technical Committees, dealing with tests on specific apparatus to choose how to associate voltage levels and PD intensity. The general tendency in these committees was thus to attempt to specify the PD intensity that may cause a reduction in the life expectancy of a given insulation system. Guidelines were framed to identify the most typical behaviour of an insulation from the number, position and amplitudes of PD along a voltage cycle. The revised edition in principle is the same as the previous one but contains more details about the calibration as well as sensitivity and accuracy requirements for the measuring instruments. Direct voltages are also included. Special consideration was given to the problem of extraneous disturbances and several methods have been suggested for their reduction by means of electronic processing. Detection of a PD intensity of 5 or 10 pC is possible and, hence, a different approach in qualifying a high voltage apparatus by a PD test is followed. This paved way to the non-destructive PD test as a routine test for high voltage apparatus.

Various standard institutions such as National Electrical Manufacturers Association (NEMA), American National Standards Institute (ANSI), International Special Committee on Radio Interference (CISPR) also
formed panels of specialists from universities, industries and other concerns to direct their efforts in the area of PD.

It is, however, the common experience that it is not easy to obtain reproducible results in PD measurements, even if performed on similar high voltage apparatus using similar instrumentation. Even if well separated from noise, PD amplitudes appear to be randomly distributed and varying in time. They seem to be sometimes increased and sometimes reduced by a prolonged test. Revised standard is based on the knowledge of the physical aspects of the PD processes to a certain extent. It takes into account the economic consequences of more severe requirements for high voltage apparatus approval and the possibilities of more sophisticated instrumentation.

An extensive literature survey suggests that manufacturers of dielectric materials and high voltage apparatus frequently perform PD tests on their products to assure compliance with customer requirements or established standards. The field of PD detection, location and interpretation will continue to evolve as manufacturers continue to develop new materials which in turn will be used to manufacture new and improved equipment. Such progress will require modified or new standards and will probably require improved or modified test and measuring apparatus to meet the new standards. In short, PD measurement and interpretation is a timely and practical topic epitomising the deterioration of insulation of power equipment.

1.4 STATE OF THE ART

From early PD techniques to the present ones, there have been tremendous developments mainly due to new generations of electronic circuitry. Recent developments in instrumentation for PD measurement
have led to renewed efforts to apply this nondestructive technique for quality control and ageing diagnosis of insulation system. The growing application of modern computer technology to PD data collection and analysis has led to the development of sophisticated PD pattern recognition procedures. The latest-generation PD detector provides digital data recording system with provision for subsequent evaluation. In-depth analysis of PD functions is possible; test documentation can be produced based on the evaluation considering in terms of both test duration and test voltages under various field conditions. Accurate location of PD during cable testing and comprehensive interference suppression properties are also achieved.

New diagnostic techniques based on multivariate data analysis, artificial neural networks and fuzzy logic have been tried mainly for identification of discharge sources and characterisation of different stages of insulation deterioration. New developments in unconventional electrical and non-electrical methods led to different PD detection methods and measuring techniques. In-depth study of the responsible mechanisms and aspects of conventional electrical methods for PD detection and location have been carried out. It has been recognised that the ultra high frequency (UHF) method, which is based on the emission of electromagnetic waves by PDs can be applied efficiently for highly sensitive PD detection, especially in gas insulated system (GIS) arrangements. Since an exact correlation between PD intensity in the time domain and the PD spectrum in the frequency domain is not yet known, a calibration of this method is not yet possible.

When comparing different methods such as conventional electrical, UHF, acoustic methods, etc., a general ranking is not possible because the efficiency of a particular method depends strongly on the interference level during the measurement and on the kind of object being tested. The existing
distinction between measurements under laboratory conditions and on-site testing can be removed with the emerging powerful and reliable techniques for noise identification and suppression. The sources of interference of interest are pulse-shaped noise resulting from external discharges, radio interference and power frequency synchronous interference pulses. Adaptive digital filters are used to filter out noise signals from radio transmitters that can be clearly distinguished from the wanted PD signal in the frequency domain. Digital filter designed by using the REMEZ algorithm is considered to be a powerful scheme and can be attached to standard PD detectors, according to IEC 270 (Rainer 1995). For suppression of power frequency-correlated interference pulses, off-line software filtering can be used on a Fast Fourier Transform (FFT) algorithm capable of detecting travelling noise pulses. On-line filtering can be efficiently achieved with a digital correlation filter. Identification and suppression of pulse-shaped noise by means of minimum distance criterion have been achieved for wide-band PD measurements made on site. In addition, this method has been successfully applied for the location of PD sources in transformers.

Table 1.1 compares the state-of-the-art in PD measurements in the fifties and sixties with the present. The table should be supplemented by those of some more pioneers, founders and leaders of schools or research groups such as James, Phung and Blackburn in Australia, Garton, Parkman and Stannett in the UK, Fabre, Fallou and Lacoste in France, Kind and Karner in Germany, Kreuger in the Netherlands, Zaengl in Switzerland, Dakin, Devins and Mathes in the USA, Cameron, Bartnikas and Kurtz in Canada and Inuishi, Ieda, Hirabayashi and Tanaka in Japan.

Recently there has been a lot of interest in the field of artificial intelligence and its application to automated PD pulse recognition. Okamoto and Tanaka (1986) were among the first to report an automated discharge recognition system. For recognition purposes, they used the
skewness of the mean pulse height discharge distribution and this operator appeared to be a sensitive indicator of the shape of a void in which discharges occurred.

Wootton (1987) described an expert system where if-then rules were used to trace the origin of discharges. First, discharge patterns were visually observed on the power frequency ellipse on an oscilloscope screen and then the user had to answer a series of questions. By means of such a questionnaire, the classification of discharges was done on the basis of the information published by CIGRE. Clearly, results were still dependent on interpretation by the human user. Gassaway et al (1987) developed an expert system which analysed mean pulse height discharge distribution and pulse count discharge distribution. Various statistical parameters were then calculated and displayed. With human intervention, conclusion on the recognition of the discharge source was attained. Good recognition was achieved for corona and surface discharges in air. The recognition performance of the expert system was limited. Krump (1992) described a system which employed identification functions and minimum distance classifiers for the discharge recognition. The identification functions were based on various parameters viz., the discharge magnitude, energy, phase angles, etc. The author studied nine types of defects in a gas-insulated system with satisfactory results. Hozumi et al (1992) and Suzuki and Endoh (1992) applied neural networks for discharge recognition. The peak magnitude discharge distribution and mean pulse height distribution were used to classify discharge patterns in a cavity before and after tree initiation. Satish (1993) classified discharge patterns by means of hidden Markov models. In his analysis the input data consisted of a picture of the ellipse with superimposed discharges, which was obtained by CCD (charge coupled device) camera. The rejection of discharge patterns which do not belong to any of the known categories is, however, not considered in hidden Markov models. This can lead to misclassification of such discharge
patterns, which is a limitation of this procedure. Gulski developed a system for an automated classification of discharges (1991, 1993).

Table 1.1

The State-of-the-Art in PD measurements

<table>
<thead>
<tr>
<th>Subject</th>
<th>1950 - 1970</th>
<th>1997</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation of PD Phenomena</td>
<td>Circuit response using Oscillograms, photography of PD in voids (Mason), Dust figures (Bertein).</td>
<td>Digital recording and analysis, Sub-ns image converters, Wide-band oscilloscopes, UHF detection technique.</td>
</tr>
<tr>
<td>Study of pulses and sequences</td>
<td>a-b-c circuit (Gemant, Philipoff), Pulse regimes (Whitehead, Dakin), Void periphery (Heller, Veverka).</td>
<td>Field theoretical approaches to void geometry and location.</td>
</tr>
<tr>
<td>Mechanisms, Discharges acting on matter</td>
<td>Isolated approaches (Garton, Mason, Salvage, Fabre, Lacoste, Devins, Bartnikas).</td>
<td>Gas discharge physics, charge dynamics, solid state physics, radiation chemistry, polymer science.</td>
</tr>
<tr>
<td>Electrical treeing</td>
<td>Observation, statistics of inception, propagation description (Olyphant, Kitchin, Pratt).</td>
<td>Theoretical and fractal approaches to inception and space charge.</td>
</tr>
<tr>
<td>Electrical Insulation diagnostics</td>
<td>Lissajous traces (Kreuger, Mole), Integrating tanθ bridges (Meyer, Dakin), DLA (Dakin, Simons), Pulse sequences (Lacoste, Bartnikas).</td>
<td>Digital pulse storage, analysis, PDA, PRPDA in different service modes. Pattern recognition techniques.</td>
</tr>
<tr>
<td>Application oriented degradation studies on Electrical Insulation Modelling and Scaling</td>
<td>Phenomenological emphasis on scaling, modelling and acceleration (Dakin, Moses, Botts, McMahon, Carlier, Fallou, wohlfahrt).</td>
<td>Test conditions based on knowledge of mechanisms.</td>
</tr>
</tbody>
</table>
In summary, the three phases of development in Electrical Insulation and its evaluation are enumerated (Kelen 1995) as shown below:

♦ Phase 1: The sharing of operational experience in the old times when insulation was made of few natural materials.
♦ Phase 2: After the polymer revolution, experimental functional evaluation of materials and systems, with emphasis on good modelling, on test acceleration and also based on service experience.
♦ Phase 3: The modern scientific approach, where evaluation is based on service experience.

Phase 1 approaches are, however still being attempted, and thermal endurance is the most striking illustration of it. The present state of art is in phase 3 or in phase 2, depending on the kind of equipment under consideration.

1.5 SCOPE OF THE PRESENT WORK

The work reported in this thesis is outlined as shown below:

♦ Detection of the electrical energy exchange of very feeble partial discharge transients in the order of micro volts to milli volts.

♦ Preparation of two electrode physical samples for investigation towards the characterisation of partial discharge defects.

♦ Coupling an entire system (test set-up) to record all pertinent information during the test time period for further processing.
Unambiguous recognition and characterisation of partial discharge defects based on statistical approach and development of a software tool to recognise PD sources.

Train the popular artificial neural networks using the quantitative partial discharge data acquired.

Evolution of neural networks based on genetic algorithm towards better training and recognition of partial discharge defects.

Validation of the 'interpreted results' using experimental data of various power apparatus and the spectral analysis of the transient partial discharge pulses.

1.6 ORGANISATION AND APPROACH OF THE WORK

A brief outline of the various chapters of the thesis is as follows:

Chapter 1 gives a general introduction to the PD activities and their traits which make PD measurements and interpretation difficult. The necessity for a highly reliable diagnostic system to discriminate different discharge defects due to the intricacies that exist on PD onset is outlined.

Chapter 2 describes the discharge detection. It gives the design and implementation details of the detector. The different display processing are also discussed at length. The classic way of PD characterisation and calibration details of PD during measurements are discussed.

Chapter 3 reports the need for generalised modelling, sample preparation for extensive investigation of the defects on distribution patterns, necessity of statistical approaches, phase resolved measurements
and characterisation. It also deals with the experiments conducted to quantify or characterise the PD process using statistical approach.

Chapter 4 gives an account of application of artificial neural networks for the classification and characterisation of PD. Different artificial neural network paradigms have been tried out. Their traits and limitations are delineated. Comparative analysis of various paradigms is included.

Evolution of artificial neural network using genetic algorithm raises the curtain of chapter 5. It deals with the optimisation of ANN structure for better recognition of PD defects.

A review of the work reported and a comprehensive summary of conclusion reached from this research are presented in chapter 6. Further the demonstration of the effectiveness of the proposed model and few suggestions for future work are included.