A STUDY OF PARTIAL DISCHARGE CHARACTERISTICS IN HIGH VOLTAGE INSULATORS

A project submitted in partial fulfilment of the requirement for the degree of

Bachelor of Technology

In

Electrical Engineering

By

Bedaprakash Ratha

(Roll No.: 108EE022)

&

Tushar Mishra

(Roll No.: 108EE031)

Department of Electrical Engineering

National Institute of Technology, Rourkela

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Under the guidance of

Prof. Subrata Karmakar

Department of Electrical Engineering

National Institute of Technology, Rourkela

Odisha

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National Institute of Technology

Rourkela

CERTIFICATE

This is to certify that the thesis entitled, "**A Study of Partial Discharge Characteristics in High Voltage Insulators**" submitted by Bedaprakash Ratha and Tushar Mishra in partial fulfilment of the requirements for the award of Bachelor of Technology Degree in Electrical Engineering at the National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any Degree or Diploma.

Date:

Prof. S. Karmakar

Dept. of Electrical Engineering

National Institute of Technology, Rourkela

Rourkela- 769008

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Place: National Institute of Technology, Rourkela

Date: 1. Bedaprakash Ratha

2. Tushar Mishra

Abstract

Insulators are the integral part of the high voltage power equipment. Several types of insulators are used in high voltage electrical power system to protect the power equipment. For the purpose of safety and better efficiency, it is necessary to keep the insulators in a healthy condition during its operation. As the insulators are always in impure form due to presence of air bubbles/other impurities inside the insulators, the local electrical breakdown so called partial discharge (PD) takes place due to the high voltage tresses. Due to this, PD occurs and property of insulators deteriorates enormously. Therefore, detection of PD is the one of the important task for electrical engineers to keep the high voltage power equipment in healthy condition. In this work, an electrical circuit model of an epoxy resin (i.e., an insulator) with a cubical void (air bubble) as an impurity is taken for realization of actual PD activity inside the insulator with the application of high voltage using MATLAB Simulink environment. In this study, the maximum amplitude of PD, partial discharge pulses at different applied voltages, and amplitude of PD with frequency is studied.

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Symbol/Nomenclature	Acronyms and Abbreviations
PD	Partial Discharge
ε_0	Permittivity of free space
ε_r	Relative permittivity
C_m	High voltage measuring capacitor
C_k	Coupling capacitor
C_a	Capacitance of healthy part of insulator
C_b	Capacitance of remaining dielectric in series with void
C_c	Capacitance of void

CHAPTER-1

Introduction

Chapter 1

Introduction

1.1 Introduction

Rapid growth in power system has given the opportunity to protect the equipments for reliable operation during their operating life. The insulation quality plays a vital role in high voltage power system equipment. It has been seen by power engineers that one of the major problems in high voltage (HV) power system is breakdown of insulators or degradation of insulators. Due to the degradation of insulators in power system engineering other equipments tends to give less efficiency. Insulators are the major equipments in power system. For the purpose of safety and better efficiency, it is necessary to keep the insulators in a healthy condition during its operation. As the insulators are always in impure form due to presence of air bubbles/other impurities inside the insulators, the local electrical breakdown so called partial discharge (PD) is takes place due to the high voltage tresses. The failure of insulation arises due to the presence of partial discharges. Due to PD, the properties of such insulators deteriorate enormously. Finally, the breakdown is takes place and entire power system is collapsed. Therefore, continuous monitoring and detection of PD is the one of the important task for electrical engineer to keep the high voltage power equipment in healthy condition. In this work, an electrical circuit model of an epoxy resin (i.e., an insulator) with a cubical void (air bubble) as an impurity is taken for realization of actual PD activity inside the insulator with the application of high voltage using MATLAB Simulink environment. In this study, the maximum amplitude of PD, partial discharge pulses at different applied voltages, and amplitude of PD with frequency is studied.

1.2 Objective of the thesis

The main objective of the thesis:

- To find the capacitance of the insulator.
- To find out the partial discharge pattern at different applied voltages.
- To find out the maximum amplitude of partial discharge.
- To find the frequency response of the partial discharge pulse.

1.3 Organisation of the thesis

This thesis is divided into five chapters including introduction. Chapter 1 contains the introduction, the objective of the thesis. Chapter 2 contains the background and the literature review about partial discharge, classification, ageing and breakdown of insulators and detection of partial discharge. Chapter 3 includes the method and modelling of electrical circuit used for the detection of partial discharge characteristics in high voltage insulators. Chapter 4 includes the simulation result. It consists of the partial discharge pulses at different applied voltages and the frequency plot of partial discharge pulses. Chapter 5 consists of the conclusion as well as future work of the project.

CHAPTER-2

Background and

Literature Review

Chapter 2

Background and Literature Review

2.1 Background

The main objective of this is to detect and measure the partial discharge so that the equipments can be rescued from damaging. It is required to observe and detect the partial discharge in a regular manner. Partial discharge detection and measurement can be done both by experiment and simulation. Here the simulation part is only considered, and by that process the partial discharge is measured by applying different voltages. Mainly the consideration is based on voltage profile and that is why the input voltage is being changed.

2.2 Literature review

Partial Discharge is a localized dielectric breakdown which bridges the insulation between electrodes.

In high voltage electrical system several solid, liquid and gaseous materials are used for the purpose of insulation. The insulators used in the power system are not 100% perfect. The presence of air bubbles degrades the quality of insulator. It degrades enormously the insulation property due to many stresses like electrical, mechanical and thermal stresses [1].

2.2.1 Partial discharge occurrence

Partial discharge occurs either in the insulation medium or in the surface of the insulation medium. It occurs when the applied electric field is lesser than the dielectric strength of the specific insulating material. In high voltage power cables, partial discharge occurs due to unequal distribution of electric field. Partial discharges are of three types in power cable systems. It depends on the place where partial discharge occurs.

1. Discharge from internal cavity.
2. Discharge on the surface or interfaces.
3. Discharge in the form of treeing.

Sometimes a tree like path of electrical breakdown occurs in the insulation. It is called electrical treeing. The direction of electric treeing is same as the direction of the electric field lines. When this deterioration connects one electrode to the other then the complete discharge in the insulators will occur [2].

2.2.2 Materials used as insulators and their application

1. The application of epoxy resins are low pressure castings for switch gear orifices, bus bars, bushings, instrument transformers. A fluidized bed dip coating for bus bar insulation and dough moulding for bus bar barriers and secondary terminals.
2. The application of epoxy resin bounded glass fibre are for components such as arc control devices, circuit breaker operating rod and high pressure feed pipes for air blast circuit breakers.
3. The application of polyester resins are insulating lever for circuit breaker and phase barrier plate in switch board.
4. Uses of porcelain are insulators and bushings of circuit breakers, power transformers and instrument transformers.
5. Vulcanized fibres are used in arc chamber segments.
6. Synthetic resin bonded paper are used in bushings and arc chambers etc.
7. Nylon is used in injection moulding for arc control devices in circuit breakers.
8. Silicon rubber is used in filling for moulded joint boxes in air insulated circuit breakers.

9. Butyl rubber is used in pressure moulding of current transformers.
10. The application of chloro-sulphonated polyethylene is cable insulation for use in air or oil.

The insulating material used in this work is epoxy resin due to its high dielectric strength, mechanical strength and durable chemical properties.

2.2.3 Mechanism of breakdown in composite dielectrics

It is known that if dielectric losses are less, the cumulative heat produced will be less and thermal breakdown will not occur. However several other factors cause long and short term breakdown.

a. *Short term breakdown*: If electric field stress is very high, failure of equipment may occur slowly or faster without any substantial damage to the insulator. It has been observed that breakdown occurs when applied voltage is close to the breakdown value. There exists a critical stress in the dielectric at which discharges can enter the insulator or on the surface of the insulator and propagate rapidly to cause breakdown. It has been observed that breakdown occurs more rapidly when the bombarding particles are electrons rather than positive ions. In addition to this there are some local field intensifications due to the presence of impurities and varying the thickness of insulators play a vital role in doing breakdown [3].
b. *Long term breakdown*: This type of breakdown is also called as ageing of insulation. Thermal process is responsible for the ageing of insulators which give rise to their breakdown. The charge stored and conduction on the surface of insulators contributes to avoid breakdown in insulation [3].

2.2.4 Ageing and breakdown due to partial discharge

Due to the manufacturing defect of insulators, gas filled cavities or voids are present inside the dielectrics or adjacent to the surface in between the dielectric and the conductor. On applying voltage to those voids electric discharges occurs. A typical partial discharge pulse along with the applied voltage is shown in Fig. 1. The applied high voltage is given in the surface of the solid insulation contain void inside the insulator, where V_a represents the voltage across the healthy part and V_c represents the voltage across the void. At a certain voltage impact on the surfaces produce a deterioration of the insulating property. Due to these reasons study of partial discharge is very important [4].

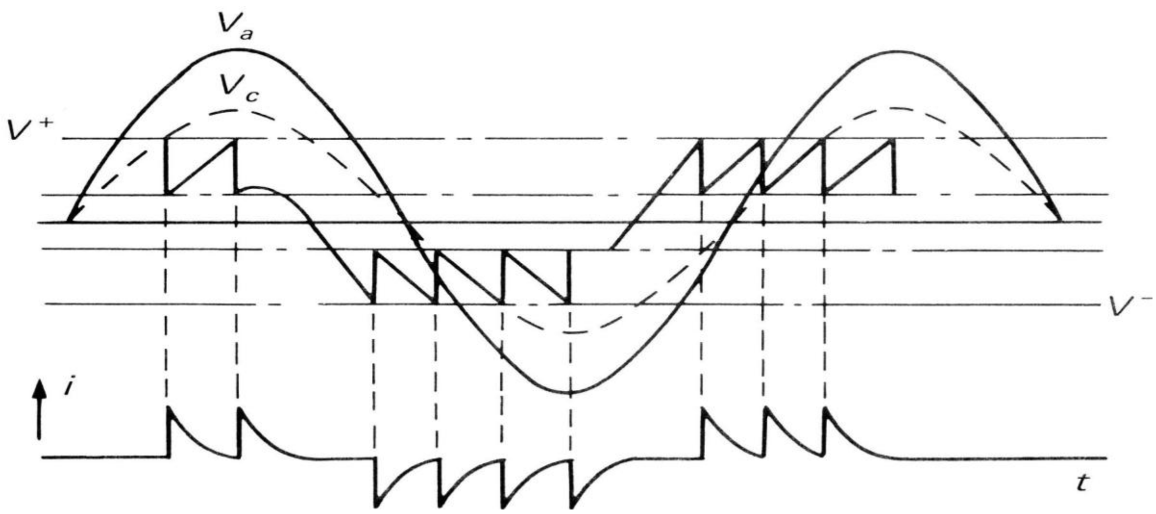

Figure 1: Voltage and Current in discharging cavity

2.2.5 Necessity and detection of partial discharge

The insulators that are used in our daily life are found in impure form. Within the insulating material voids are created because of the presence of air bubbles. Due to this, the insulation weakens; hence partial discharge occurs with the application of high voltage on the insulator. As the dielectric constant in voids is less than that of the insulator there is a failure in insulation in high voltage equipments. Even though the magnitude of partial discharge is less still it is responsible for degradation of the insulator. Finally, there is a failure in the insulation system due to partial discharge, for this reason the detection and measurement of partial discharge is necessary.

The main reason for the appearance of partial discharge is due to voids enclosed within a solid dielectric. These discharges partially bridges the distance between the electrodes. It is also seen that partial discharge can occur on the surface of different insulating materials, if the surface electric field is high for breakdown on the insulating surface.

2.2.6 Classification of partial discharge

The phenomenon of partial discharge can be classified into two different types:

a. *External Partial Discharge*: The partial discharge taking place externally out of the power equipments is known as the external partial discharge. This type of discharge generally occurs in overhead transmission lines [5].
b. *Internal Partial Discharge*: The partial discharge taking place within the power equipments is known as internal partial discharge. The discharges taking place in voids belong to internal partial discharge [5].

There are different methods for partial discharge measurement. Partial discharge can be measured due to the generation or loss of energy related to the electrical discharge. There are different types of discharges:

i. *Corona discharge*: The non uniformity of electric field on surface of conductor subjected to high voltage results in corona discharge. Due to this type of discharges, the supplied insulation is gas, or air, or liquid. This type of discharges appears for a long duration and they do not attack directly to the insulation system [6].

ii. *Surface discharge*: This type of discharges occurs on the interface of dielectric material such as gas or solid interface and this type of discharges occur at any point on the surface of insulator between electrodes and this discharge occurrence depends on various factors such as

- Permittivity.
- The distribution of voltage between two electrodes.
- The properties of the medium where partial discharge occurs [7].

iii. *Treeing channel*: When the electric field intensity is very high, it results in deterioration of the insulating material that is responsible for production of more partial discharge which is called treeing channel [7-9].

iv. *Cavity discharge*: Normally cavities are seen in solid or liquid insulating materials. These are cavities are filled with gas or air. When stress occurs in these cavities partial discharge is seen.

2.2.7 Effect of a partial discharge in the insulating medium

The degradation of an insulating material is mainly due to the appearance of partial discharge. Again the rate of discharge is responsible for thermal, mechanical and chemical degradation of the insulating material. The effect of discharge causes severe harm to the insulation system in high voltage power equipment. This damage occurs mainly due to appearance of partial discharge. The chemical changes in the dielectric increases the conductivity property of the insulating material. There are several types of dielectrics like organic and inorganic dielectric. Porcelain, glass, fibre belong to inorganic dielectric. On the other hand polymer dielectric belongs to organic dielectric [5].

Heat energy is generated due to partial discharge which is responsible for degradation of insulation. This is normally known as thermal effect which is used in high voltage power equipment. The deterioration of partial discharge is known by measuring and detecting the partial discharge activities. It is necessary to monitor the partial discharge values which will be helpful for the power equipment to keep it in a healthy condition.

Partial discharge can be eliminated by thorough full design or by selecting proper insulating material. Hence prevention of partial discharge is required for operation of high voltage equipments.

2.2.8 Methods used for the detection of partial discharge

There are several methods to detect and measure the partial discharge both by electrical and non-electrical phenomenon [10-11]. These methods are

i. Electrical detection method
ii. Optical detection method
iii. Acoustic detection method
iv. Chemical detection method

2.2.9 Factors influencing dielectric strength of insulating material

The factors which influences the insulating material used for high power equipments are

- Dielectric strength should be high.
- Its mechanical properties should be good.
- The resistance of the insulation should be high.

CHAPTER-3

Methodology for Partial Discharge Detection

Chapter 3

Methodology for Partial Discharge Detection

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. The symbol and the values for the parameters used for simulation is depicted in Table 1.

TABLE 1: Parameters used for simulation

Sl. no	Parameter	Symbol	Value	Dimension
1	High voltage measuring capacitor	C_m	1000	pF
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	50	Ohm
6	Inductance	L	0.60	mH
7	Capacitance	C	0.45	µF

3.1 Partial discharge measurement system

For measurement of partial discharge required components are:

- High voltage supply having low quantity of noise is used so that it can pass the discharge magnitude which is to be measured for a particular input voltage.

- For the reducing the noise present in the high voltage supply a high voltage filter is used.
- A detector circuit consisting of resistance, inductance and capacitance is used for collecting the partial discharge signals. It is the major equipment for a partial discharge measurement system.
- A coupling capacitor having low inductance is used to keep low partial discharge pulses and it helps in measurement of partial discharge pulses. It acts as a filter for partial discharge measurement system.
- 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 which is shown in Fig. 2.
- 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.

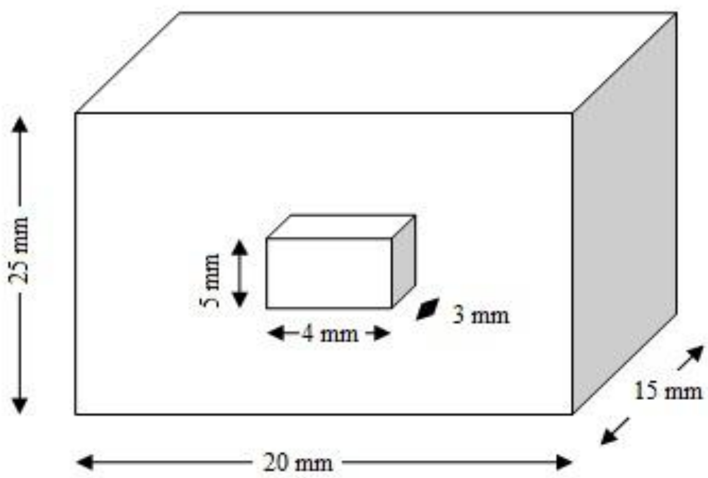

Figure 2: Void model of the epoxy resin insulator

3.2 Electrical circuit model for partial discharge observation

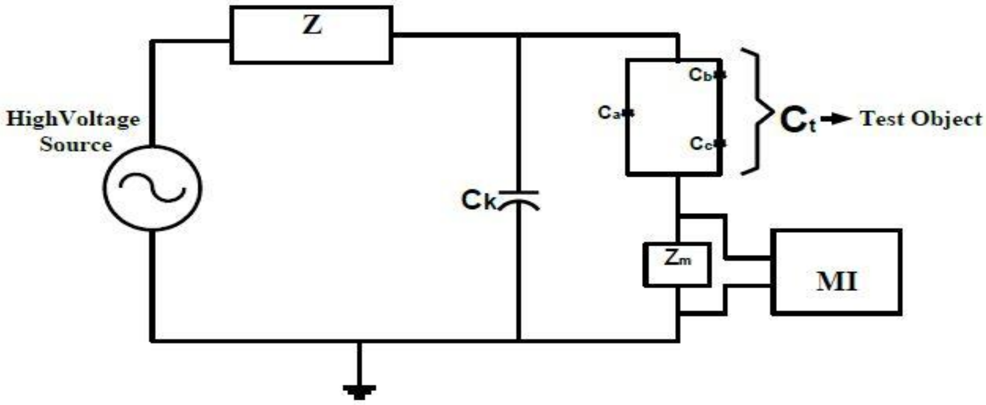

Figure 3: Electrical circuit model for partial discharge measurement

Fig.3 consists of three capacitors. Capacitor C_c represents capacitance of the void present in the test object which is shown in Fig. 3. 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. 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 15mm, 20mm and 25mm is considered. In that insulator a cubical void is present. The void is having dimensions 3mm, 4mm and 5mm. As the electrical circuit model consists of three capacitors the value of those capacitors is to be found out. It is known that, $C = [(\varepsilon_0 \varepsilon_r A)/d]$ where, C is the capacitance, ε_0 is the permittivity of free space and ε_r is the relative permittivity and d is the distance between the electrodes. Therefore,

$$C_c = \frac{(\varepsilon_0 A)}{t} = 2.079 * 10^{-13} F$$

$$C_b = \frac{(\varepsilon_0 \varepsilon_r A)}{(d - t)} = 5.420 * 10^{-13} F$$

$$C_a = \frac{(\varepsilon_0 \varepsilon_r A)}{(d)} = 30.6 * 10^{-13} F$$

The capacitances values of the three capacitors are calculated. This value is required for measurement of partial discharge pulses. Partial discharge is a localised dielectric discharge seen in the region of insulating medium in high voltage power equipment. Partial discharge is usually seen in voids, cracks or bubbles present in the insulating material. In some cases partial discharge is seen on the surfaces of insulating material due to bad conductor profile and disambiguation. 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 centre of the insulation medium. The value of three capacitors shown in the electrical circuit model is calculated. Here generally, ($Ca >> C_b >> Cc$). 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. 4.

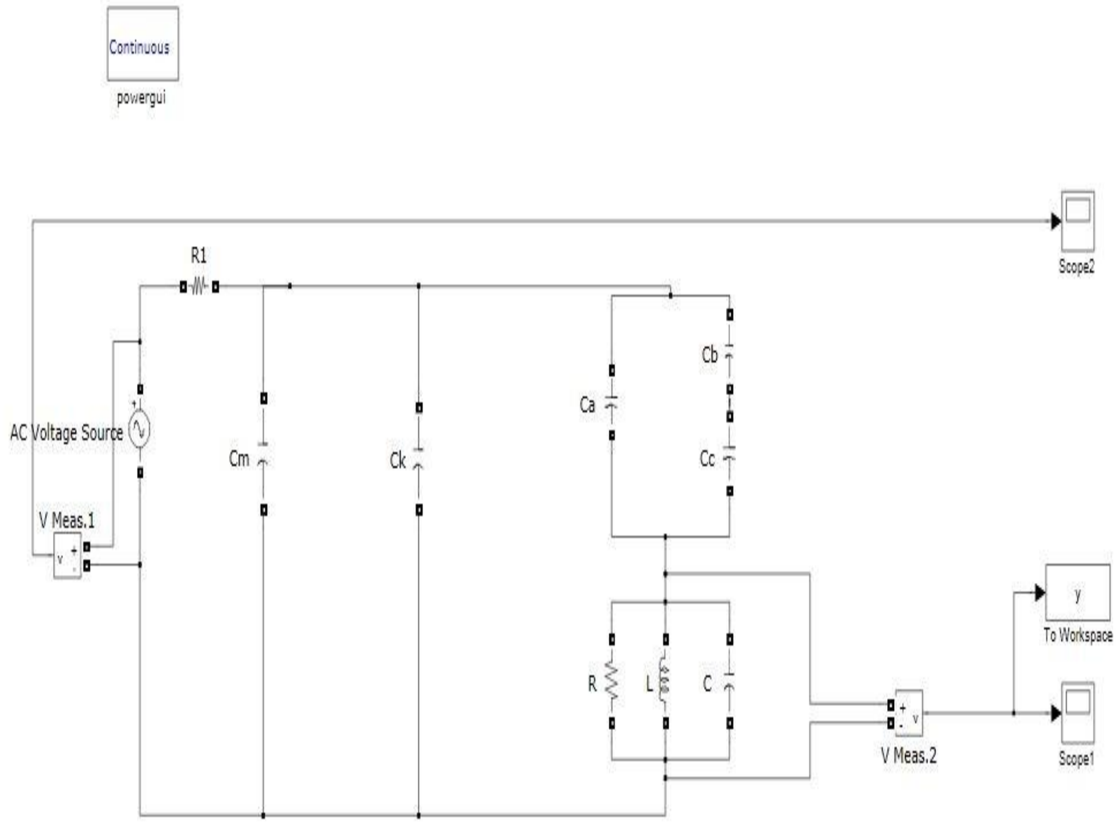

Figure 4: Simulink model for partial discharge detection

The model drawn in Fig.4 is simulated using MATLAB. In Fig. 4 the partial discharge characteristics is seen in scope1 which is connected to voltage measurement 2. In Fig. 4 an ac voltage is applied to the source and through the detector circuit via V Meas.2. Partial discharge pulse is seen in scope1.Here C_m refers to the measuring capacitor and C_k refers to the coupling capacitor.

CHAPTER-4

Simulation Results

and

Discussion

Chapter 4

Simulation Results and Discussions

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 in between the electrodes. 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.

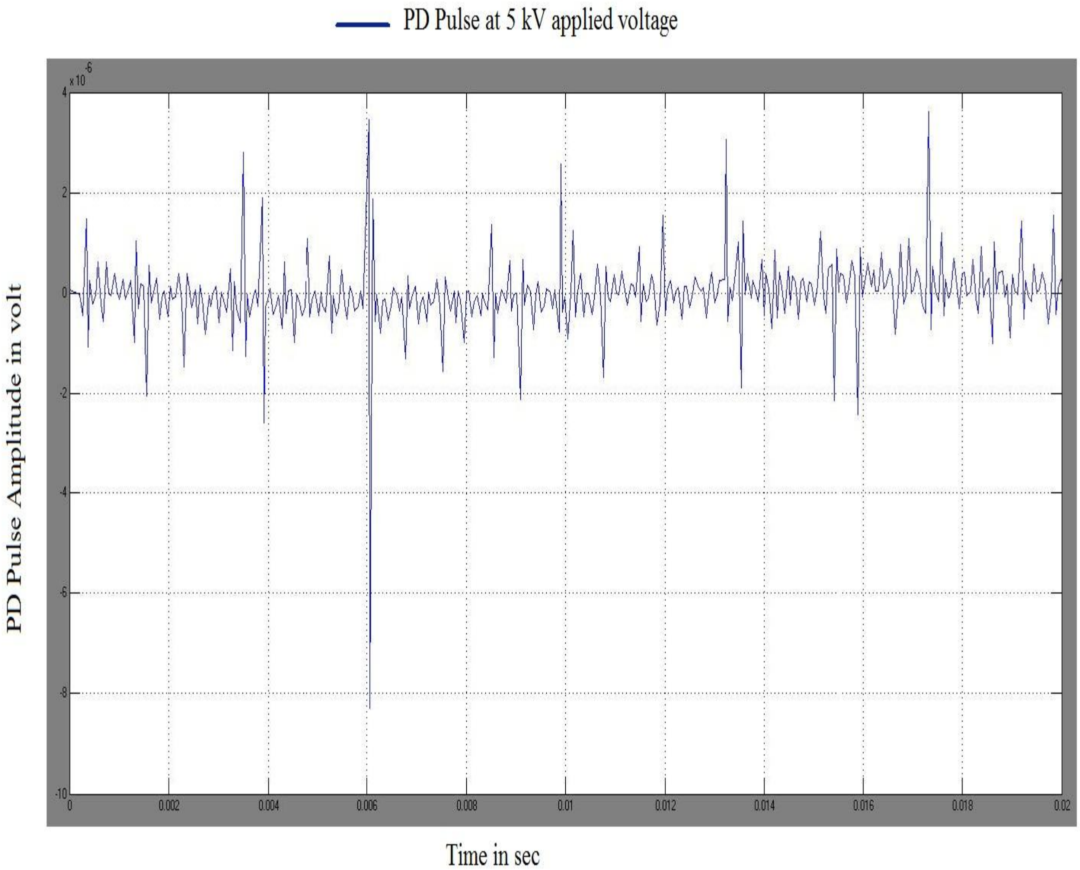

Figure 5: The observed partial discharge pulse at 5 kV

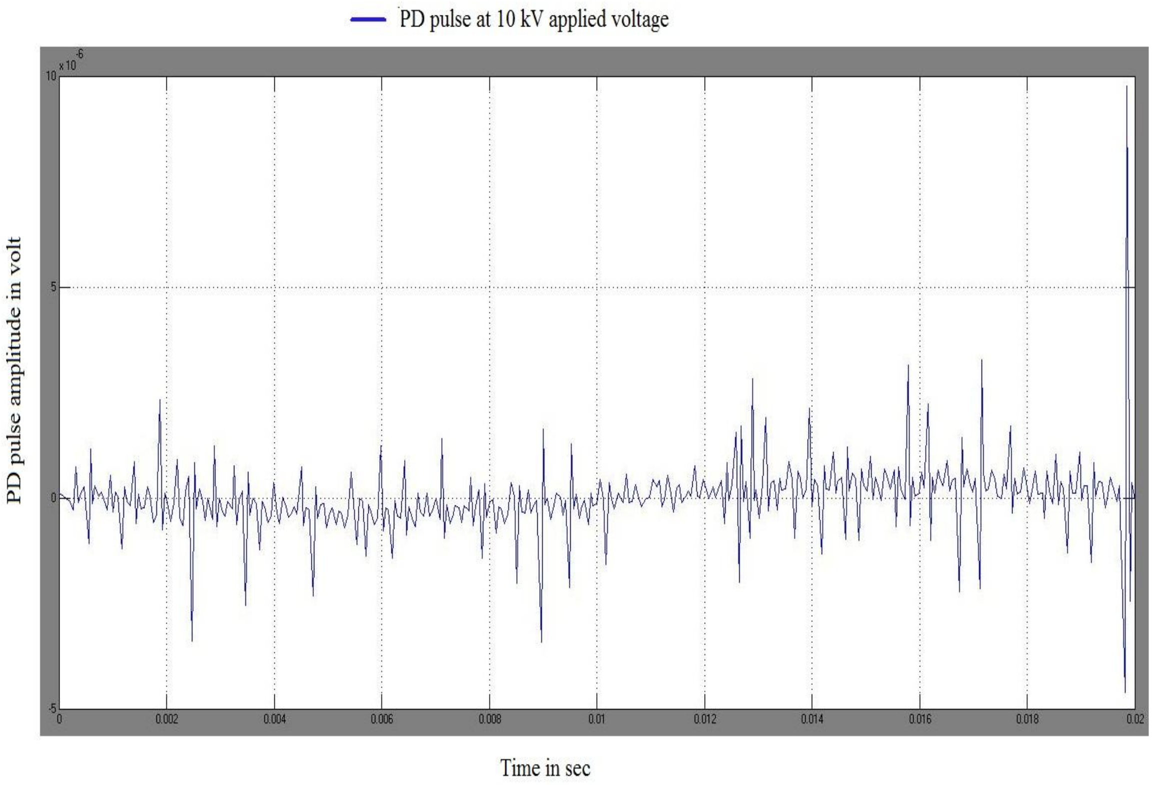

Figure 6: The observed partial discharge pulse at 10 kV

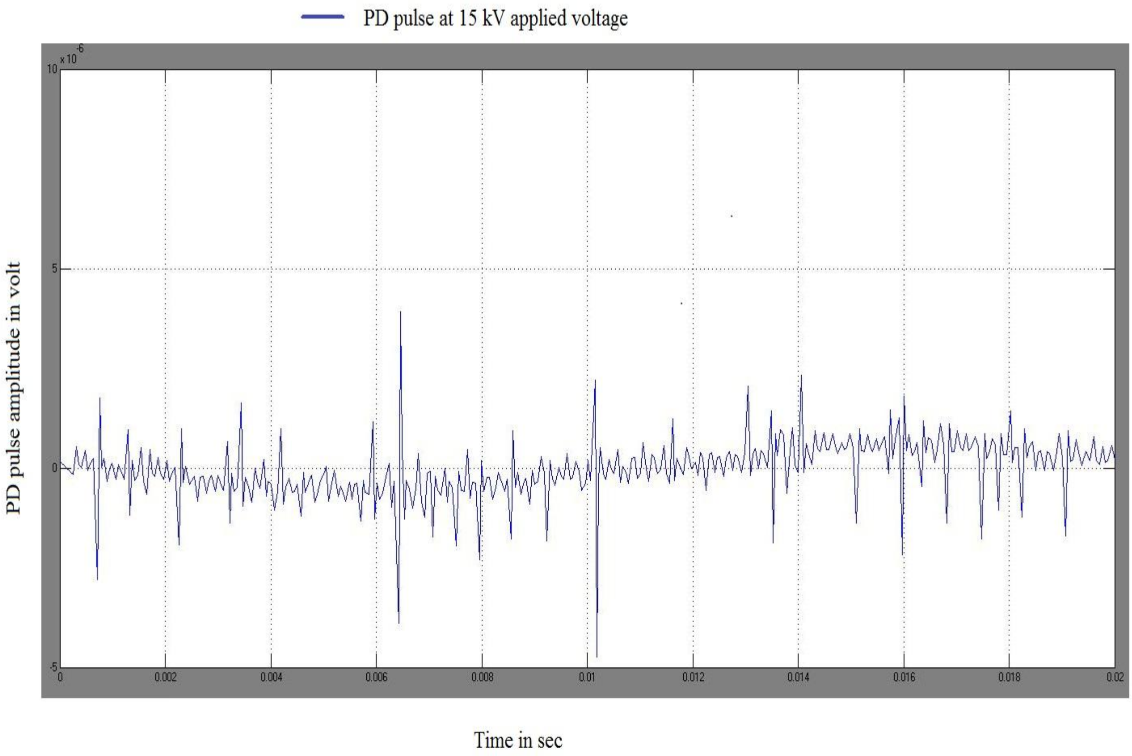

Figure 7: The observed partial discharge pulse at 15 kV

The Fig. 5 shows the partial discharge characteristics at 5 kV; Fig. 6 shows the partial discharge characteristics at 10 kV and Fig.7 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. An increasing voltage of 0-15 kV is applied to the solid insulation to observe the partial discharge characteristics which is shown in Fig. 8 and corresponding data found from the result is depicted in Table 2.

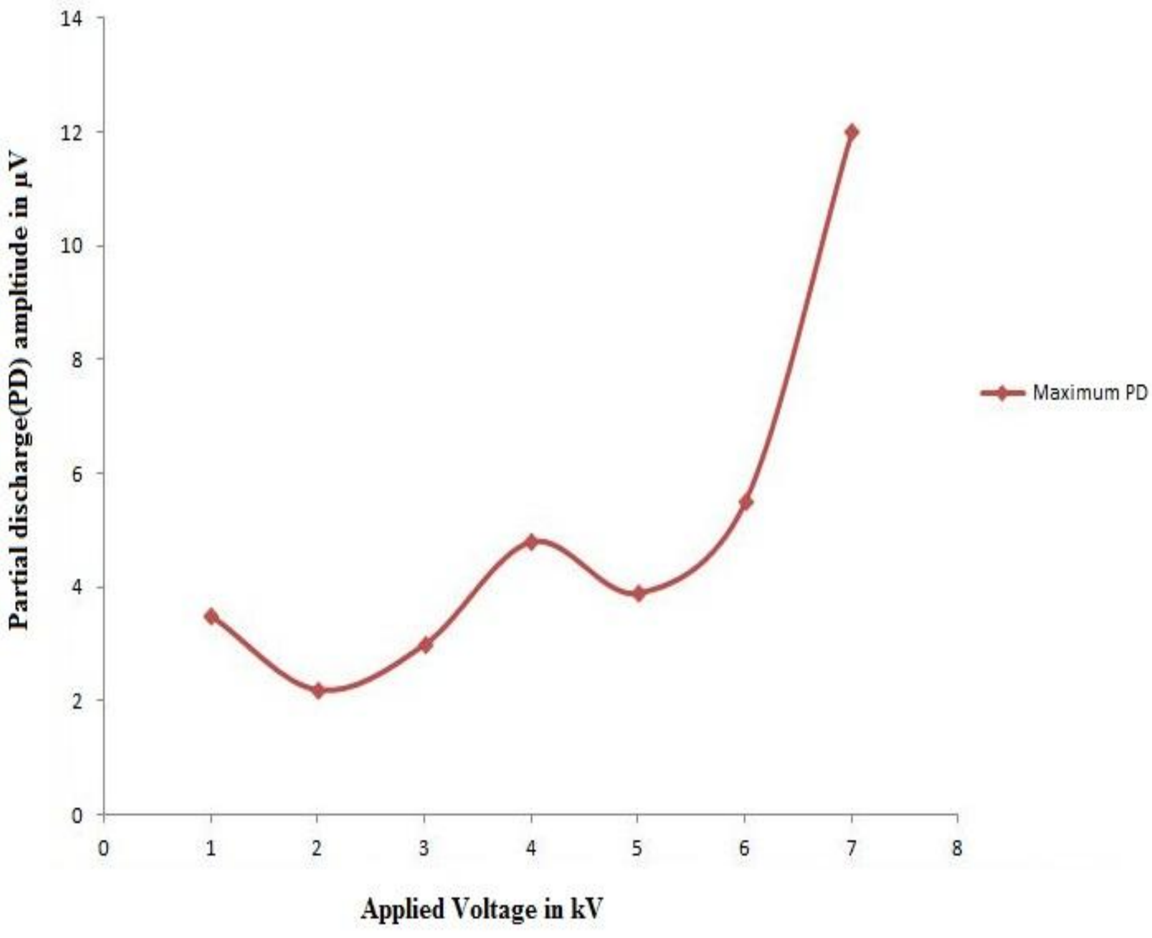

Figure 8: Maximum Partial discharge amplitude variation with different applied voltage

TABLE 2: Maximum Partial discharge values at different applied voltages

Sl. No.	**Applied voltage in kV**	**Amplitude of PD in μV**
1	1	3.5
2	2	2.2
3	3	3
4	4	4.8
5	5	3.9
6	6	5.5
7	7	12

In Figure 8 the characteristics of maximum partial discharge are shown at different applied voltages ranging from 1-7 kV depicted in Table 2. To observe the partial discharge characteristics it is necessary to see the maximum partial discharge values at different applied voltages. It helps for the partial discharge detection and measurement in high voltage power equipment system. We cannot see partial discharge characteristics for a long time interval. So the applied voltage is increased to see the maximum partial discharge and thus the partial discharge pulses are seen that are short term breakdown.

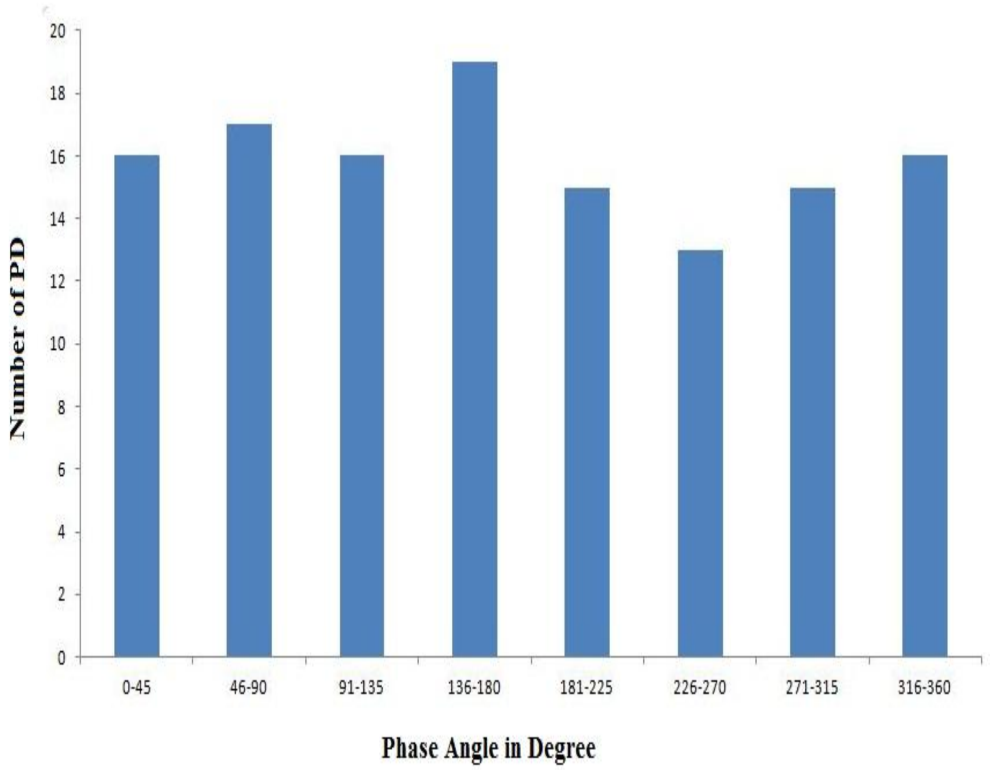

Figure 9: Partial discharge pulses at different phase angle with applied voltage of 5 kV

A cycle is taken and divided into eight sections of 45^0 phase angle each. The partial discharge pulse is then analysed in these eight sections. The numbers of partial discharges are calculated from the partial discharge pulses and a column graph is plotted with these values. The Fig. 9 shows the number of partial discharge in eight sections of a single cycle of 50 Hz. It is seen that the number of partial discharges appearing is not constant and varies randomly. As the partial discharge phenomenon is random, the number of partial discharges appearing is not constant for every cycle. In Fig. 9 the column graph is plotted which clearly shows the presence of PD pulse in the specific applied voltage phase angle.

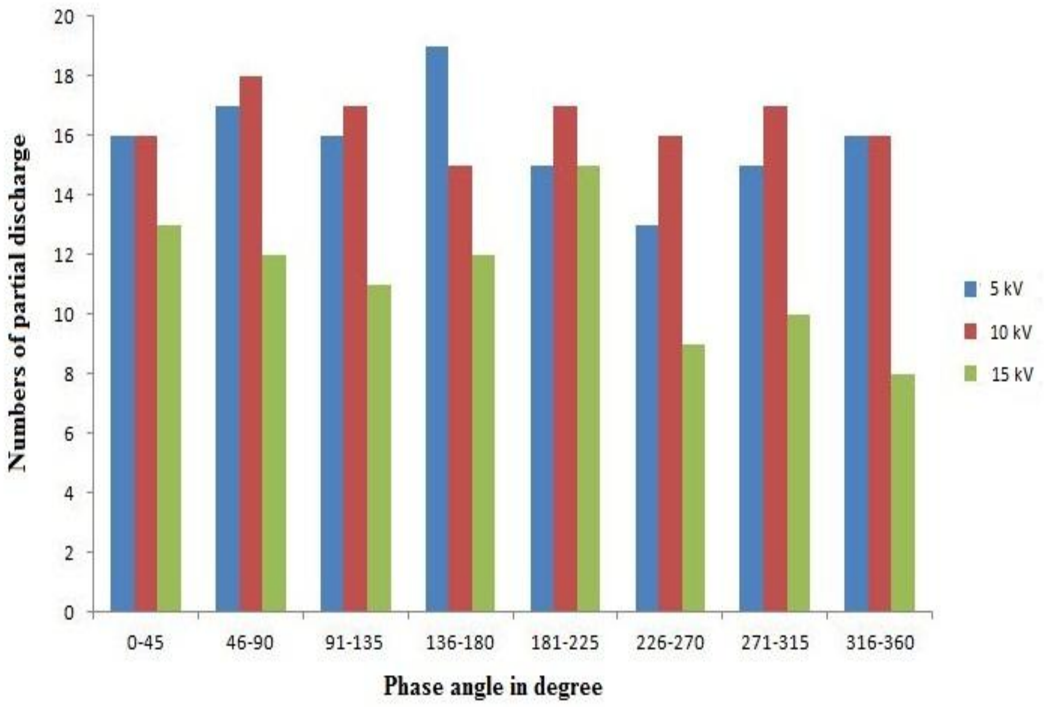

Figure 10: Partial discharge pulses at different phase angle with different applied voltages

TABLE 3: Number of Partial discharge at different applied voltages at phase angles

Sl. No.	Phase Angle in degrees	5kV	10kV	15kV
1	$0-45$	16	16	13
2	$46-90$	17	18	12
3	$91-135$	16	17	11
4	$136-180$	19	15	12
5	$181-225$	15	17	15
6	$226-270$	13	16	9
7	$271-315$	15	17	10
8	$316-360$	16	16	8

Further an analysis is made to see the partial discharge values at different voltages ranging from 5-15 kV which is depicted in Table 3. In Fig. 10 three applied voltages are taken into account, and varying the voltages the number of partial discharges are visualised at different phase regions. Here one cycle of the applied voltage is divided into eight sections of 45^0 each. At each section the number of partial discharges are observed and tabulated. The partial discharge pulse appeared in each section is not fixed, as the partial discharge is random in nature. In the Fig. 10 the partial discharge values at different region of phase angle are randomly distributed, as the partial discharge is random in nature.

Again an analysis has been done to find the frequency content in the observer partial discharge pulse.

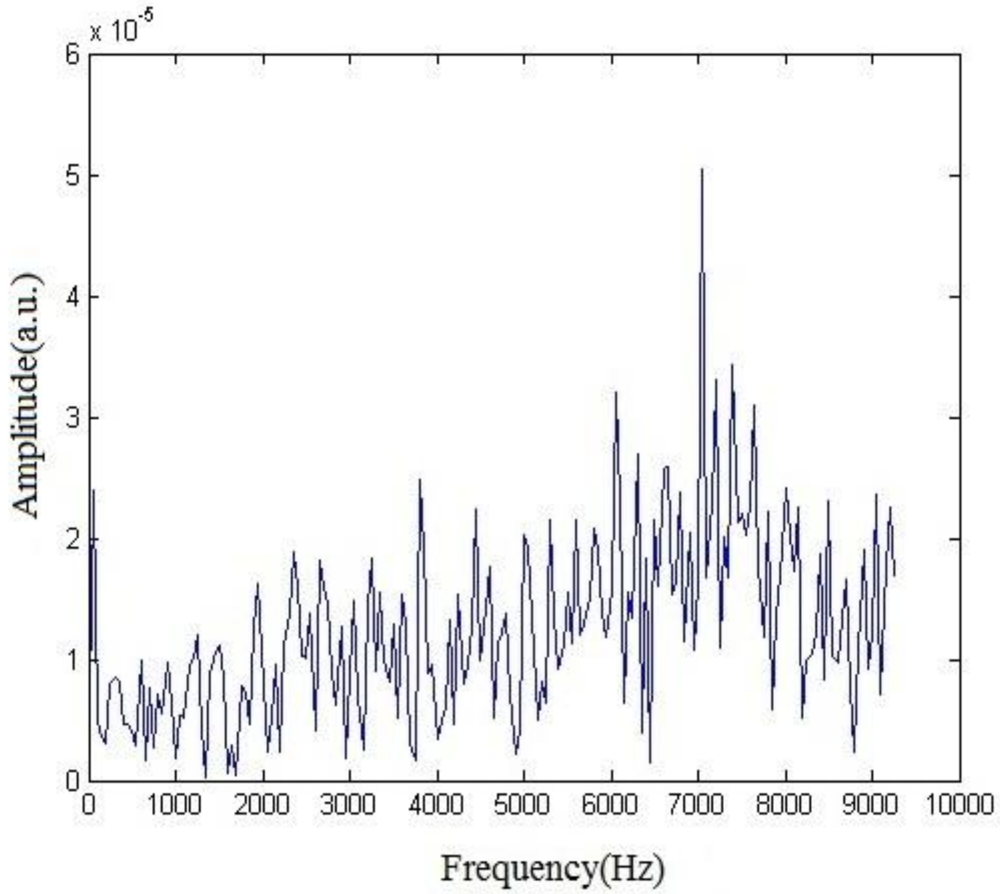

Figure 11: The Frequency plot of the partial discharge pulse at 5 kV applied voltage

The Fig. 11 shows that the frequency response of the observed partial discharge pulses with applied voltage of 5 kV in the range 0-10 kHz. It is observed that the frequency varies accordingly with the different frequency ranges. As the partial discharge pulses are random in nature, so the distribution of partial discharge in different frequency regions is also random. For the analysis of the partial discharge pulse, the recorded partial discharge data is analysed by Fast Fourier transform (FFT). The corresponding frequency spectrum of the partial discharge pulse is plotted. As the supply voltage frequency is always fixed and known value is 50 Hz, therefore the unknown frequency content has been plotted by considering the partial discharge values. It is observed that the number of frequency spectrum found is due to the presence of partial discharge pulses at different time intervals.

CHAPTER-5

Conclusion

and Future Work

Chapter 5

Conclusion and Future Work

Partial discharge is the main problem in high voltage power equipment system. Therefore, detection and measurement of partial discharge is necessary to keep the equipments 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 observe the partial discharge activity inside the solid insulation. It is found that with the increase in applied voltage to the void present inside the insulation, partial discharge increases. This study is employed to find out the maximum partial discharge, the number of partial discharge values, the frequency content of partial discharge pulse and other partial discharge parameters. Based on the SIMULINK model partial discharge characteristics are plotted.

The present work can also be extended for different high voltage power equipment model for detecting the PD activity. Further the collected PD pulse can be processes with the help of Wavelet Transform and S- Transform for time frequency analysis.

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