A Matlab Simulink Model for a Partial Discharge Measuring System

S.D.M.S Gunawardana[1], A.A.T. Kanchana[2], P.M. Wijesingha[3], H.A.P.B. Perera[4], R. Samarasinghe[5], J.R. Lucas[6]

Department of Electrical Engineering,
University of Moratuwa,
Katubedda, Sri Lanka
[1]sdmsgunawardana@gmail.com, [2]kanchana.thilini185@gmail.com, [3]wprasadmanjula@gmail.com,
[4]pasan91629@gmail.com, [5]rasara@elect.mrt.ac.lk, [6]lucas@elect.mrt.ac.lk

Abstract— **Failures in high voltage equipment are often caused due to internal faults which cause a local electrical stress concentration in the insulation; called as partial discharge. Therefore partial discharge detection is highly important for an early detection of insulation failure. Here in this study the simulation of partial discharge has been carried out with a void inside an insulation medium. This paper gives a detailed description about a simulation done with MATLAB SIMULINK package, of the measurement of partial discharges. Further a calibrator for the measuring equipment has been designed and integrated into the circuit. The linearity of the measuring system has also been confirmed using the calibrator. The model developed has been validated using a cylindrical void inside an epoxy resin insulator. Results obtained show a close similarity with results obtained by other researchers**.

*Keywords— **Partial Discharge, Calibrator, Modelling***

I. Introduction

With the rapid development of technology, electricity has now become a basic necessity, and providing uninterrupted power supply to mankind has become a major priority. Insulation quality plays a vital role and one of the major problems in a high voltage power system is the breakdown of insulators or continuous degradation of insulating system. Partial discharge (PD) is one of the major issues which will lead to break down of insulators.

Partial discharge is defined as a localized electrical discharge that only partially bridges the insulation between conductors and which may or may not occur adjacent to a conductor [1]. PDs 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 less than 1 μs [2]. PD occurs if dielectric strength within a certain region of the insulation of an electric device is locally exceeded, but the surrounding insulation is strong enough to prevent total breakdown. In order to understand the occurrence of PD and the response of electrical network to the excitation by discharge pulses, it is important to model the system. MATLAB SIMULINK has been used to model the PD of a cylindrical void inside an epoxy resin cube and the mechanism to measure the maximum charge discharged.

II. Selection of Void Parameters

The most important factors for partial discharge modelling are void parameters**.** PD characteristics change accordingly with size of void. There are several types of voids as such as cylindrical, cubical, etc.

The test object used as shown in Fig. 1 is assumed to be made of epoxy resin and for modelling purposes is represented using three capacitors; two are connected in series with parallel to the other. The series capacitances are the capacitance of the void and the capacitance of the healthy insulator in series with the void. The parallel capacitor to the above two is the capacitance of the remaining parts of the insulator. The dimensions of the test object used for the modelling is illustrated in Fig. 1.

III. Partial Discharge Measurement System

The major components required for the PD measurement are a coupling capacitor, a high voltage supply, high voltage connections, measuring impedance, a test object, a measuring instrument and a software to analyse obtained data.

The test circuit used for simulation is depicted in Fig. 2. The test object is modelled by the capacitance model developed by Gemant & Philippoff in 1932 [3].

The 50 Hz High Voltage supply has a peak value of 10 kV. The inductor near the HV supply acts as an open circuit for high frequency PD pulses. The breaker simulates the breakdown of the air gap at the set time. The breaker is set to close and open once during the simulation period. Therefore only one PD pulse will be modelled for simulation purposes.

When a high voltage supply is applied to the circuit model, the void gets charged and breakdown occurs leading to partial discharges in the insulator.
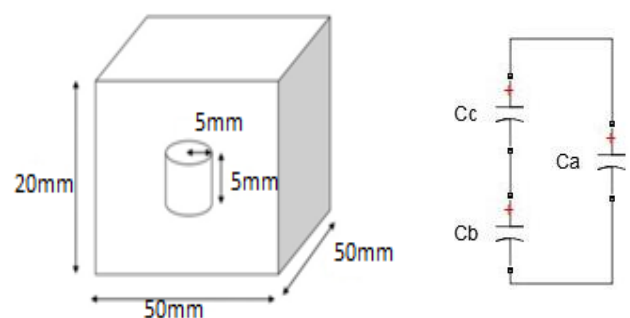

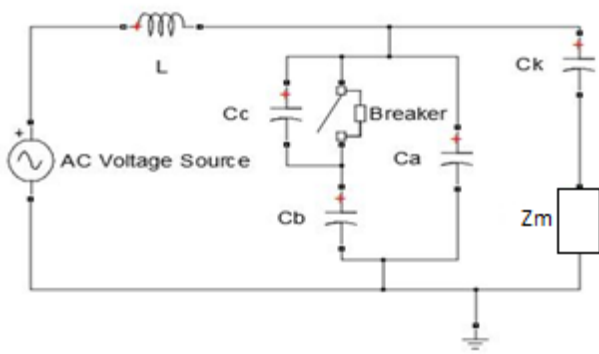Fig. 1. Void model of the Epoxy Resin Insulator.

Fig. 2. Test circuit for PD modelling.

In practice, a measuring instrument is connected across the detector circuit in order to receive this pulse from the test object through a detector circuit. An epoxy resin insulator with dimensions 50 mm, 50 mm and 20 mm is considered for this simulation as shown in Fig.1. In that insulator a cylindrical void is present.

The electrical circuit model consists of three capacitors and the value of those capacitors can be calculated using

$$C = \frac{\varepsilon_o \varepsilon_r A}{d}, \tag{1}$$

where C is the capacitance, ε_o is permittivity of free space and ε_r is the relative permittivity and d is the distance between electrodes.

Assuming that ε_o = 8.85 x 10^{-12} F/m and ε_r = 3.5,
For the model shown in Fig. 1,
C_c = 0.139*10^{-12} F
C_b = 0.162*10^{-12} F
C_a=3.752 *10^{-12} F

The coupling capacitor is 3.2 nF and the measuring impedance Z_m is designed to resonate for 50 Hz.

The test circuit was modified to obtain the required graphs and the components of the measuring equipment were added as shown in Fig. 3.

The simulation was done with MATLAB SIMULINK. Simulation was run for 0.06 seconds. ODE23tb solver was used since continuous time solvers showed a large time to complete the simulation. The waveforms PD current, and voltage across measuring impedance were obtained and are shown in Fig. 4 and Fig. 5 respectively. Fig. 6. shows the same waveforms obtained by other researchers. The output from the measuring impedance has been improved by allowing to resonate at 50 Hz.

IV. PD SIGNAL PROCESSING

Individual PD events happen during time periods of nanosecond range due to very fast formation of electron avalanches [1]. So the true shape of PD current pulses which occurs in very short time period cannot be directly measured due to technical limitations [2]. Therefore PD pulses have to be decoupled from the terminals of the test object to measure PD transients. Due to the ineluctable attenuation and dispersion of the PD pulses when travelling from the PD source inside the test object to the terminals of the test object, the frequency content of the PD signal is severely reduced. If a measuring frequency as low as possible is used PD pulses with maximum accuracy can be recorded. However, if PD pulses are measured with much lower frequency than frequency content of actual PD pulses, it result in the measured output to return the time integral of the input pulses.
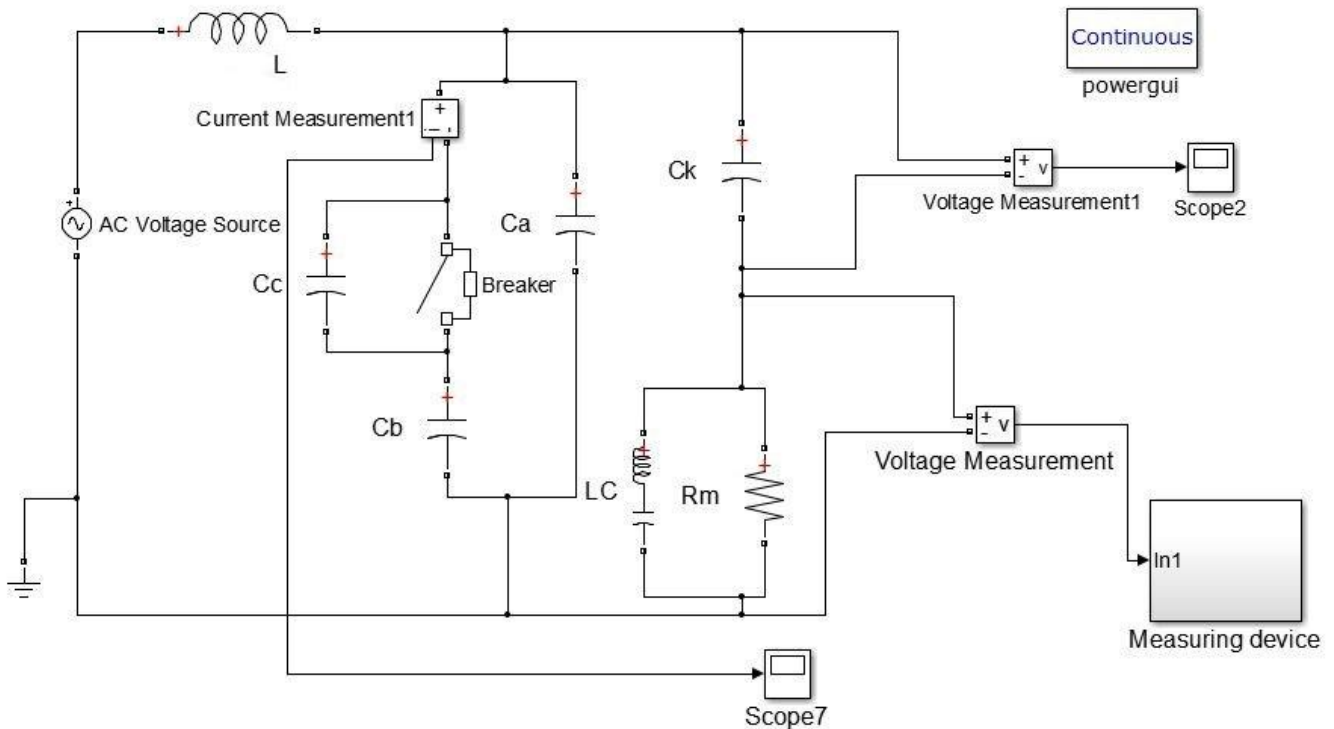

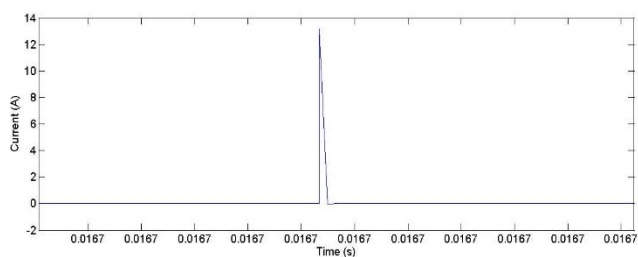Fig. 3. Test Circuit with measuring instrument.

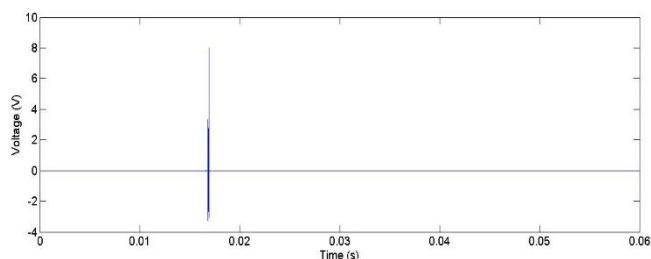Fig. 4. Partial Discharge Current.
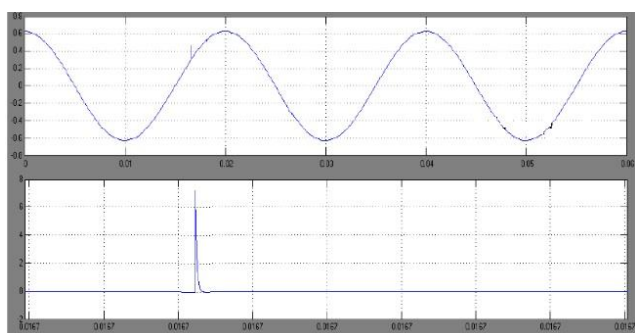

Fig. 5. Voltage across measuring impedance.

Fig. 6. PD voltage (above) and PD current (below) obtained by a similar simulation research [4].

The time integral of current is equal to charge. This has been considered in the IEC 60270 [1] which recommends the measurement of the PD quantity, apparent charge to ensure comparative and reproducible PD measurements. This procedure is called quasi integration. The power frequency component should be removed from the PD signal. This can be achieved by using a band pass filter measuring the PD signal. According to network theory, the output of the band pass filter with lower upper limit (working as a low pass filter for high frequency input signals) is proportional to the time integral of input current pulse. According to practical experiences it is required to use an upper limit frequency not higher than 1 MHz for most test objects [5].

Wide-band instruments and narrow-band instruments can be distinguished by using bandwidth $\Delta f = f_2 - f_1$ used for PD signal processing. The frequency parameters are recommended in the IEC 60270: 2000 are as follows [1].

1. For wide-band PD measurements,

   Lower limit frequency : 30 kHz < f_1 < 100 kHz

   Upper limit frequency : f_2 < 500 kHz

   Bandwidth : 100 kHz < Δf < 400kHz

2. For narrow-band PD measurements,

   Centre frequency: 50 kHz < f_0 < 1000 kHz

   Bandwidth : 9 kHz < Δf < 30 kHz

Narrow band equipment may create super position error when multiple pulses are present very close to each other. Therefore, a wideband equipment was modeled in this study. The model for the measuring equipment consists of the band pass filter and a peak detector to obtain the maximum peak as shown in Fig. 7.

Typical band pass filter having an upper and a lower limit frequencies of f_2 = 320 kHz and f_1 = 40 kHz, and frequency responses in MATLAB simulation is shown below in Fig. 8. Fig. 9 and Fig.10 illustrates the band pass filter response and peak detector output respectively. The waveforms of actual PD equipment are shown in Fig. 11. A close analogy can be seen with actual waveforms and simulation results in Fig. 5 and Fig. 9.
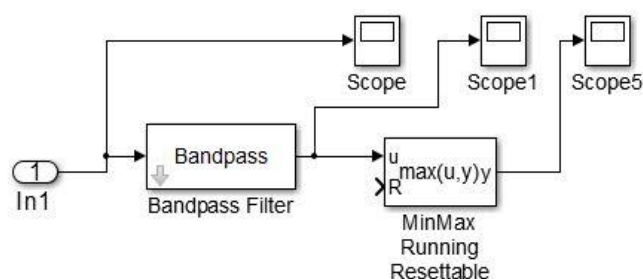

Fig. 7. SIMULINK model for measuring device.
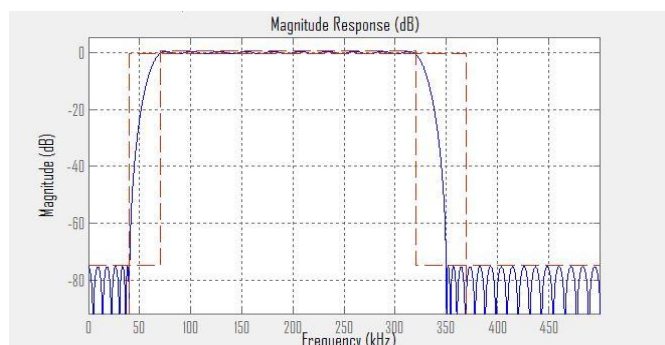

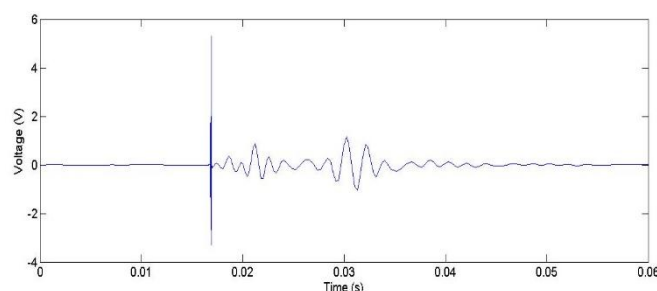Fig. 8. Frequency response of bandpass filter.
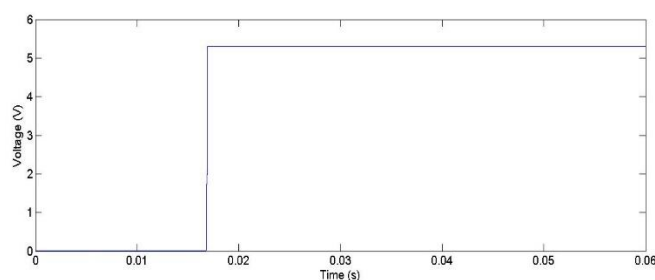

Fig. 9. Output of the band pass filter.

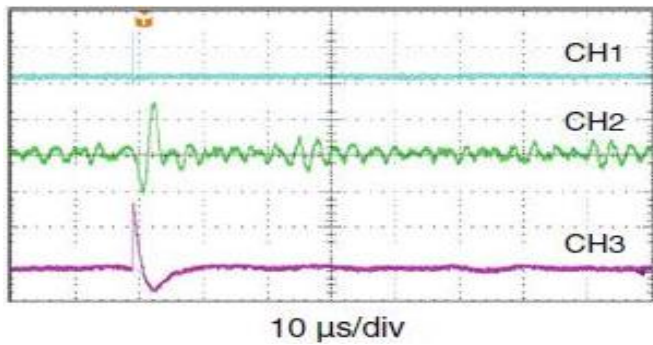Fig. 10. Output of the peak detector.

Fig. 11. Results gained for a 20-pC calibrating pulse injected in a XLPE MV power cable.
CH 1: Input signal captured from a wide-band measuring impedance
CH 2: Signal after band-pass filtering (f2 = 600 kHz)
CH 3: Signal after wide-band amplification (f2 = 20 MHz) and electronic integration [5].

V. ANALYSIS AND SIMULATION OF CALIBRATOR

As mentioned above, PD is a type of electrical discharge which will lead to severe problems in high voltage electrical equipment. PD cannot be measured directly as the value of charge stored in voids of insulating material and cannot be quantified directly. As a solution, an apparent charge method is considered in this paper to quantify the PD in the epoxy resin insulator model. The apparent charge; the charge which if injected within a very short time across the terminals of the device under test in a specified test circuit, would give the same reading on the measuring instrument as the PD current pulse itself[1], is usually measured in pico coulombs. When measuring the above mentioned apparent charge measuring instrument needs to be calibrated as PD is mostly dependent on the geometrical shape of the void location.

In brief, the main objective of using calibrator circuit is to determine the measuring system scale factor, which is the ratio of the input quantity to the instrument indication as measuring system response depends on the test circuit configuration.

A. Calibrating Procedure

PD calibrator circuit is formed using two major parts; a step voltage generator and a series capacitor.

In the calibration procedure, a current pulse of known charge which is generated by the PD calibrator is injected across the device under test when there is no high voltage supply.

B. SIMULINK Model for the calibrator

When modelling the calibrator in MATLAB-SIMULINK environment, first two subsystem circuits; pulse generator subsystem circuit and controller subsystem circuit (as shown in Fig. 12 and Fig. 13 respectively) were created separately. Then after integrating these subsystems the calibrator was simulated.

For modelling purposes, a pulse voltage source with parameters as shown in Table I were considered to comply with the standards.

Pulse generator is in series with parallel set of switching capacitors. These capacitors are connected in parallel.

TABLE I. PARAMETERS FOR PULSE VOLTAGE SOURCE

Parameters	Values
Initial value, V_1	0V
Pulse Value, V_2	9V
Pulse delay time, t_d	0sec
Pulse rise time, t_r	10^{-9}sec
Pulse fall time, t_f	10^{-9}sec
Pulse width, pw	4×10^{-4}sec
Pulse period, per	16×10^{-4}sec

Variable charge levels can be obtained by switching to different capacitors. A controller is used to obtain this switching action. Here controller is also modelled using MATLAB as subsystem circuit of the calibrator.

Through the controller, switches which are connected to each capacitor can be controlled. After an input choice is given to the controller the required capacitor can be switched. Here for the simulation five switching capacitors were used, which have the values as shown in Table II.

TABLE II. SWITCHING CAPACITOR VALUES.

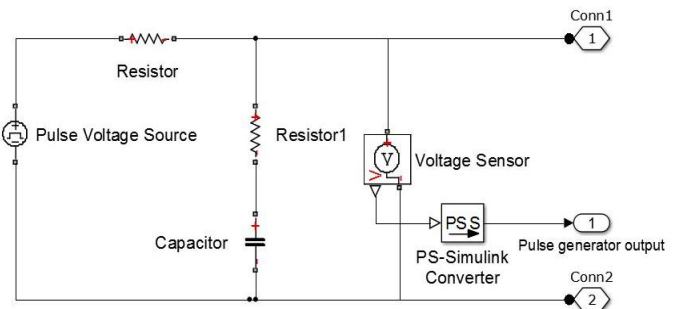| Parameter	Values
Capacitor 1	1 pF
Capacitor 2	5pF
Capacitor 3	10pF
Capacitor 4	15pF
Capacitor 5	20pF

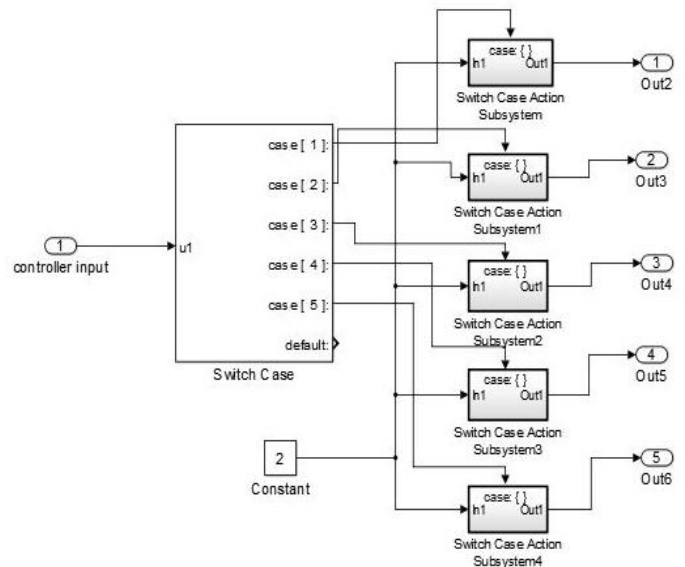Fig. 12. Pulse generator sub system circuit.
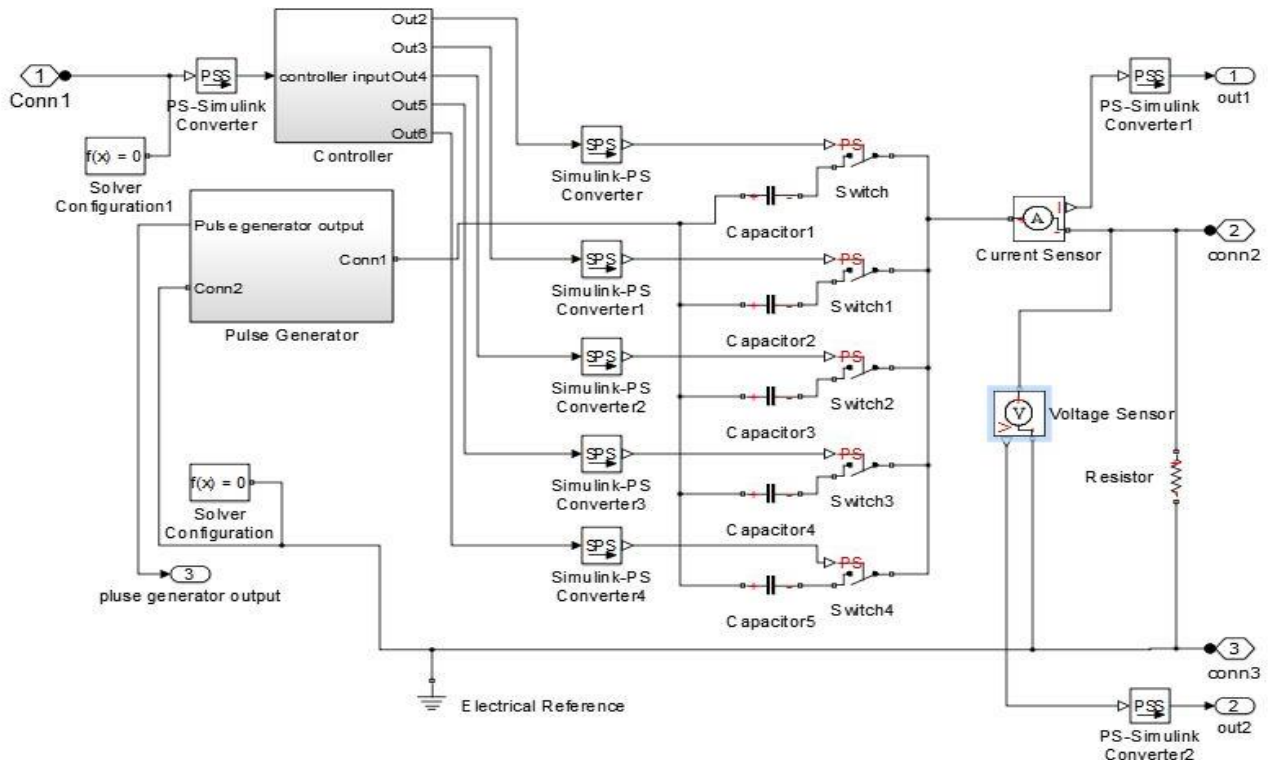

Fig. 13. Controller sub system circuit.

Fig. 14.   Complete PD calibrator circuit [6].

The complete calibrator circuit is shown in Fig. 14. with the switching capacitors added to the system. Next step is to connect the calibrator circuit across the test object and observe the pulses through the measuring device.

VI. SIMULATION OF THE CALIBRATOR

This calibrator consists of two major subsystems called Pulse Generator System and Controller Sub system. All these circuits were implemented with SIMULINK application in MATLAB software.

The Measuring equipment should be calibrated using the calibrator for each test object [1].

The measuring circuit, with the calibrator connected is developed in Matlab SIMULINK as shown in Fig 15. The output current waveform of the calibrator, output voltage waveform of the calibrator and the discharge current are illustrated in Fig. 16 -18 respectively.
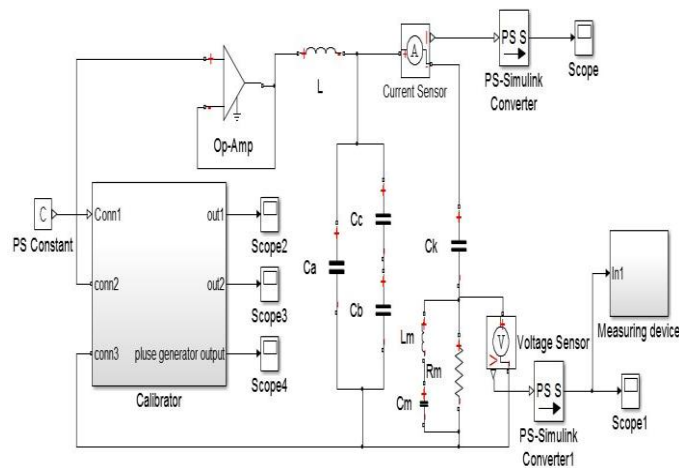
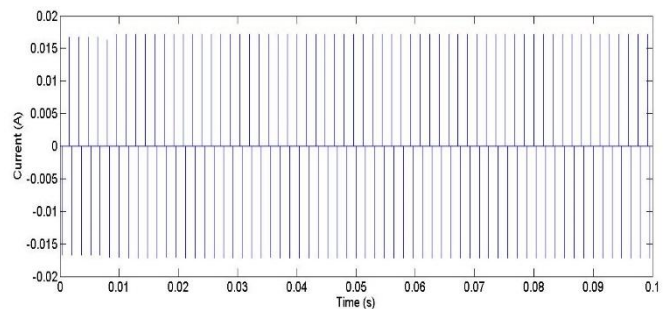

Fig. 15.   PD Calibrator with test circuit.

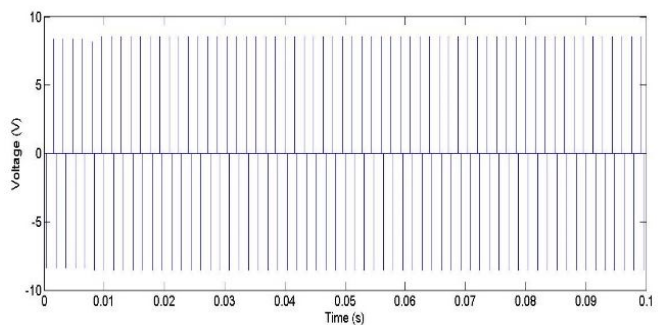Fig. 16.   Calibrator output current vs. Time.

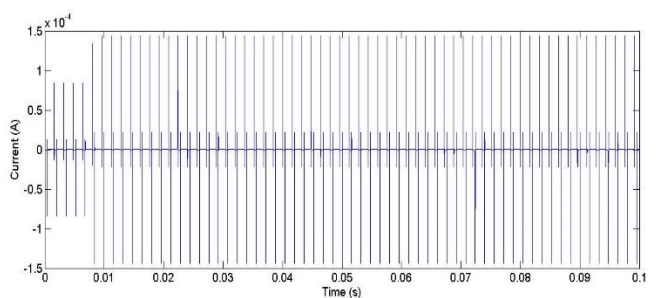Fig. 17.   Calibrator output voltage vs. Time.

Fig. 18.   Discharge current vs. Time.

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In the simulation, the solver uses initial value problems for ordinary differential equations (ODEs). A different solver can solve with different accuracy. We have chosen ode23tb to solve this problem because continuous solvers take a long time to solve and simulate.

The simulation was run for 0.1 second and the results obtained are discussed in the following section.

VII. SIMULATION OF THE MEASURING DEVICE WITH THE CALIBRATOR CIRCUIT

Measuring device consists of mainly a band pass filter and a peak detector. Block diagram of the measuring device is shown in Fig. 19 and Fig. 20. The outputs of band pass filter and peak detector are illustrated in Fig. 21 and Fig. 22 respectively.

The response of the measuring device for known charges injected by the calibrator was recorded and plotted against charge injected. Taken into account that the magnitude of the output pulse from the pulse generator is 9V, the charge transferred is 9*C where C is a known capacitance. The obtained results are shown in Table III and Fig. 23.
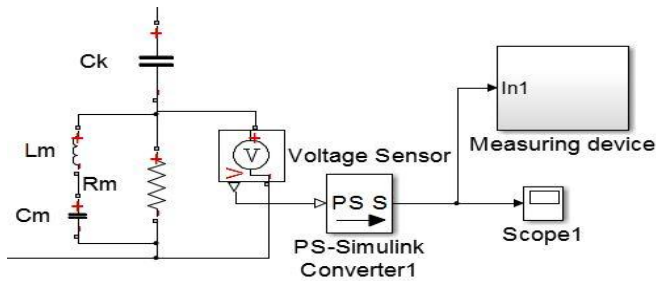

Fig. 19. Connection method of the measuring device.
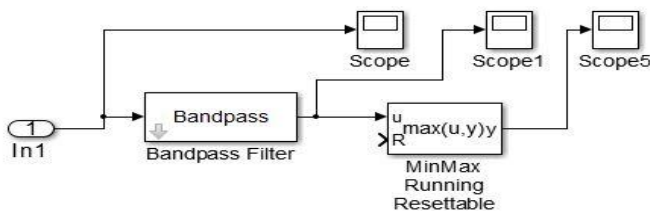

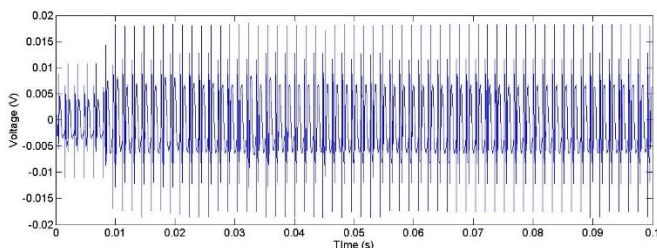Fig. 20. Block diagram of the measuring device

Fig. 21. Output waveform of the band pass filter
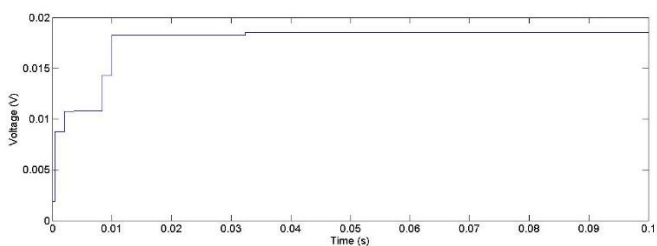

Fig. 22. Output waveform of the peak detector

TABLE III. READINGS FOR KNOWN CHARGES

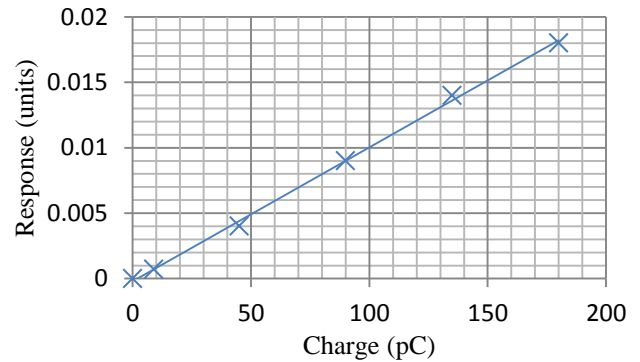| Charge (pC)	Response (units)
0	0.00
9	0.0007
45	0.004
90	0.009
135	0.014
180	0.018

Fig. 23. Response of the measuring system vs. charge injected.

It can be seen that the measuring device response is fairly linear.

VIII. CONCLUSION

The paper has presented the modelling of a partial discharge measuring system with a test object, wideband measuring device and the calibrator in a high voltage environment. The modelling has been simulated using MATLAB SIMULINK and the behaviour has been studied, especially for the linearity of the measuring system. Further, the results obtained from SIMULINK are compared with those of an actual published PD measuring system and show a high similarity of results. Slight deviations are observed in the exact shape of a PD pulse current from the software.

ACKNOWLEDGMENT

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