MODELING OF CALIBRATION CIRCUIT FOR PARTIAL DISCHARGE MEASUREMENT

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MODELING OF CALIBRATION CIRCUIT FOR PARTIAL DISCHARGE MEASUREMENT

A Thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology in “Electrical Engineering”

By

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May-2013

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CERTIFICATE

This is to certify that the thesis entitled “**Modelling of Calibration circuit for Partial Discharge Measurement**”, submitted by **Aditya Kumar Gupta (Roll. No. 109EE0271) and Sachet Ray (Roll. No. 109EE0181)** in partial fulfillment of the requirements for the award of **Bachelor of Technology** in **Electrical Engineering** during session 2012-2013 at National Institute of Technology, Rourkela. A bonafide record of research work carried out by them under my supervision and guidance.

The candidates have fulfilled all the prescribed requirements.

The Thesis which is based on candidates’ own work, have not submitted elsewhere for a degree/diploma.

In my opinion, the thesis is of standard required for the award of a bachelor of technology degree in Electrical Engineering.

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ACKNOWLEDGEMENTS

On the submission of our thesis entitled "**Modelling of Calibration Circuit for Partial Discharge Measurement"** we would like to extend our gratitude & our sincere thanks to our supervisor **Dr. Subrata Karmakar**, Asst. Professor, Department of Electrical Engineering for his constant motivation and support during the course of our work in the last one year. We truly appreciate and value his esteemed guidance and encouragement from the beginning to the end of this thesis. He not only served as our supervisor but also encouraged and challenged us throughout the academic program. He guided us through the dissertation process, never accepting any less than our best efforts. His reliable and incredible support throughout our research work and his technical knowledge has led us through many problems easily. We thank him for help and profiting us by his skill, support and valuable time and criticisms, without which this project would not have been possible.

At last but not least, we would like to thank the staff of Electrical engineering department for constant support and providing place to work during project period. We would also like to extend our gratitude to our friends who are with us during thick and thin.

Aditya Kumar Gupta

B. Tech (Electrical Engineering)

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<u>Dedicated to</u>

Our beloved Parents

ABSTRACT

Most of the high voltage equipment suffers from failure due to internal faults. The type of fault caused due to insulation failure as a consequence of local electrical stress concentration in the insulation, whether gas, solid or liquid is very widely prevalent. This is called as partial discharge. So, partial discharge detection is highly important for an early detection of insulation failure. In this study, the simulation of partial discharge has been carried out with consideration of a cylindrical void inside an epoxy resin. The PD characteristic is studied by applying different high voltages across the insulation, which is necessary for designing of a calibration circuit. A calibration circuit has been modelled in SIMULINK for generation of PD pulses of known charge magnitude. The calibrator was connected across the test object and the pulses were detected via detector. A physical model of calibrator was made and output calibrating pulses were observed at Digital Storage Oscilloscope.

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LIST OF ABBREVIATIONS

IEC standard	International Electro Technical Commission
PD	Partial Discharge
HV	High Voltage
MI	Measuring Instrument
PRPD	Phase Resolved Partial Discharge
NEMA	National Electrical Manufacturers Association
IC	Integrated Circuit
DUT	Device Under Test
DSO	Digital Storage Oscilloscope

CHAPTER 1

INTRODUCTION

Introduction
Literature review
Motivation and Objective of the Thesis
Organization of the Thesis

1.1 INTRODUCTION

With the rapid growth of electrical energy consumption over the years, increasingly in the developed countries like India, has led to the development of many high voltage transmission and distribution systems and that too with increasing levels of sophistication. But, as is the case with almost all the equipment, however perfect their initial state is, continuous use of the instrument inevitably leads to the failure of insulation. Heat and vibration, thermal cycles and the presence of high electric stress are major culprits responsible for degradation of integrity of the dielectric system. Thus the major problem associated with increasing levels of complexity and efficiency is reliability and lifetime of the instrument [1].

So, as is obvious, it becomes quite pertinent to measure the quality of the insulation at periodic intervals. Partial discharge (PD) measurement is one of the many methods used to determine the quality and lifetime of insulation. Partial discharge is defined as localized electrical discharge that only partially bridges the insulation between electrodes. It is known that no type of insulation is completely pure and does not contain any impurities. Some form of impurity or air bubbles is always present during the manufacturing process [2]. The presence of these impurities weakens the insulation and is responsible for occurrence of partial discharge. Thus partial discharge measurement becomes an important process to determine the state of insulation [3].

1.2 LITERATURE REVIEW

Although high voltage technology for electrical power generation and transmission systems, was introduced during the earlier parts of last century, by then partial discharge had been recognized as a harmful source for insulation ageing in the high voltage apparatus. With passing time, many techniques have been developed for detection, measurement and behavior study of PDs in insulation. The very beginning of partial discharge recognition dates back to the year 1777, in which Lichtenberg reported on novel results of experimental studies during a session of Royal Society in Gottingen. Since then, many authors have presented their work about the detection and measurement of PDs, as well as study the characteristic of PDs. The very beginning of partial discharge recognition dates back to the year 1777, in which Lichtenberg reported on novel results of experimental studies during a session of Royal Society in Gottingen. Although it was almost 100 years, before it could be clarified that Lichtenberg dust figures manifest electrical discharge channels on the surface of the dielectrics [4].

With rapidly increasing HV transmission voltage level, a substantial improvement in the insulating materials was required. So, the first facilities for electrical PD recognition were introduced at the beginning of the last century, which helped in continuous improvement of knowledge about PDs. With increasing knowledge about PD recognition, industrial PD detectors were developed in the middle of the last century, which essentially paved the way for further achievements in the field.

During the 1970's, the measurement of PDs down to pC range was demanded due to the introduction of extruded materials for the insulation of power cables as PDs of few pc may lead to an inevitable breakdown of insulation. This enforced the development of improved PD measuring systems, which were also capable of localization of PD sites in long distance power cables [5]. Along with that, PD tests in compliance to IEC 60270 were compulsorily applied for quality assurance checks of power transformers.

Since the 1970s, conventional analogue instruments have been increasingly substituted by digital instruments which are more powerful and produce better results, to satisfy the ever increasing technical and scientific interest in the stochastic nature of PDs. For the first few years, multi-channel pulse height analyzers were used, which was later substituted by computerized PD measuring systems capable of processing, acquisition and phase-resolved visualization of very complex PD data. Now days, the digital PD measurement technique is common practice in the laboratories all over the world.

1.3 MOTIVATION AND OBJECTIVE OF THESIS

PDs are generally caused due to imperfections in the insulation system which inevitably leads to failure of high voltage equipment. The insulation of equipment plays a major role in the lifetime of equipment. So, it is necessary for the insulation to be high quality to maintain the efficiency. But it is nigh impossible to produce insulation materials, which are completely free of impurities, PD detection is of paramount importance. The impurities present are in the form of solid, liquid or gas. It is commonly noted that, during manufacturing process of solid insulations, air bubbles are present which leads to weakening of the insulation on application of high voltage [6].

Since it is practically impossible to quantify the PD that appears in the insulation defect, a related electrical quantity called as apparent charge q, is used to quantify the PD phenomenon. The apparent charge, q, is defined as the charge which when injected across the Device Under Test (DUT) for a very short period of time in a specified test circuit, produces the same result as the PD pulse itself [7]. The ratio of the input quantity to the instrument reading, also known as scale factor is determined by means of a suitable calibrator in the test circuit. To a great extent, the accuracy of the PD calibrator used in the circuit determines the accuracy of the PD measurement.

The main objectives of the thesis are:

- To find out PD activity inside the void enclosed with the solid insulation using MATLAB based SIMULINK models for different input voltages.
- To find out the
    - Maximum PD magnitude variation with different applied voltage
    - Number of PDs and other PD related parameters like PD distribution
    - Frequency content of obtained PD pulse.
- To design a MATLAB based SIMULINK model of calibrating circuit for partial discharge detection.
- To utilize the calibrating circuit to produce PDs.
- To design a physical model of calibrator and observe the experimental results.

1.4 ORGANISATION OF THESIS

The thesis is categorized into five different chapters including the introduction.

Chapter 1: This chapter comprises of introduction, motivation & objective of the project along the literature review on partial discharge characteristics as well as the organization of the thesis.

Chapter 2: This chapter describes basic concepts of partial discharge i.e. the necessity and detection of partial discharge in high voltage power equipment and the role of apparent charge for PD measurement.

Chapter 3: The mathematical modelling of partial discharge inside solid insulation is discussed in this chapter. It includes the cylindrical void model present in the solid insulation and its equivalent circuit model for measurement of PD pulses.

Chapter 4: This chapter describes the concepts of apparent charge and the method to calibrate a PD measuring instrument. A MATLAB-SIMULINK model of calibrator is made for different charge level. The model is also simulated across test object.

Chapter 5: This chapter presents the physical model of calibrator circuit. It consists of IC555 TIMER circuit, series RC circuit, a set of capacitors connected in parallel and output resistor. Varying charge level is obtained by different capacitors.

Chapter 6: In this chapter the results of simulation of PD pulse generation, simulation of calibrator circuit, simulation of calibrator circuit with test object and output waveforms of physical model is presented.

Chapter 7: In this chapter the conclusion and future work has been discussed.

CHAPTER 2

BASIC CONCEPTS OF PARTIAL DISCHARGE (PD)

Partial discharge
Necessity of Detection of Partial Discharge
Classification of Partial Discharge
Effect of Partial Discharge on Insulating Systems
Partial Discharge Detection Methods
Role of Apparent Charge in Partial Discharge Measurement

2.1 PARTIAL DISCHARGE

According to IEC 60270 (International Electro-technical Commission), Partial Discharge is defined as: “*localized electrical discharge, that only partially bridges the insulation between conductors and which may or may not occur adjacent to a conductor. Partial discharges are in general a consequence of local electrical stress concentration in the insulation or on the surface of insulation. Generally, such discharges appear as pulses having duration of much less than 1µs*”. PD activity, in general, is observed in high voltage power equipment like transformers, bushings and many others [8].

2.2 NECESSITY OF PARTIAL DISCHARGE DETECTION

PD usually occurs within voids, cracks, or in any inclusions within a solid dielectric, at the conductor-dielectric interface within a solid dielectric, or in bubbles within a liquid dielectric. As the PDs are only limited to a portion of the insulation, the discharges can only partially bridge the distance between electrodes. Partial discharge (PD) can also occur along the boundary between different insulating materials, also along the surface of solid insulating materials if the surface tangential electric field is high enough to cause a breakdown along the surface of the insulator [9]. This phenomenon is commonly manifested in overhead line insulators, mainly on contaminated insulators during days of high humidity. This phenomenon is also known as corona effect.

Most of insulators are in impure form due to presence of air bubbles which creates voids within the insulating material. It is responsible for weakening of the insulating material and appearance of PDs. The reason being, the dielectric constant of the void as compared to its surrounding is less. So, it leads insulation failure in high voltage and high power equipment. Although such type of discharges has very low magnitude, over a sufficient period of time, it leads to degradation of the insulating material, which ultimately leads to the failure of the system. For this reason, PD detection and measurement is of utmost importance.

2.3 CLASSIFICATION OF PARTIAL DISCHARGE

Partial Discharge phenomenon can be divided into two categories [3]:

- External Partial Discharge: External Partial discharge is defined as the partial discharge occurring in ambient air, also normally known as corona discharge. This type of discharges is usually reversible and thus generally considered as harmless.
- Internal Partial Discharge: Partial discharges occurring due to imperfections in insulating liquids and solid dielectrics as well as in compressed gas are defined as internal partial discharges [10].

PD phenomenon can also be classified into the following types:

- Corona Discharge: It takes place due to the non-uniformity of electric field on sharp edges of conductor subjected to high voltage. The insulation used for such type of discharge may be gas or air or liquid [11]. This type of discharges appears for a long duration along the bare conductor. The Ozone formed due to the corona effect is responsible for the degradation of the insulation material.
- Surface Discharge: It takes place on interfaces of dielectric materials such as gas/solid interface. This usually occurs in bushings, end of cable, any point on insulator surface, between electrodes (high voltage terminal & ground). The existence of such discharge depends on various factors such as:

    - Permittivity of the dielectric materials used
    - Voltage distribution between the conductors
    - Properties of the insulating materials

- Treeing Channel: At the sharp edges of an insulating material, high intensity fields are produced, resulting in deterioration of the insulating material. This leads to a continuous partial discharge, also known as Treeing Channel.
- Cavity Discharge: This type of discharge usually occurs in solid or liquid insulating materials. The cavity present is generally filled with gas or air. When the gas in the cavity is over stressed, Cavity Discharge takes place.

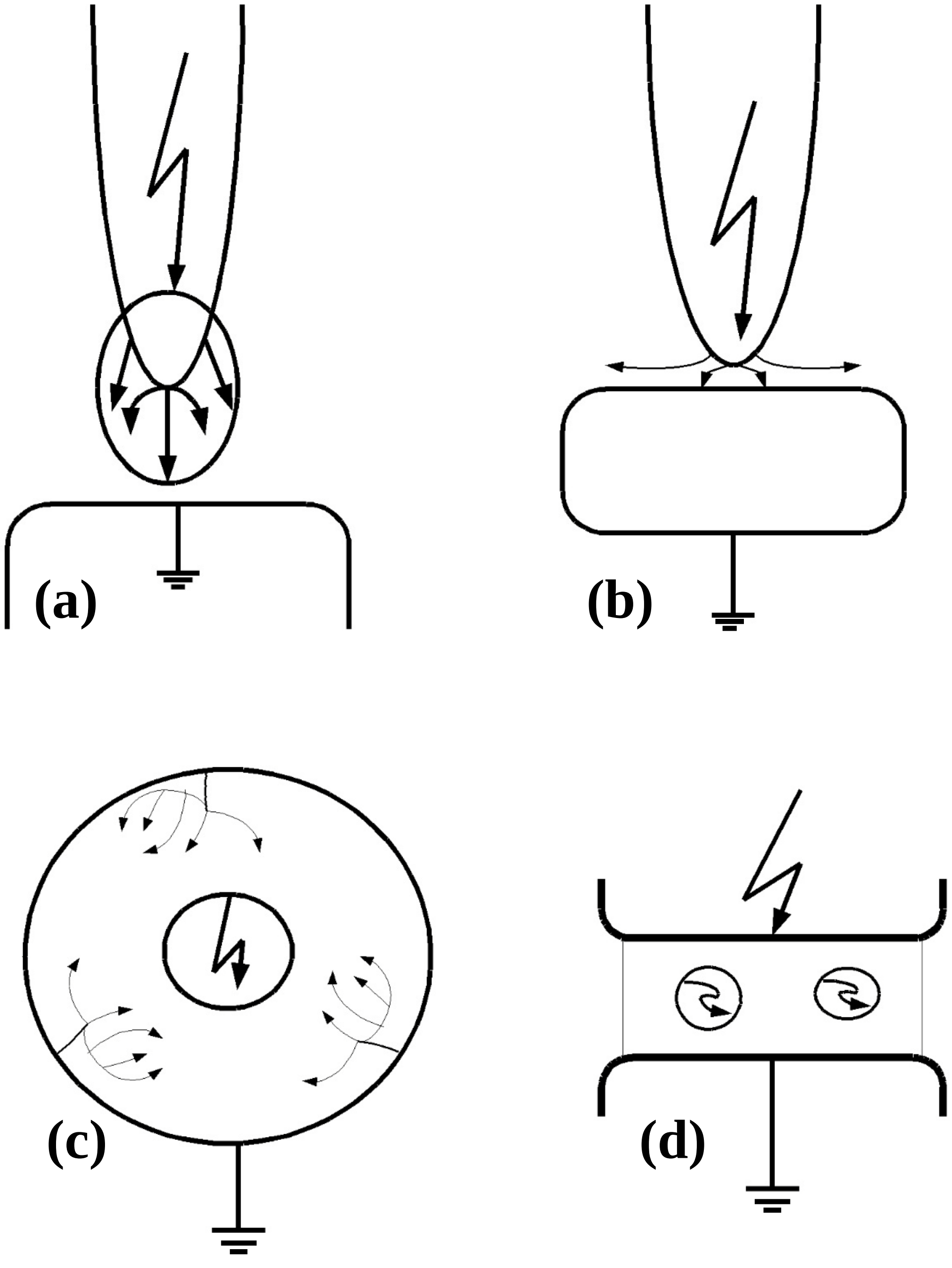

FIGURE 2.1: Various Types Of Partial Discharge Occurring in the Insulator a) Corona or Gas Discharge, b) Surface Discharge, c) Treeing Channel and d) Cavity Discharge

2.4 EFFECT OF PARTIAL DISCHARGE ON INSULATING SYSTEM

Once started, PD causes progressive deterioration of the insulating material, eventually leading to electrical breakdown of the system. The effects of PD within high voltage cables and equipment can be very serious. The collective effect of partial discharges within solid dielectrics leads to treeing effect which causes the formation of numerous partially conducting discharge channels. Repetitive discharges cause irreversible mechanical and chemical deterioration of the insulating material. Damage is usually caused due to the energy dissipation by high energy electrons or ions from the discharges, and liberation of gases at high pressure due to chemical breakdown processes. The chemical transformation of the dielectric is also responsible for increase in the electrical conductivity of the dielectric material surrounding the voids, which lead to increase in the electrical stress in the unaffected gap region, accelerating the breakdown process of the insulating material.

PD dissipates energy, generally in the form of heat, but sometimes in the form of sound and light as well, for example the hissing and dim glowing around the overhead line insulators. Heat energy dissipation may cause thermal degradation of the insulation, although to a very small extent. For high voltage equipment, the reliability of the insulating material can be confirmed by monitoring the PD activities. PD in high-voltage electrical equipment should be monitored closely to ensure supply reliability and long-term operational sustainability, along with early warning signals for inspection and maintenance.

2.5 PARTIAL DISCHARGE DETECTION METHODS

Many techniques are used for the detection of PD as well as its measurement on the basis of both electrical and non-electrical methods. The techniques which are popularly used for measurement of PDs are,

- Chemical Detection Method
- Acoustic Detection Method
- Optical Detection Method
- Electrical Detection Method

2.6 ROLE OF APPARANT CHARGE IN PD MEASUREMENT

Partial discharge is a type electrical discharge that can lead to serious problems in high voltage equipment. The value of charge stored in the voids in the insulating material cannot be directly measured as the PD sources are not accessible.. Thus, partial discharge cannot be quantified by direct methods. To overcome this problem, an apparent charge method is used for the measurement of the PD activity inside the solid insulation model. Apparent charge is defined as the amount of charge which when injected across the terminals of the Device Under Test (DUT) in a specified test circuit produces the same result on the measuring instrument as does the PD current pulse itself. The apparent charge is usually in Pico-coulombs. And in order to measure the apparent charge the measuring instrument needs to be calibrated as the partial discharge is highly dependent upon the geometrical configuration of the void location inside the solid insulation.

CHAPTER **3**

MODELLING OF PARTIAL DISCHARGE INSIDE SOLID INSULATION

Selection of Void Parameters
Partial Discharge Measurement System
Electrical Circuit for Partial Discharge Measurement
Simulink Model Description for Detection of Partial Discharge

3.1 SELECTION OF VOID PARAMETER

The most important factor for partial discharge characteristics is void parameters. Partial discharge characteristics changes accordingly, with the size of void. There are several types of voids as such as cylindrical, cubical, rectangular, etc. So the main parameters which are required for the analysis are height, length, breadth, diameter and volume of the void.

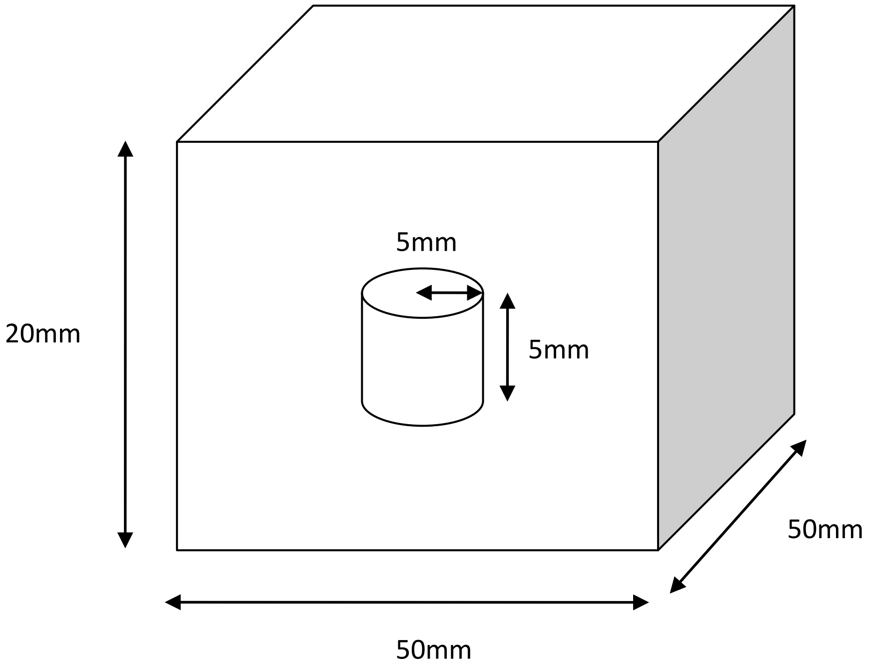

FIGURE 3.1: Void Model of the Epoxy Resin Insulator

The test object used is made up of epoxy resin and consists of three capacitors. Among three capacitors, two are connected in series with parallel to the other. Where, C_a is the capacitance of the healthy part of the test object, C_c is the capacitance of the void present in the test object and C_b is the capacitance of the part of the test object leaving C_a and C_c [12].

3.2 PARTIAL DISCHARGE MEASUREMENT SYSTEM

The major components required for Partial Discharge Measurement are:

- ❖ A coupling capacitor, when connected in series with the measuring system, due to its low high impedance holds up the low level partial discharge at a particular applied voltage for measurement of partial discharge. A higher level of partial discharge is measured when coupling capacitor and measuring system is connected separately while the measuring system is connected in series with the test objet.
- ❖ A High voltage supply with low degree of background noise is provided as input supply to the system.

- High voltage connections having sufficiently low degree of background noise.
- R_m, L_m, and C_m are taken as the input impedances for the measuring system. The input impedance of the system determines the wave shape of the PD impulse.
- The test object consists up of three capacitors: one connected in parallel with the other two which are connected in series.

Test object →

- C_c represents the cylindrical void present inside the Solid insulation.
- C_b represents the capacitance of the remaining series insulation with void (C_c)
- C_a represents the capacitance of the remaining Discharge free insulation of the rest of the solid insulator

- A measurement instrument is used across the detector circuit to measure the partial discharge pulses produced due to presence of void inside the test object
- PC software is used for characteristic study and analysis.

3.3 ELECTRICAL CIRCUIT MODEL FOR PD MEASUREMENT

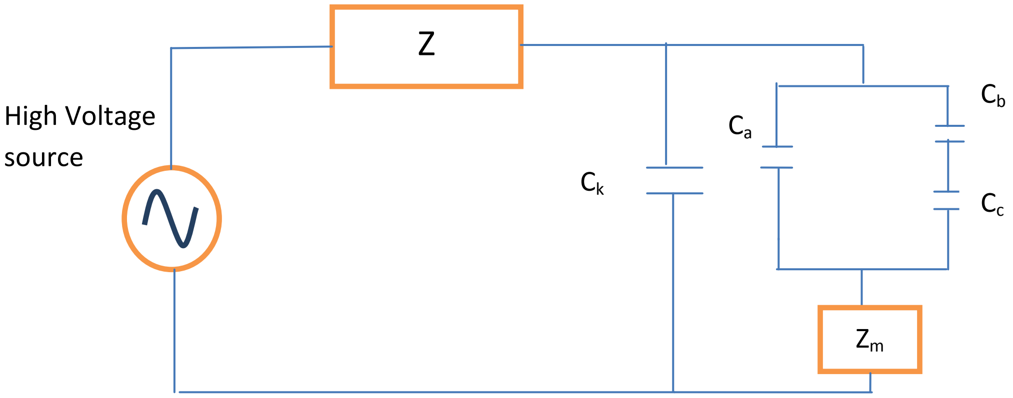

FIGURE 3.2: Electrical Circuit Model for Partial Discharge Measurement

Fig.3.2 consists of three capacitors. Capacitor C_c represents capacitance of the void present in the test object which is shown in Fig. 3.1. Capacitor C_b represents capacitance of the healthy part connected in series with the void. Capacitor C_a represents capacitance of the healthy part leaving C_c and C_b. When a high voltage supply is given to the circuit model then discharge occurs. With this high voltage the void gets charged and breakdown starts [13]. A measuring instrument is connected across the detector circuit in order to receive this pulse from the test object through detector circuit. An epoxy resin insulator with dimensions 50mm, 50mm and 20mm is considered. In that insulator a cubical void is present. The void is having radius of 5mm and height of 5mm. As the electrical circuit model consists of three capacitors the value of those capacitors is to be found out. It is known that,

$$C = [(\varepsilon_0\varepsilon_r A)/d] \qquad (1)$$

Where, C is the capacitance, with permittivity of free space and the relative permittivity and d is the distance between the electrodes. Therefore,

$$Cc = \frac{(\varepsilon_0 A)}{t} = 0.139\times10^{-12}\text{ F} \qquad (2)$$

$$Cb = \frac{(\varepsilon_0\varepsilon_r A)}{d-t} = 0.162\times10^{-12}\text{F} \qquad (3)$$

$$Ca = \frac{(\varepsilon_0\varepsilon_r A1)}{d} = 3.752\times10^{-12}\text{ F} \qquad (4)$$

The capacitances values of the three capacitors are calculated. This value is required for measurement of partial discharge pulses.

When this circuit is energized by a high voltage AC source, a recurrent discharge occurs.

Voltage across the capacitance C_C is given by

$$V_c = V_a \times C_b/(C_a + C_b) \qquad (5)$$

The apparent charge measurable at the high voltage terminal and ground terminal can be calculated from the following equation

$$Q = C_b \times V_c \qquad (6)$$

3.4 SIMULINK MODEL FOR DETECTION OF PARTIAL DISCHARGE

A simple equivalent capacitor circuit of model of the solid insulator is used in the MATLAB SIMIULINK to evaluate the fundamental quantities of the PD pulse.

TABLE3.1: Parameters Used for PD Simulation

Sl. no	Parameter	Symbol	Value	Dimension
1.	Input Resistance	R_{in}	1000	Ohm
2.	Coupling Capacitor	C_k	1000	µF
3.	Permittivity	ε_0	$8.85*10^{-12}$	F/m
4.	Relative Permittivity	ε_r	3.5	-
5.	Resistance	R_m	100	Ohm
6.	Inductance	L_m	0.6	mH
7.	Capacitance	C_m	0.1	µF

Here, an equivalent circuit of solid insulator having a cubical void is taken to evaluate the partial discharge pulses. In this insulator the void is present at the center of the insulation medium. The value of three capacitors shown in the electrical circuit model is calculated. Here generally, (C_a>>C_c>>C_b). In this study the value of void model and other parameters are calculated. The figure below shows the SIMULINK model which is used for the detection of partial discharge which is shown in Fig. 3.3.

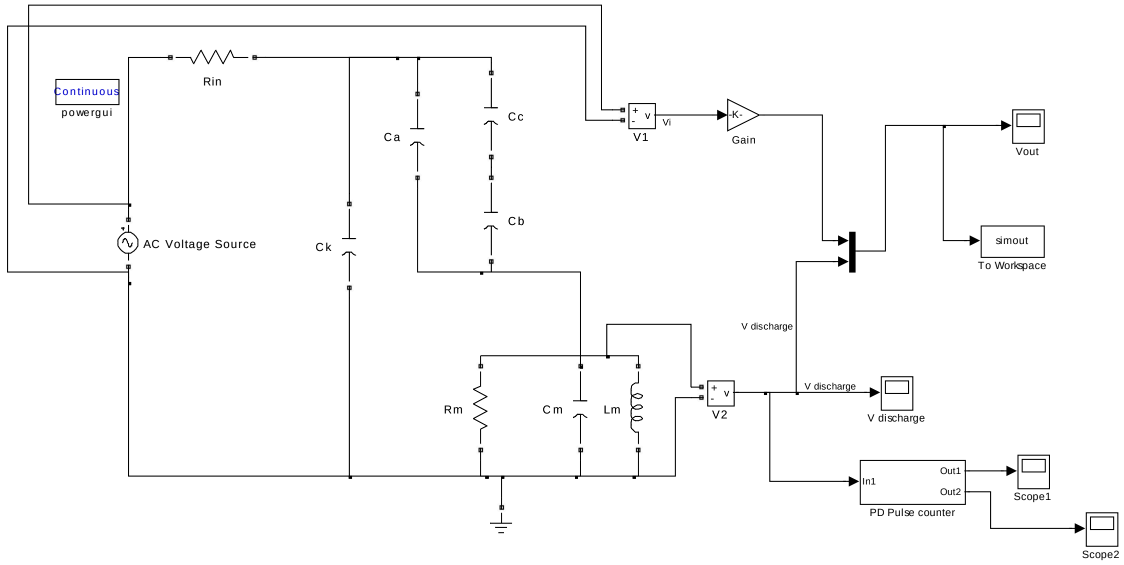

FIGURE 3.3: Simulink Model for Partial Discharge Detection

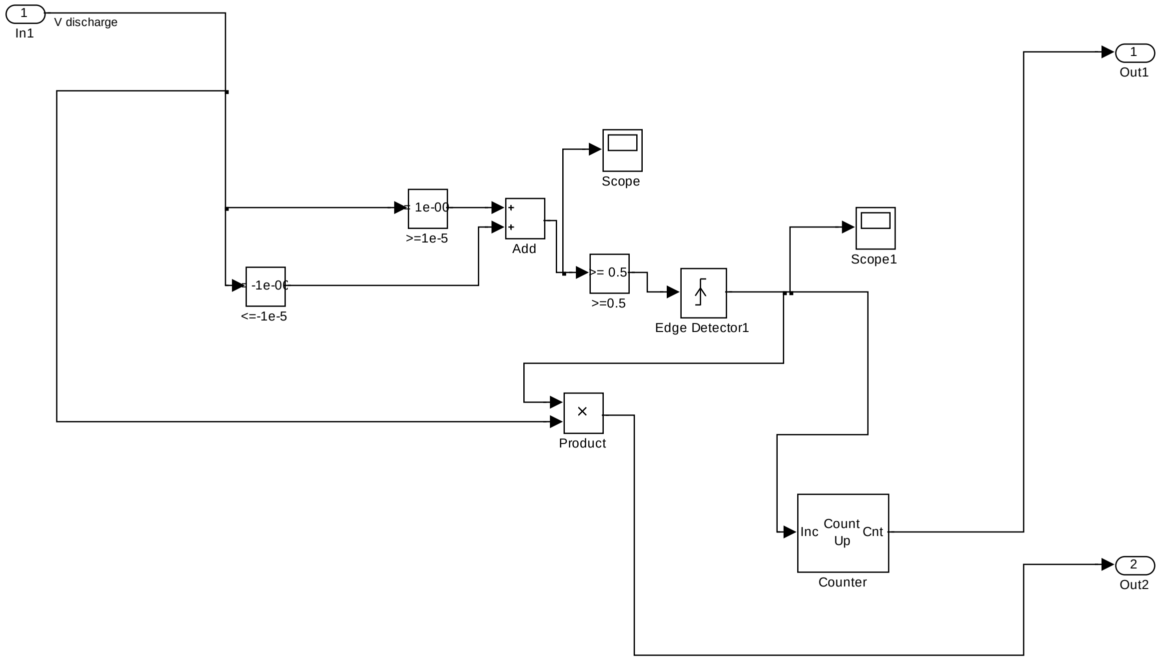

FIGURE 3.4: PD Pulse Counter Subsystem Circuit

3.5 PROGRAM TO COUNT NUMBER OF PD PULSES FOR ONE CYCLE

PD pulse output was considered for one ac cycle i.e. for 0.02sec or 2π radians. The number of PD pulses was counted by the PD Pulse Counter subsystem shown in figure 3.4. An edge detector was used whose output becomes 1 as soon as it detects a rising edge of input i.e. PD pulse waveform. The output of edge detector was fed to a pulse counter which counts the PD pulses. This output values were taken to workspace. A program was composed in MATLAB. A while loop and for loop were used which counts the number of PD pulses appearing in each section of 45^oor for time interval of 0.0025 sec for one ac cycle [14]. PD pulses were counted for 5 KV and 10 KV, and the numbers were plotted in form of chart.

CHAPTER **4**

ANALYSIS AND SIMULATION OF CALIBRATOR

Apparent Charge
Calibration of PD Measuring Circuit
Pulse Shape Parameters
Calibrator Circuit Model
Circuit Model of Calibrator with Test Object

4.1 APPARENT CHARGE

Since actual PD, which appears inside the insulation defect, cannot be directly measured, another related electrical quantity, the apparent charge q_a, is used to quantify the PD phenomenon. The ‘apparent charge’ of a PD pulse is the charge which, if injected within a very short time across the terminals of the Device Under Test (DUT) in a specified test circuit, would give the same reading on the measuring instrument as the PD current pulse itself. PD tests are performed by applying, through a supply circuit, the high voltage to the DUT and by measuring the apparent charge consequent to the PD event [15]. The determination of the measuring system scale factor, that is the ratio of the input quantity to the instrument indication, is performed by means of a suitable calibrator in the complete test circuit, because the measuring system response depends on the test circuit configuration [16]. The calibration procedure consists in injecting across the DUT a current pulse of known charge, generated by a PD calibrator, in absence of high voltage supply. The calibrator is essentially composed of a step voltage generator and a series capacitor.

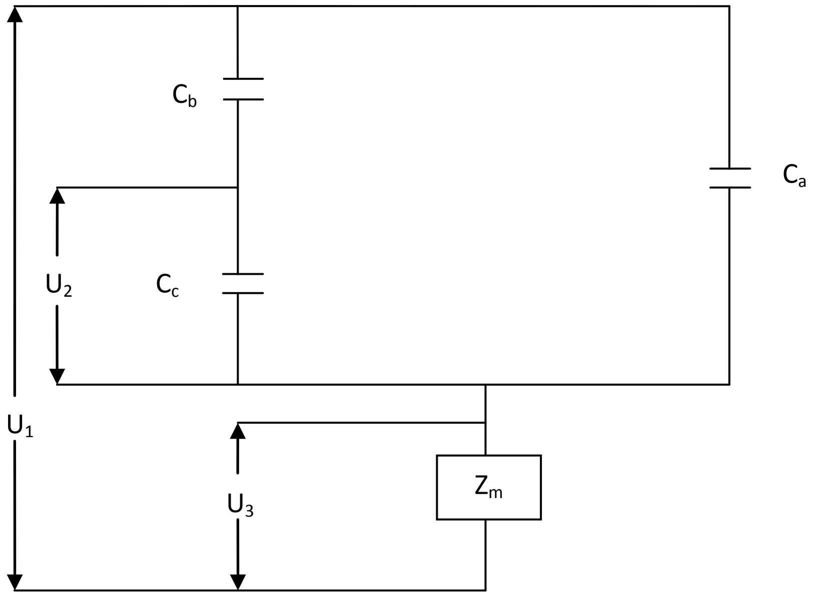

FIGURE 4.1: Voltages across Test Object

Where,

U_1= Test voltage applied

U_2= Voltage across PD source

U_3= Voltage across Z_m

$$U_3 = U_1 \times \frac{Ca}{(Ca+Cm)} \quad (7)$$

As $C_m >> C_a$,

$$\Rightarrow \quad U_3 \times C_m = U_1 \times C_a = q_a = \text{apparent charge} \quad (8)$$

It means that q_a stored temporarily in virtual test object capacitance can be evaluated by measuring transient voltage magnitude U_3 across measuring capacitance C_m.

As $C_a >> C_b$,

$$Q_a = U_1 \times C_a = U_2 \times C_b \quad (9)$$

$$\Rightarrow \quad Q_a = U_2 \times C_a \times \frac{Cb}{Ca} = q_c \times \frac{Cb}{Ca} \quad (10)$$

As $C_b/C_c << 1$ thus the charge at test object terminals is only a small fraction of charge created at PD site.

4.2 CALIBRATION OF PD MEASURING CIRCUIT

The quantitative assessment of the apparent charge transferred from the PD source to the terminals of the test object is based on the approach of Gemant and Philippoff, often referred to as a – b – c model due to the characteristic capacitances. Due to the series connection of C_b and C_c , where the condition C_b / $C_c << 1$ is always satisfied, the apparent charge q_a detectable at the test object terminals can be written as:

$$q_a = q_c \times \frac{Cb}{Cc} \quad (11)$$

That means the measurable apparent charge q_a is only a small fraction of the true pulse charge q_c created in the PD source. Consequently, the PD severity of HV apparatus cannot be estimated on the basis of the apparent charge alone, because the ratio C_b / C_c is not known at all. Therefore, knowledge rules for PD diagnosis have been established in the past which are based on practical experiences gained from comprehensive PD studies in laboratory and on-site [17]. Each PD event causes a reading R_i of the PD instrument which is proportional to q_a. To measure this quantity in terms of Pico Coulomb (pC) the Standard IEC 60270 specifies a calibration method which is based on the simulation of the internal charge transfer between the PD source and the terminals of the HV apparatus by means of an external adapted calibrator. Based on this calibration procedure the apparent charge of a PD pulse is defined in IEC 60270 as: “that charge which, if injected within a very short time between the terminals of the test object in a specified test circuit, would give the same reading on the measuring instrument as the PD current pulse itself.” The PD calibrator is generally equipped with a pulse generator connected in series with a calibrating capacitor. In order to simulate the transient voltage across the PD defect the pulse generator creates equidistant voltage steps of known magnitudes U_0 [18]. If the value of the calibrating capacitor C_0 is substantially lower than the value of the virtual test object capacitance C_a, the calibrating charge injected in the test object terminals, can simply be expressed by:

$$q_0 = C_0 \times U_0 = C_a \times U_1 \tag{12}$$

If real PD events appear, the apparent charge is given by:

$$q_a = C_a \times U_2 \tag{13}$$

Introducing equation (12) in equation (13) the unknown value of C_a can be eliminated. Thus,

$$q_a = q_0 \times (U_2 / U_1) \tag{14}$$

Because the transient voltages U_1 and U_2, which appear across the test object capacitance C_a, cause the readings R_0 and R_i, equation (14) can also be written as:

$$q_a = q_0 \times (R_i / R_0) \tag{15}$$

Where the ratio R_i / R_0 represents the scale factor, S_f of the PD measuring circuit applied.

Thus a PD calibrator is equipped with a pulse generator in series with a calibrating capacitor so that calibration pulses are produced which are repetitive charge of magnitude q_0 [19]

$$Q_0 = U_0 \times C_0 \tag{16}$$

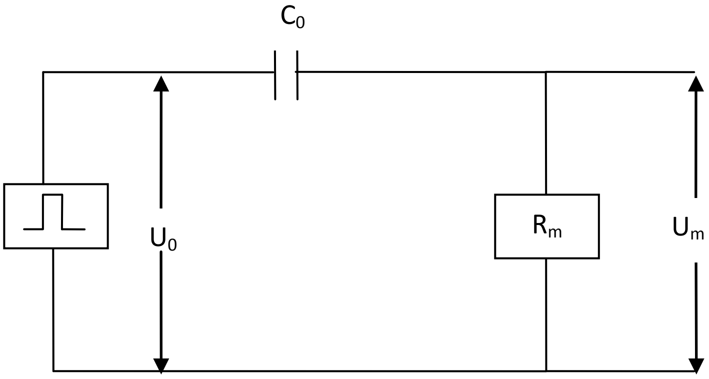

FIGURE 4.2: PD Pulse Generator

Where,

U_0 = Input step voltage

C_0 = Calibrating generator capacitance

U_m = Output voltage across R_m

In order to determine magnitude of calibrating charge, time dependent voltage $U_m(t)$ appearing across R_m has to be integrated in order to determine the magnitude of calibrating charge.

$$q_0 = \int i_m(t)dt \tag{17}$$

$$\Rightarrow\ q_0 = \frac{1}{R_m} \times \int i_m(t)dt \tag{18}$$

4.3 PULSE SHAPE PARAMETERS

As the charge transfer from PD site to test terminals is finished in few nanoseconds. Therefore step pulse generator should have an equivalent rise time, because charge transfer by calibrating capacitor is governed by t_r. The impact of step pulse shape on the uncertainty of calibrating charge can be neglected by following conditions [20]:

TABLE 4.1: Pulse Shape Parameters

Sl. no.	Parameters	Conditions
1.	Rise time	T_r<60 ns
2.	Time to steady state	T_s<500 ns
3.	Steady state duration	T_d>5µs
4.	Overshoot	$U_d<0.1U_0$
5.	Undershoot	$U_t<0.1U_0$

4.4 CALIBRATOR CIRCUIT MODEL

A PD calibrator is equipped with a pulse generator in series with a calibrating capacitor. Generator produces step voltage pulses of desired magnitude which produces PD pulses of required charge levels (in pC).

In MATLAB-SIMULINK environment, the Pulse voltage source is used with following parameters:

TABLE 4.2: Pulse Shape Parameters for Simulation

Sl. no.	Parameters	Values
1.	Initial value, V_1	0V
2.	Pulse value, V_2	9V
3.	Pulse delay time, t_d	0 sec
4.	Pulse rise time, t_r	$10^{-9}sec$
5.	Pulse fall time, t_f	$10^{-9}sec$
6.	Pulse width, pw	$4 \times 10^{-4}sec$
7.	Pulse period, per	$16 \times 10^{-4}sec$

Pulse Generator is in series with parallel set of switching capacitors. Capacitors were connected in parallel and the variable charge level was obtained by switching to different capacitors. The switching action was done by switches which were controlled by a controller. An input choice is given to controller and the required capacitor was switched.

The various parameters used for calibrator circuit:

TABLE 4.3: Switching Capacitors Used in Simulation

Sl. No.	Parameter	Values	Dimensions
1.	Capacitor 1	0.56	pF
2.	Capacitor 2	1.11	pF
3.	Capacitor 3	5.56	pF
4.	Capacitor 4	11.11	pF
5.	Capacitor 5	111.11	pF
6.	Resistor	500	kΩ

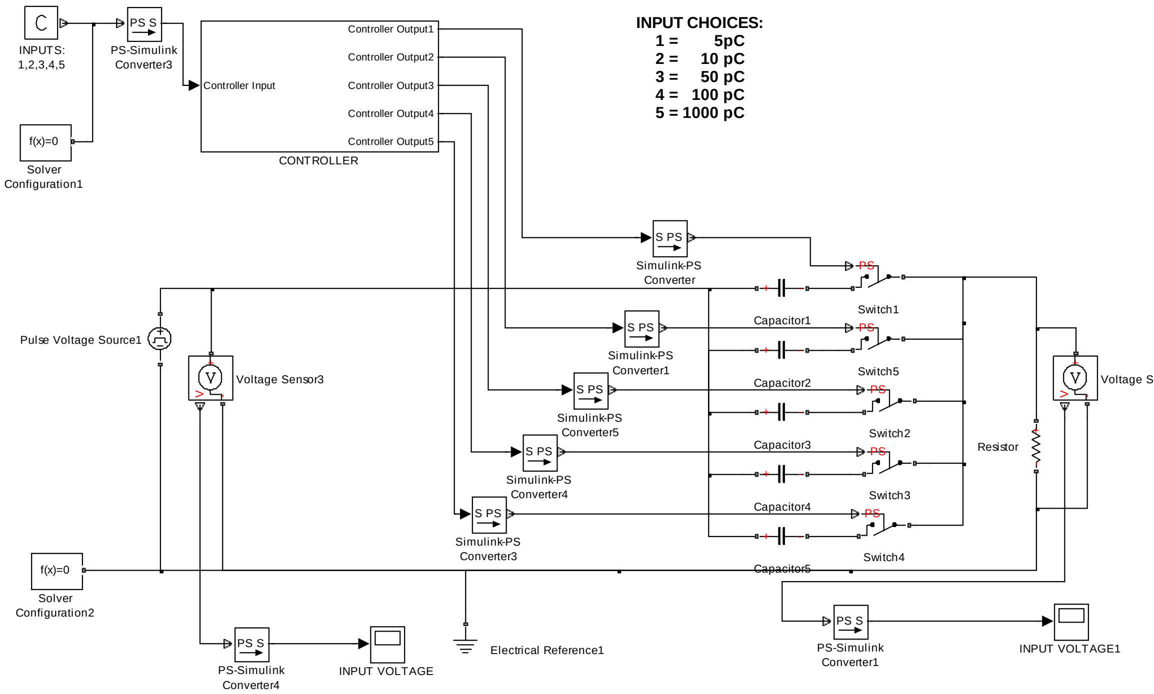

FIGURE 4.3: PD Calibrator Circuit

4.5 CIRCUIT MODEL OF CALIBRATOR WITH TEST OBJECT

Now, the calibrator was connected across the test object and the output pulses were observed through measuring circuit. The measuring circuit consists of parallel RC circuit. A coupling capacitor was connected in series to the measuring circuit. This measuring circuit in series with coupling capacitor was connected across the test object.

The parameter values for measuring circuit were as:

TABLE 4.4: Measuring Circuit Parameters

Sl. no.	Parameter	Symbol	Value
1.	Measuring Capacitor	C_m	1 µF
2.	Measuring resistor	R_m	100 Ω

As the capacitance of the test object and its voids are in Pico-coulomb range and the capacitors used in calibrators are also in Pico-coulombs. Hence, before connecting to the test object, the calibrator is connected to a buffer amplifier to prevent loading effects.

Input choices were given to get the desired Pico-coulomb level charges. The output pulses were observed through measuring circuit.

The overall circuit is as:

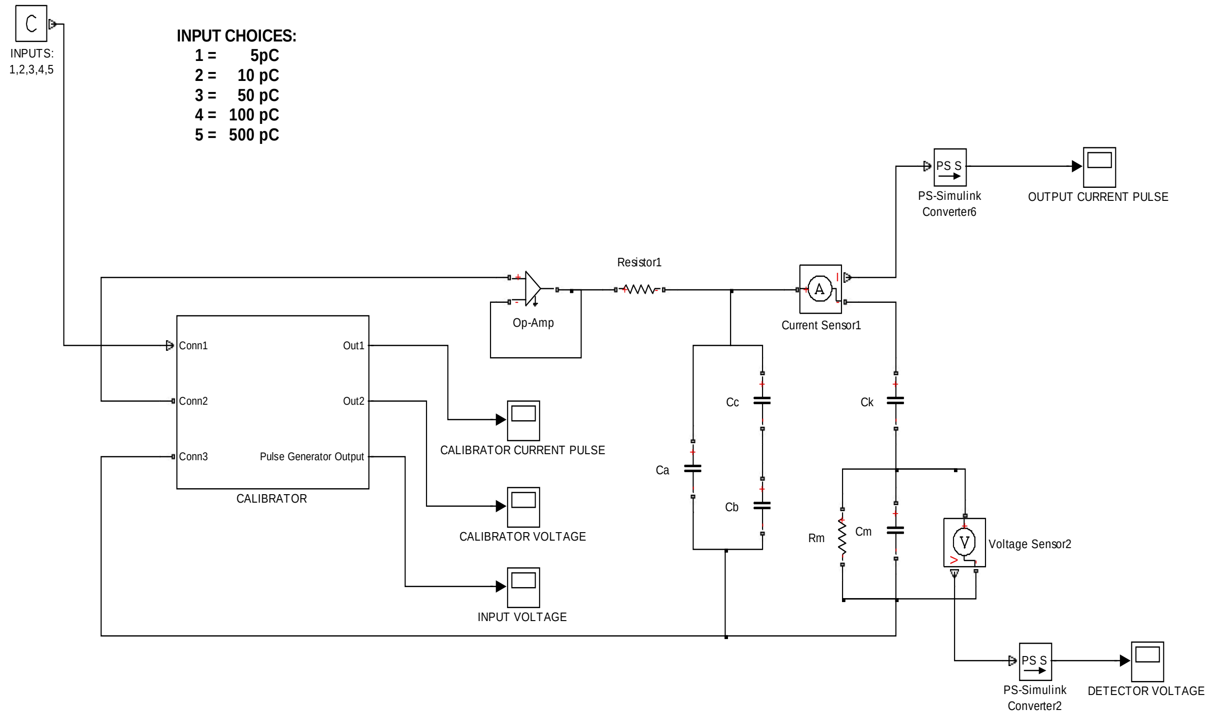

FIGURE 4.4: PD Calibrator Circuit Connected across Test Object

The calibrator circuit consisted of Pulse generator and a set of switching capacitors which were switched through inputs given to controller. The calibrator subsystem is as shown:

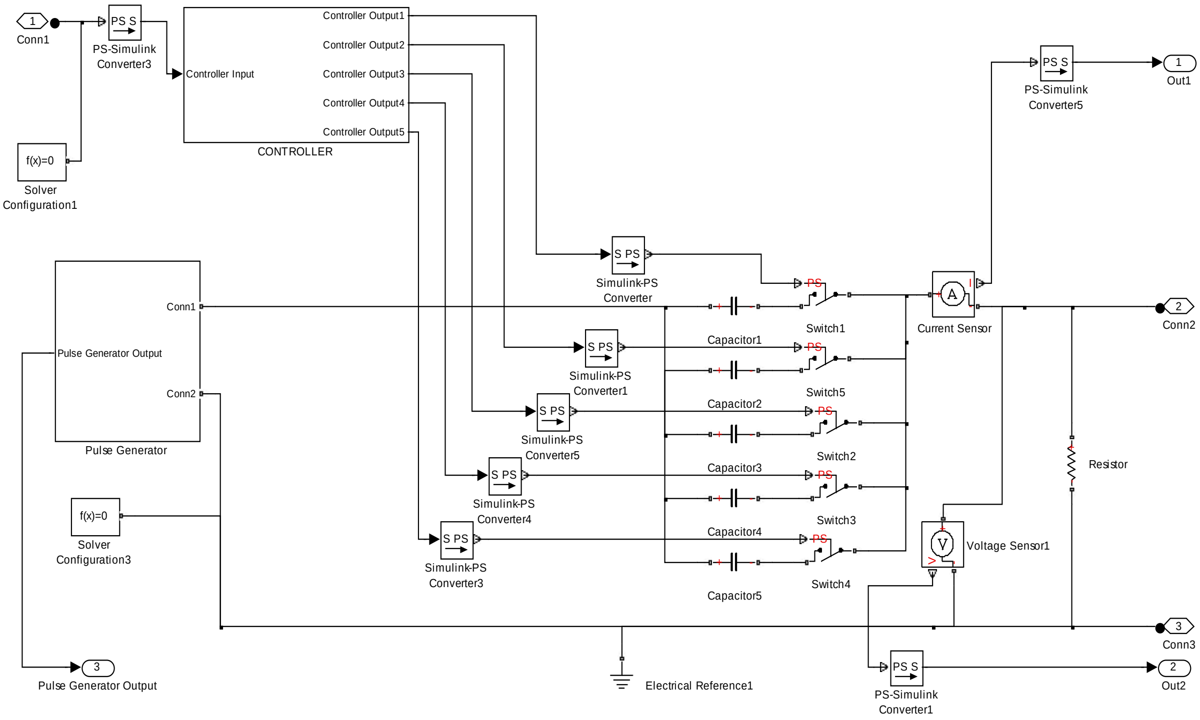

FIGURE 4.5: Calibrator Subsystem Circuit

The Pulse Generator consists of a pulse voltage source, whose output is supposed to be taken from an IC 555 timer circuit. The output pulse of the timer is then fed to a series RC circuit. The series RC circuit is used to achieve the desired rise time (<60 ns), fall time and pulse duration (>5µs).

The various parameters used for PD generator in simulation are:

TABLE 4.5: Pulse Generator Parameters Used for Simulation

Sl. No.	Parameter	Values	Unit
1.	Pulse Voltage Source	0-9	V
1.	Resistor	1	Ω
2.	Resistor 1	50	Ω
3.	Capacitor	1	µF

The Pulse Generator subsystem is shown as:

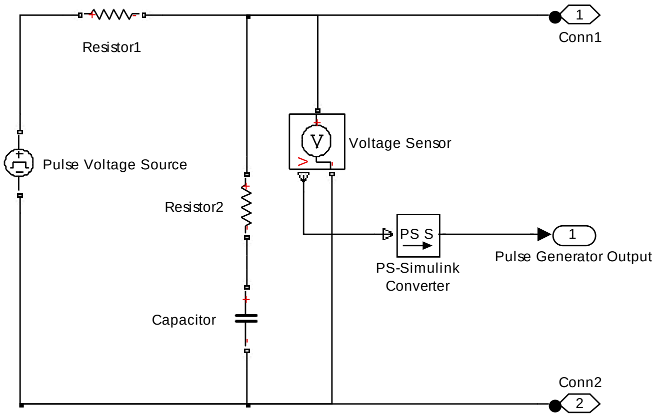

FIGURE 4.6: Pulse Generator Subsystem Circuit

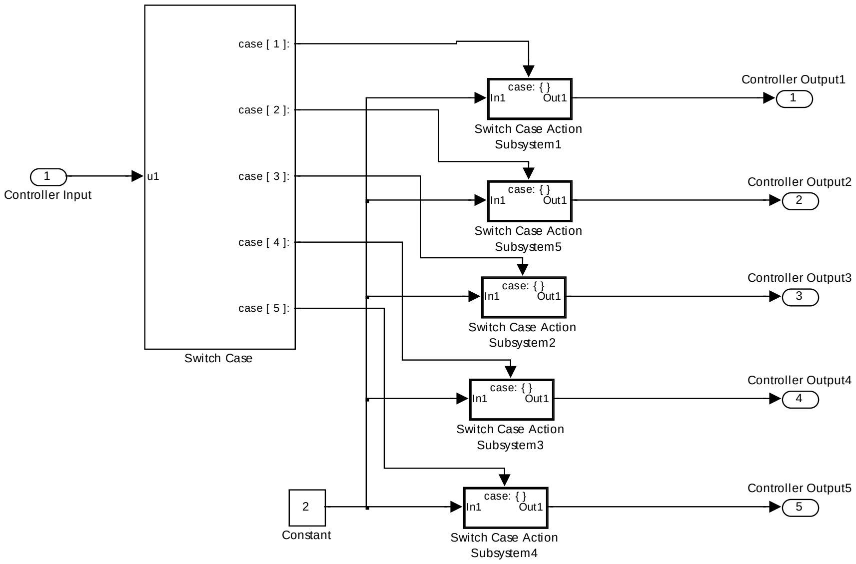

FIGURE 4.7: Controller Subsystem Circuit

CHAPTER 5

PRACTICAL IMPLEMENTATION OF PROPOSED WORK DONE

Introduction
IC555 Timer (NE555N)
Series RC Circuit
Switching Capacitors
Output Resistor
Complete Model of Calibrator Circuit

5.1 INTRODUCTION

The practical implementation of the PD Calibrator is made based on the simulated models earlier. The Calibrator is designed based on the calculated values from the simulation. However, compatible ICs, Resistors Inductors and Capacitors should be selected for ensuring proper operation of the calibrator.

The calibrator consists of Pulse Generator in series with a set of Capacitors which were connected in parallel and the variable charge level was obtained by switching to different capacitors. This switching action was done by push button switches. The pulse generation was done from an IC 555 timer circuit. The output pulse of the timer is then fed to a series RC circuit. The series RC circuit is used to achieve the desired rise time (<60 ns), fall time and pulse duration (>5µs).

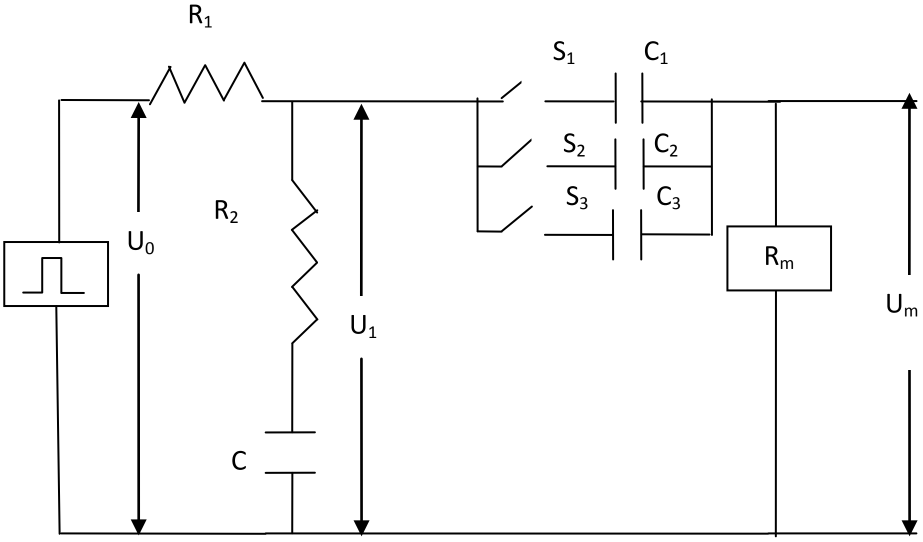

FIGURE 5.1: PD Calibrator Circuit Diagram

5.2 IC555 TIMER (NE555N)

An IC555 (NE555N) was used as a step pulse source for the calibrator. It was used in astable multivibrator mode with frequency≈ 2.75 KHz. A 9V battery was used as a voltage source for IC555. The parameters of various elements used were:

TABLE 5.1: Parameters of Elements Used With IC555

Sl. No.	Parameter	Value
1.	C_0	0.02μF
2.	C	1 μF
3.	R_A	140Ω
4.	R_B	150Ω
5.	Battery	9V

IC 555 PIN configuration:

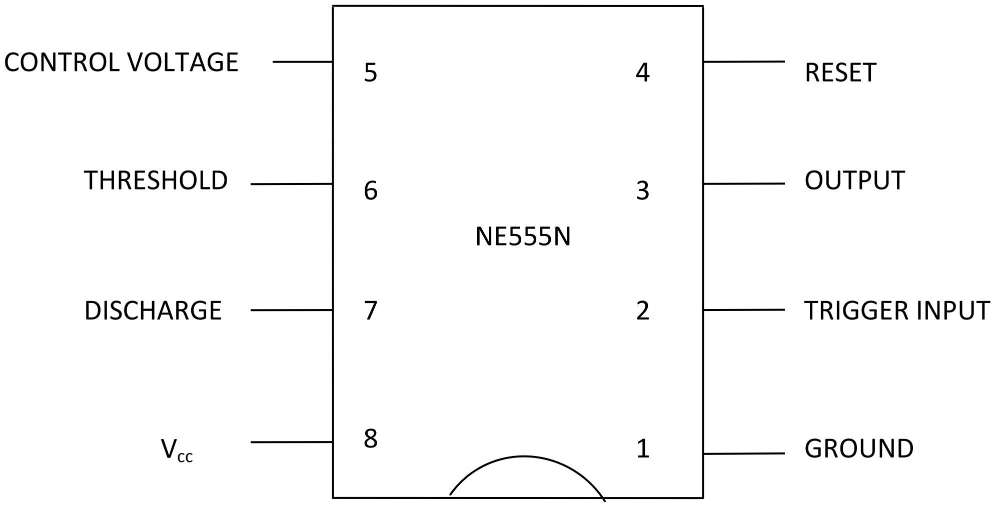

FIGURE 5.2: IC555 Pin Diagram

IC 555 in astable mode is shown:

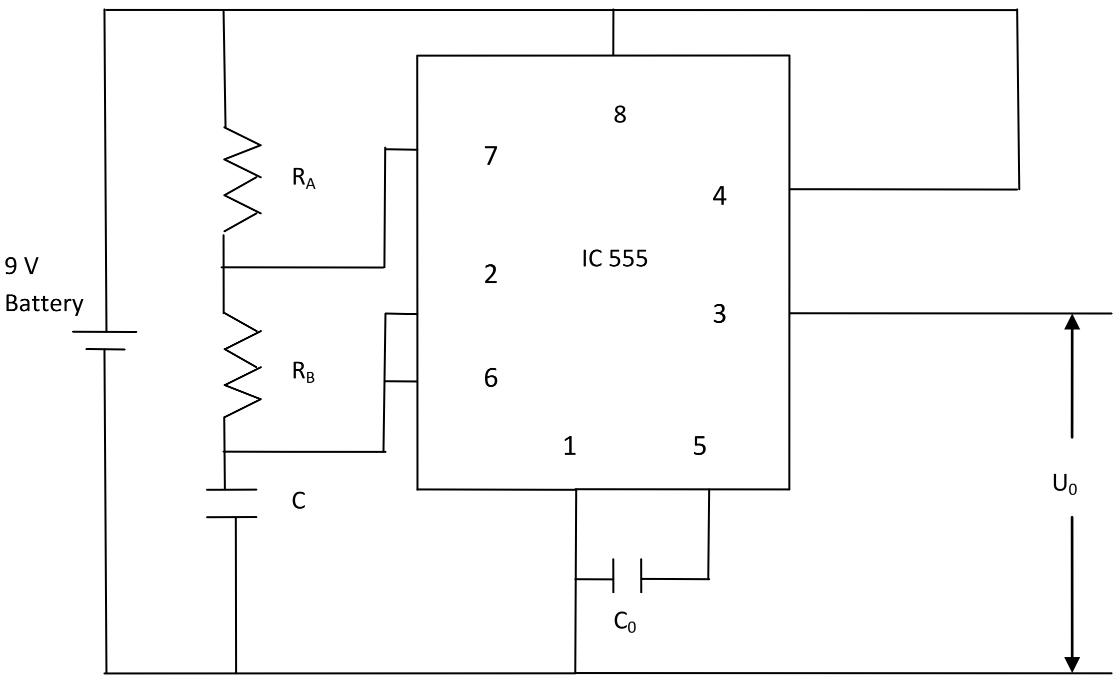

FIGURE 5.3: IC555 as Astable Multivibrator

5.3 SERIES RC CIRCUIT

The output pulse of the IC 555 timer is then fed to a series RC circuit. The series RC circuit is used to achieve the desired rise time (<60 ns), fall time and pulse duration (>5µs). The values of R and C are as:

TABLE 5.2: Resistors and Capacitor Values Used In IC 555 Connections

Sl. No.	Parameter	Values	Unit
1.	R_1	1	Ω
2.	R_2	50	Ω
3.	C_S	1	µF

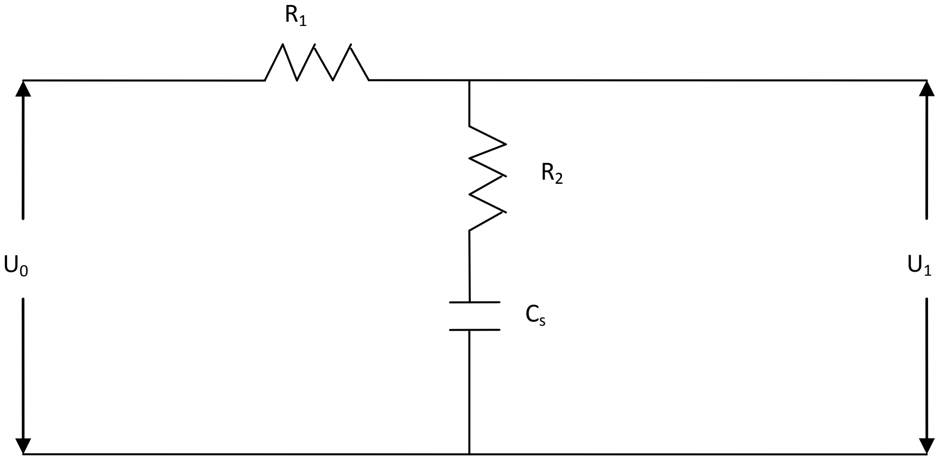

FIGURE 5.4: Series RC Circuit of PD Calibrator

5.4 SWITCHING CAPACITORS

Set of parallel capacitors were connected along with push button switches to get varying charge levels in output.

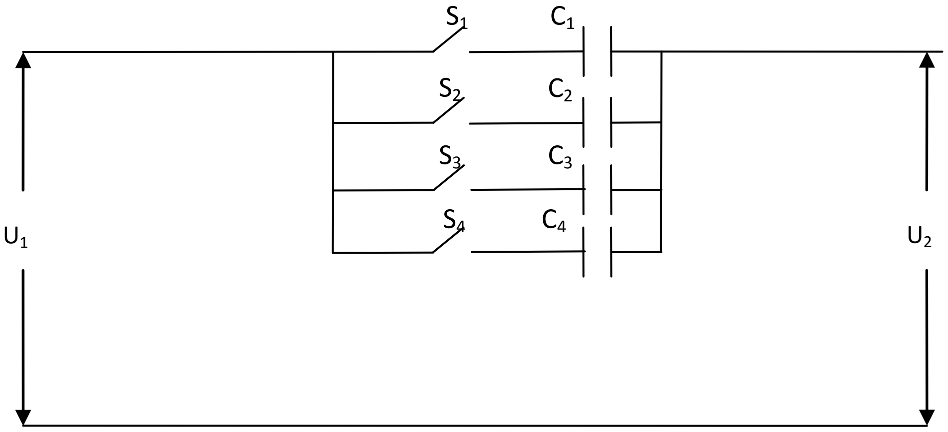

FIGURE 5.5: Parallel Set of Switching Capacitors

TABLE 5.3: Values of Switching Capacitors

Sl. No.	Parameter	Values	Unit
1.	C_1	1	pF
2.	C_2	4.7	pF
3.	C_s	12	pF
4.	C_4	56	pF

5.5 OUTPUT RESISTOR

The output was measured across resistor, R_m

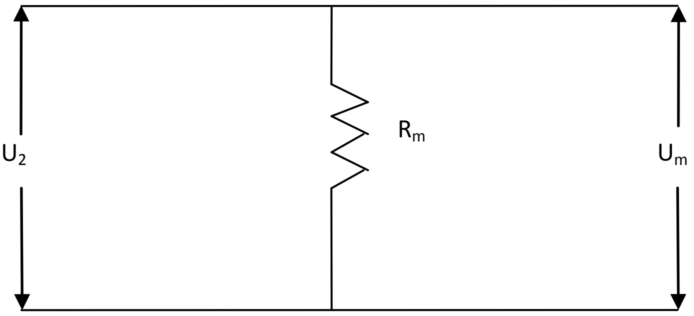

FIGURE 5.6: Output Resistor of PD Calibrator

Where, $R_m = 470\ K\Omega$

5.6 COMPLETE MODEL OF CALIBRATOR CIRCUIT

The battery, IC 555 timer, series RC circuit, parallel set of switching capacitors and measuring resistor were placed on vero-board and were soldered to form the calibrator. Output was taken across $R_{m.}$

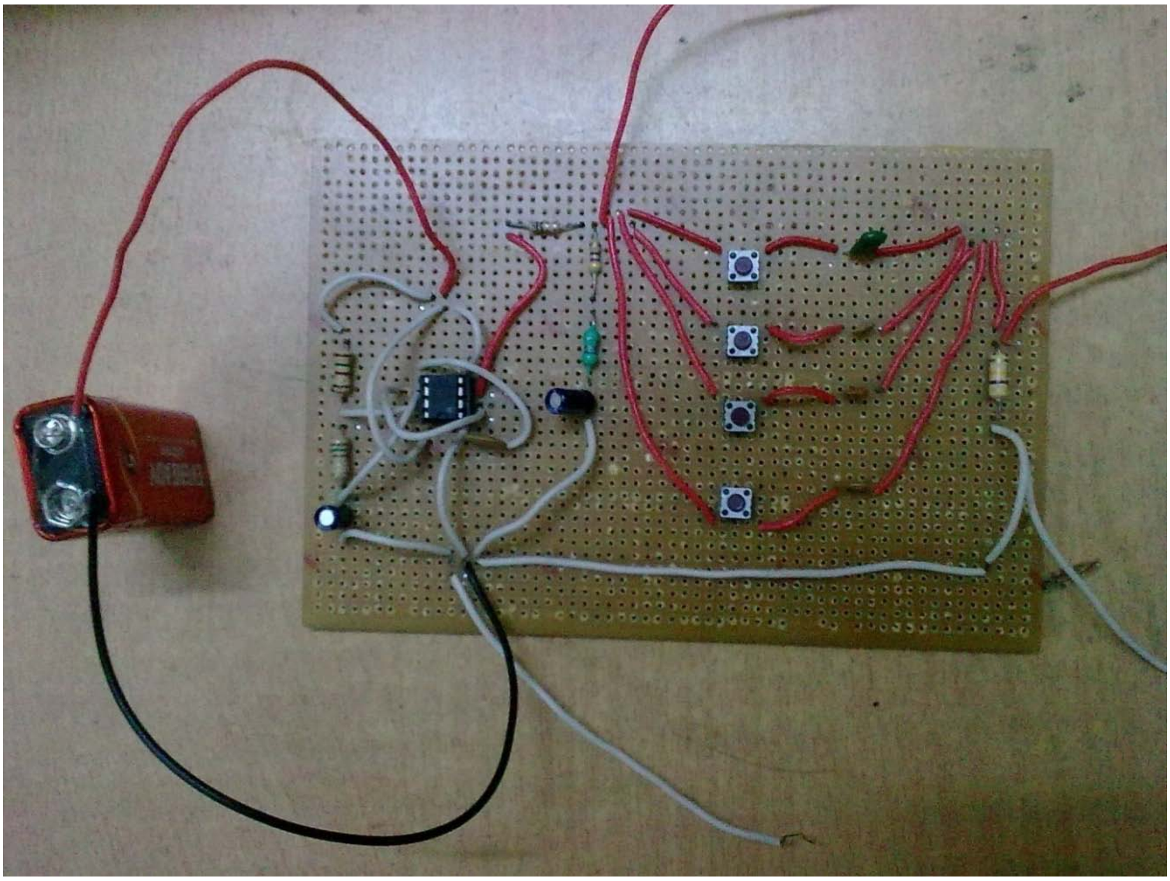

FIGURE 5.7: Photograph of PD Calibrator Circuit Model

CHAPTER **6**

RESULTS AND DISCUSSIONS

Results for Partial Discharge Pulse Generation
Simulation Result for Calibrator and Overall Circuit
Results for Physical Calibrator Model

6.1 RESULTS FOR PARTIAL DISCHARGE PULSE GENERATION

To find out the partial discharge characteristics due to the presence of cubical void inside a solid epoxy resin insulator, a high voltage of 0-15 kV is applied. The partial discharge characteristics cannot be measured directly in high voltage power equipment system. Hence it is necessary to see the characteristics of partial discharge.

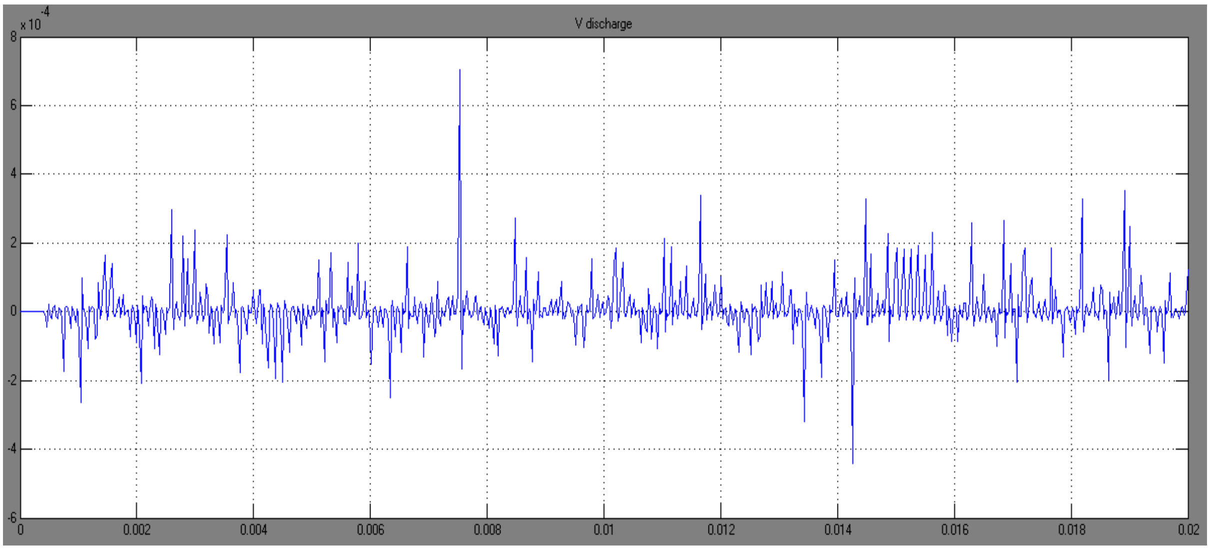

FIGURE 6.1: The Observed Partial Discharge Pulse at 5 KV

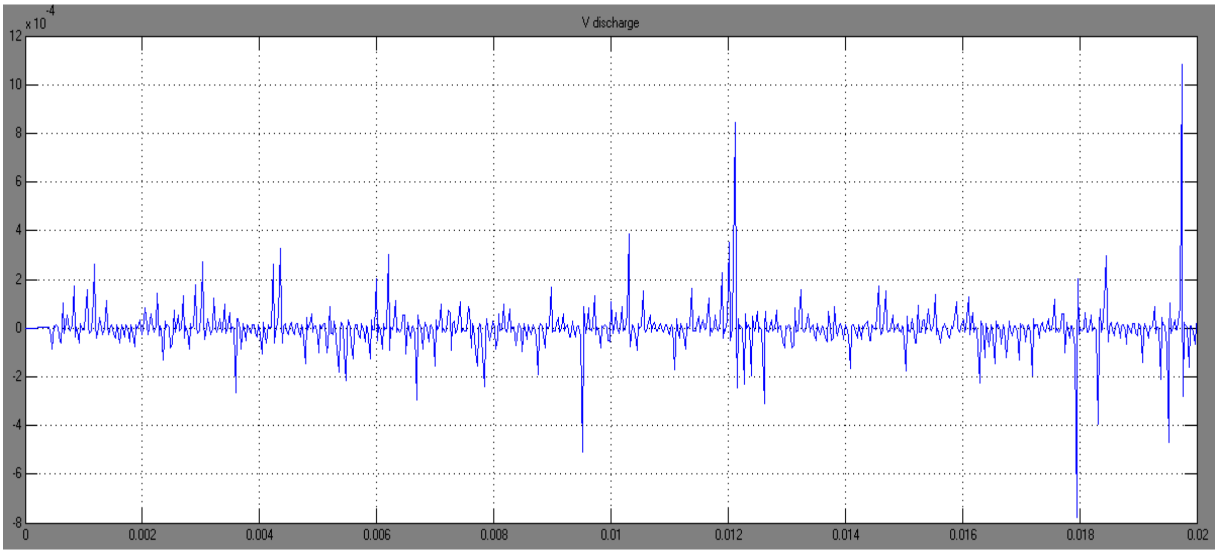

FIGURE 6.2: The Observed Partial Discharge Pulse at 10 KV

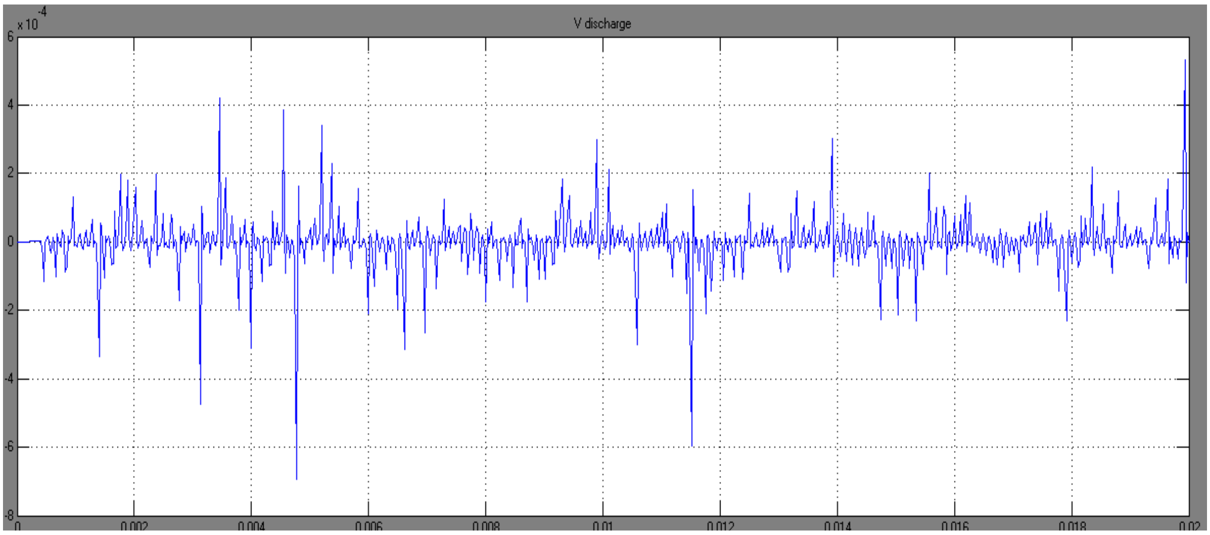

FIGURE 6.3: The Observed Partial Discharge Pulse at 15 KV

The Fig. 6.1 shows the partial discharge characteristics at 5 kV; Fig. 6.2 shows the partial discharge characteristics at 10 kV and Fig.6.3 shows the partial discharge characteristics at 15 kV applied voltage. The partial discharge characteristic inside a solid insulation is found out using MATLAB Simulink model.

The PD pulse count was found by the PD pulse count program. Here the number of pulses from the edge detector output was counted.

The PD pulse count for 45°sections were found using the MATLAB program. The PD pulse count for 5 KV and 10 KV were as shown:

TABLE 6.1: Number of PD Pulses Appearing for Phase Range of 45°

Phase angle in degrees	No. of PD pulses for 10 KV	No. of PD pulses for 5 KV
0-45	3	4
46-90	5	9
91-135	6	5
136-180	5	5
181-225	10	4
226-270	5	7
271-315	3	10
316-360	8	5

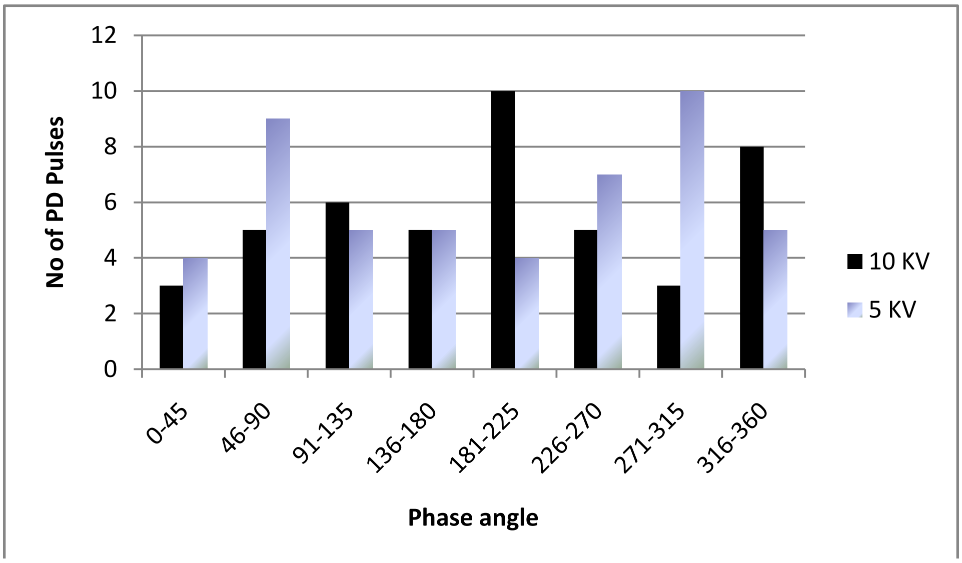

FIGURE 6.4: Bar Graph showing Number of PD Pulses with Phase Angle

6.2 SIMULATION RESULT FOR CALIBRATOR AND OVERALL CIRCUIT

The Pulse generator was made with required rise time, fall time and pulse duration. The pulse voltage source (IC 555) output was fed to series RLC circuit.

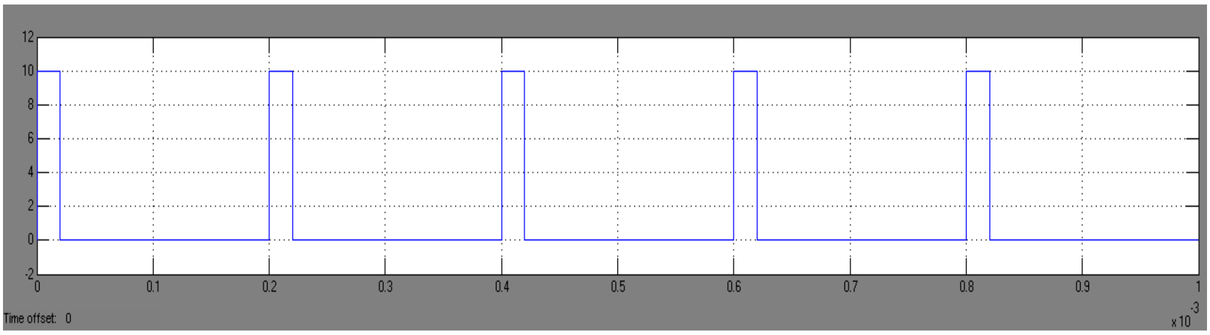

FIGURE 6.5: Pulse Voltage Source Output

The output was of pulse generator was taken at through series RLC circuit.

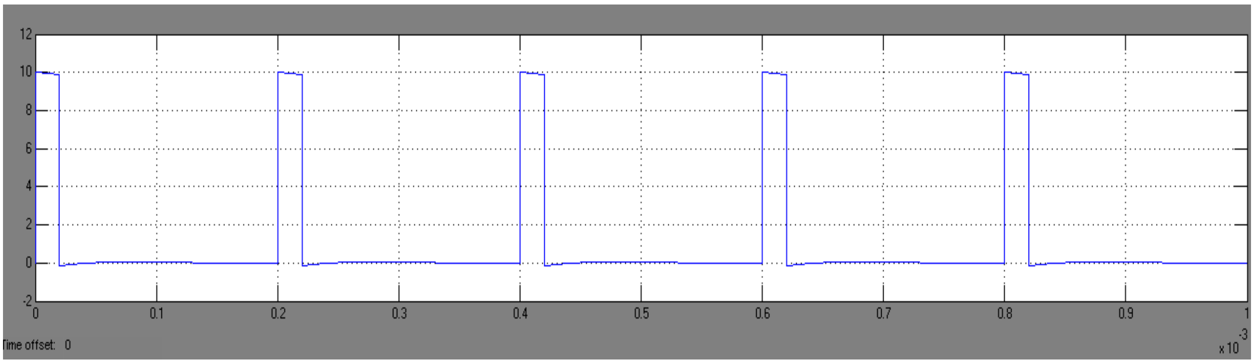

FIGURE 6.6: Output of Pulse Generator

The calibrator consists of Pulse Generator in series with switching capacitors. Capacitors were connected in parallel and the variable charge level was obtained by switching to different capacitors.

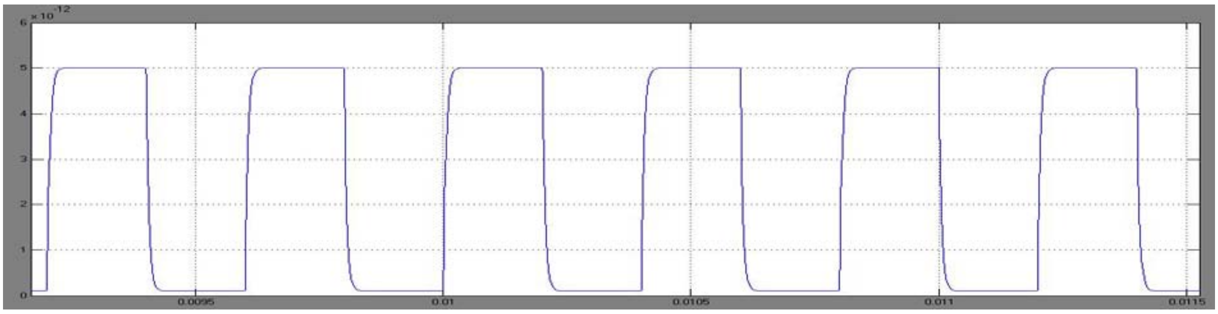

FIGURE 6.7: 5pC Charge Level Output by Choice 1

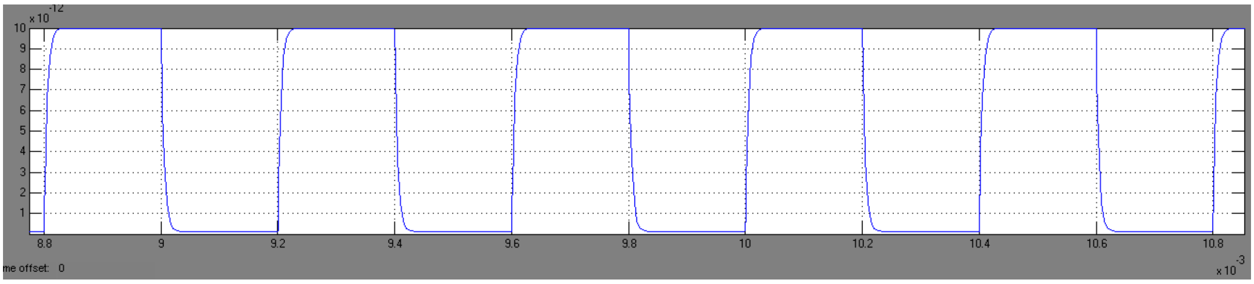

FIGURE 6.8: 10pC Charge Level Output by Choice 2

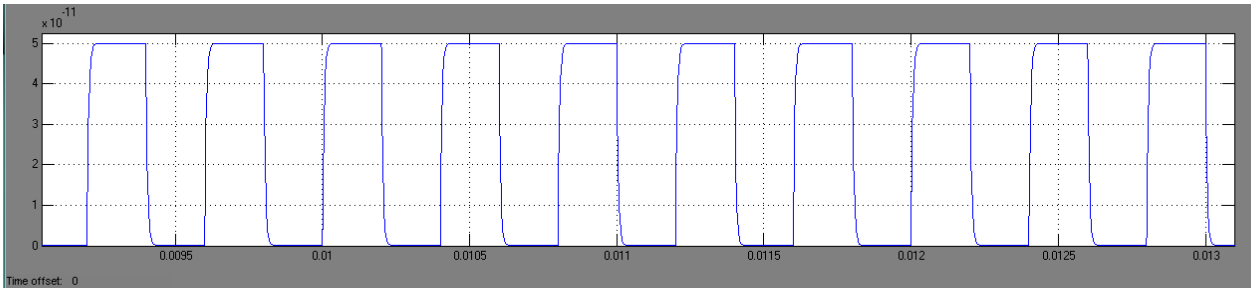

FIGURE 6.9: 50pC Charge Level Output by Choice 3

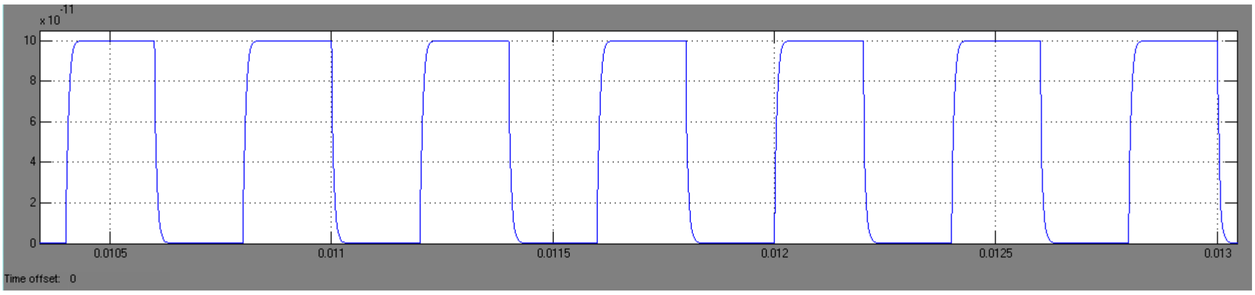

FIGURE 6.10: 100pC Charge Level Output by Choice 4

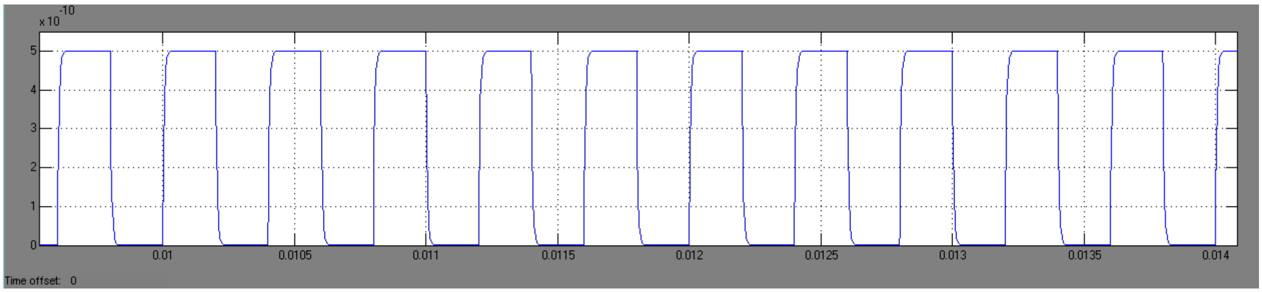

FIGURE 6.11: 500pC Charge Level Output by Choice 5

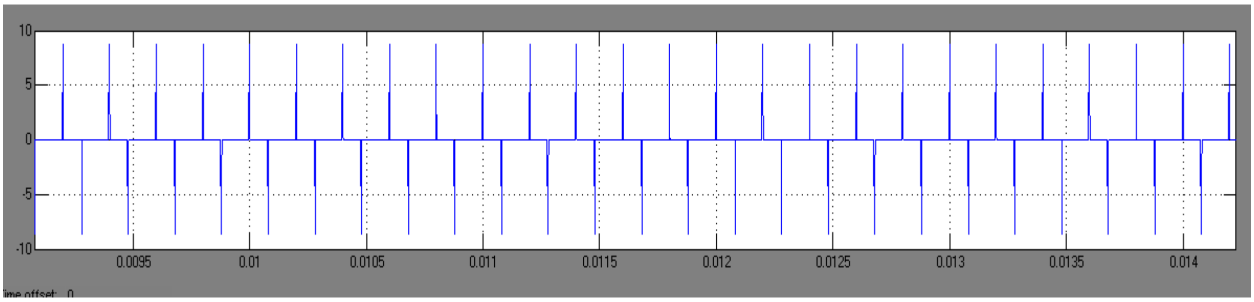

FIGURE 6.12: Output Pulses by Calibrator

The calibrator was connected to test object and output pulses were observed through measuring circuit.

FIGURE 6.13: Output Pulses from Detector Circuit

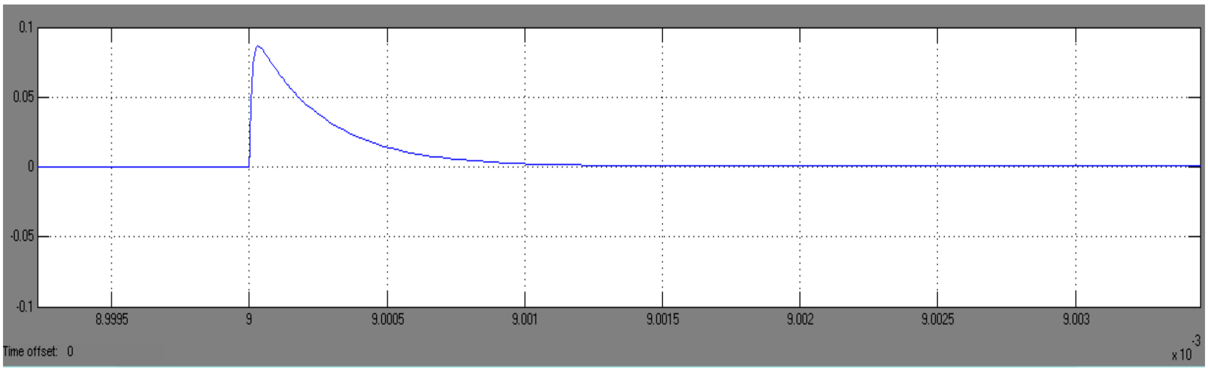

FIGURE 6.14: A Detector Circuit Output Pulse Expanded Along Time Axis

6.3 RESULTS FOR PHYSICAL CALIBRATOR MODEL

Experimental results are the most important part as it helps to validate the model of a project with the simulation results. It also ensures the proper working of the model. Here, the experimental results of the physical calibrator model are provided. The output waveforms were observed across Digital Storage Oscilloscopes.

As the IC 555 timer circuit output was fed to series RC circuit, a sufficient rise time, fall time and steady state duration was achieved.

The Output waveform from series RC circuit is:

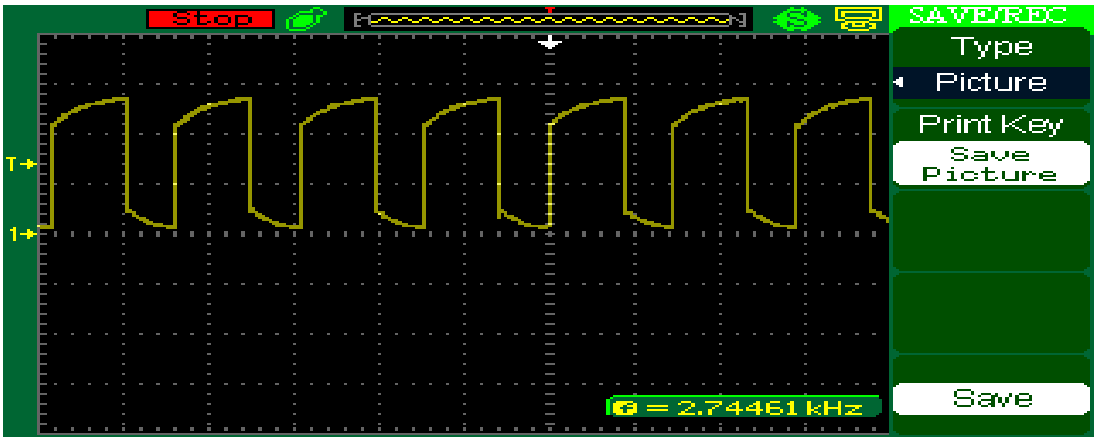

FIGURE 6.15: Output Pulses from Series RC Circuit

The Output voltage pulses seen across series RC circuit had Peak Value of 8.2 Volts with Steady state duration of 210 µs. The frequency was 2.74 KHz.

The output after RC circuit was fed to parallel set of switching capacitors. Various levels of charges were obtained by switching to different capacitors. The output waveforms were obtained at DSO.

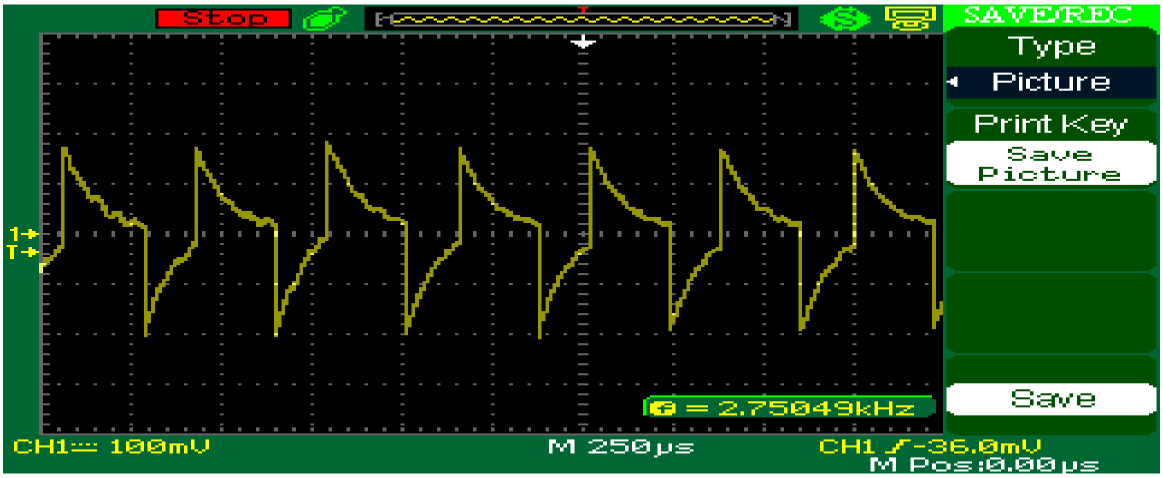

FIGURE 6.16: Output Waveform from 4.7pf Capacitor

The Output waveform when 4.7pF capacitor was connected, had Peak Output Voltage of 172 mV and the Charge associated was: $C_1 \times V = 4.7 \times 8.2 = 38.54$ pC.

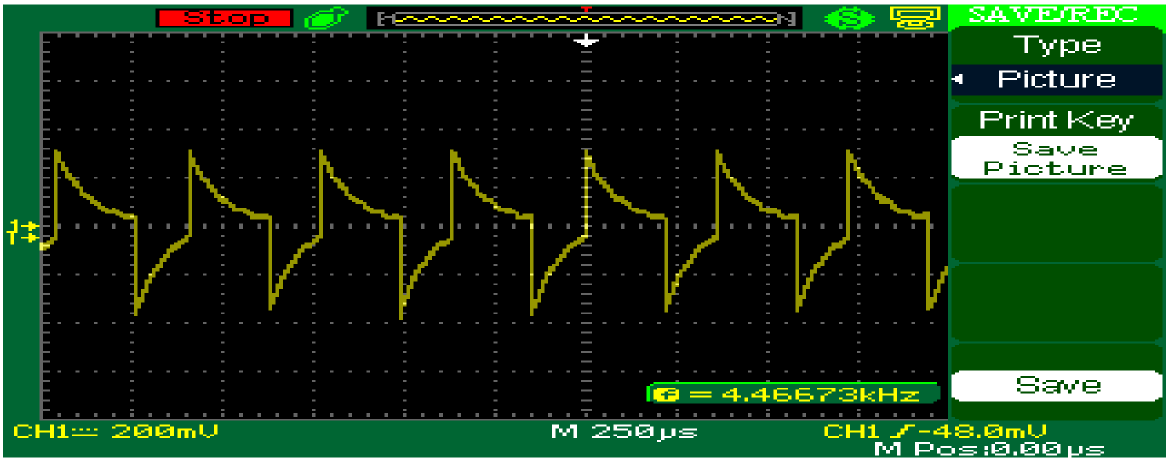

FIGURE 6.17: Output Waveform from 12pF Capacitor

The Output waveform when 4.7pF capacitor was connected, had Peak Output Voltage of 304 mV and the Charge associated was: $C_2 \times V = 12 \times 8.2 = 98.4$ pC.

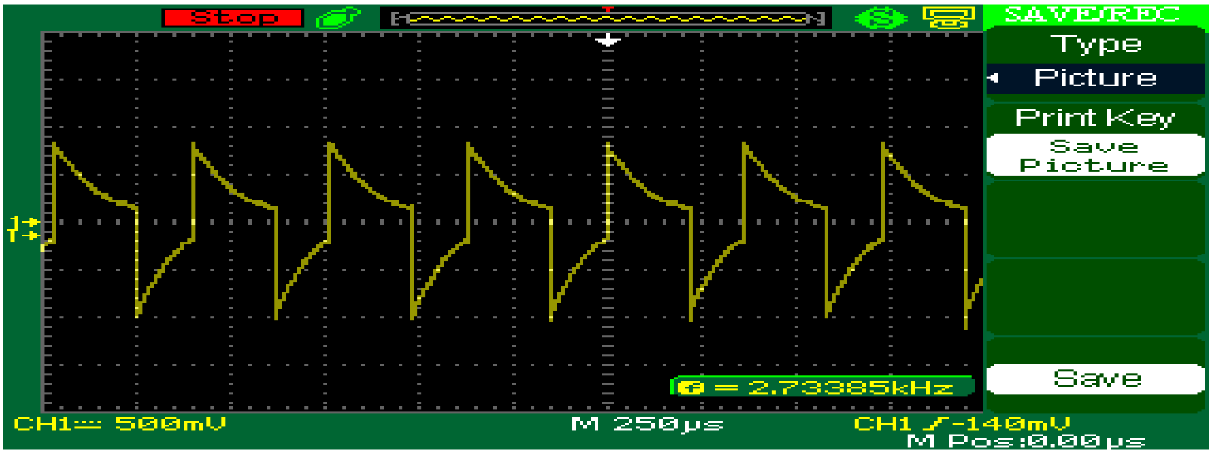

FIGURE 6.18: Output Waveform from 56pF Capacitor

The Output waveform when 56pF capacitor was connected, had Peak Output Voltage of 860 mV and the Charge associated was: $C_3 \times V = 56 \times 8.2 = 459.2$ pC.

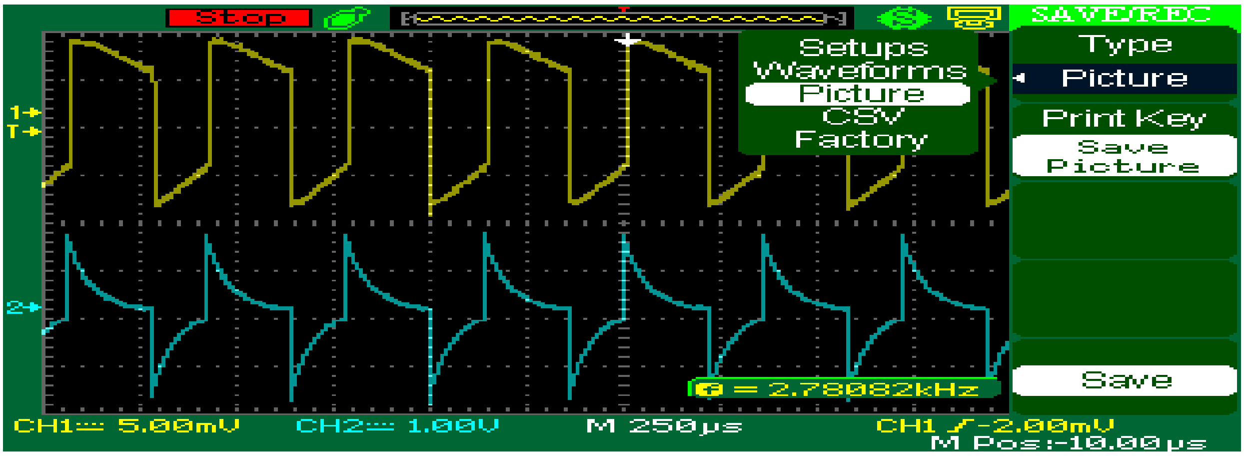

FIGURE 6.19: Input and Output Waveforms

CHAPTER 7

CONCLUSION AND FUTURE WORK

Conclusion
Future Work

7.1 CONCLUSION

Partial discharge is the main problem in high voltage power equipment system. Therefore, detection and measurement of partial discharge is necessary to keep the equipment in healthy condition during their operation. In this work an epoxy resin is taken as a solid insulation material and MATLAB Simulink based model has been introduced to generate the PD pulses and detect it. One sinusoidal ac cycle was taken and divided into 8 segments each of 45^o and the number of pulses appearing for each segment was found by MATLAB program. The results for PD pulse count for 5 KV and 10 KV were plotted as bar graph and compared. A calibrating circuit was modeled in MATLAB Simulink to create desired output PD pulses with required charge levels i.e. 5pC, 10pC, 50pC, 100pC and 500pC. The calibrator circuit was connected across the test object and output pulses were detected through the measuring circuit. The output pulses were similar to the calibrating pulses as required. A physical model of calibrator was made and output waveforms were observed on DSO. The output was similar to the simulation results. The output charge were calculated as 38.54pC, 98.4pC and 459.2pC for 4.7 pF, 12pF and 56pF respectively

7.2 FUTURE WORK

- The PD detection is based considering cylindrical void, thus a different type of void model has to be developed to investigate the performance characteristic of PD inside the different dielectric medium.
- The physical calibrator model needs to be tested across a test object and the output charge is to be measured from measuring circuit.

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