Kaan GÜLNİHAR and Mukden UĞUR / IU-JEEE Vol. 16(1), (2016), 2011-2015

DEVELOPMENT AND CALIBRATION OF A MICROCONTROLLER BASED PARTIAL DISCHARGE CALIBRATOR

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Abstract: *Partial discharge is an instantaneous energy release depending on a charge accumulation caused by an electric field localized in any section of insulation materials. In this phenomenon, there is no observation of full discharge but electrical perforation and damage in insulation materials can be occurred. Traditional measurement method of partial discharge is based on partial discharge detectors which are defined in IEC 60270 standard. This standard also defines partial discharge calibrators which are used for calibration of partial discharge detectors. This paper explains the design, construction and calibration of a simple partial discharge calibrator. Main idea of the design is based on generating fast rising and slow falling voltage pulses from digital to analog converter of an ARM7 based microcontroller. These voltage pulses are applied to a capacitor where they become charge pulses. Complete design was constructed in an aluminium case and the calibrator's performance was evaluated. Results showed that the designed calibrator is fully compatible with IEC 60270 standard.*

Keywords: *Partial discharge, partial discharge calibrator, partial discharge measurement, metrology, high voltage***.**

1. Introduction

Partial discharge (PD) is a harmful and destructive phenomenon which can be seen in high voltage devices like transformers, generators, gas insulated substations etc. It causes the degradation of insulation components as a result of which catastrophic failures occur. Monitoring of the PD level in high voltage equipments gives valuable information about the status of insulation and the remaining lifetime of the device. These are the main reasons why the measurement of a PD is an important issue [1,2].

Main method for the measurement of a PD is defined in IEC 60270 standard. It is based on detection of low level and fast rising current pulses which are generated by PD. PD detectors are used for this purpose. Certainly, like all measurement devices, PD detectors should be tested and calibrated for correct and accurate measurements, hence at this point PD calibrators are required.

PD calibrator generates PD pulses at a predefined level in picocoulombs (pC) and pulse repetition frequency (Hz). All of the required specifications are defined in IEC 60270. According to this standard;

1- Charge level of PD pulses in pC
2- Rise time of PD pulses in nanoseconds (ns)
3- Pulse repetition frequency in Hz

should be characterized. Rise time between 10 % - 90 % of the step voltage should be below 60 ns. This is very important for calibration of PD detectors to fit the requirements of frequency spectrum. Additionally, the linearity of the calibrator should be better than ± 5 % or ± 1 pC, whichever is the greater [3,4].

2. Design of PD Calibrator

There are complex structured PD calibrators in literature [5,6,7], however in this work, a simple design was aimed. Basic structure of PD calibrator is shown in Figure 1. It consists of a step voltage generator and a capacitor. PD pulses (q_0) are represented by,

$$q_0 = U_0 C_0 \tag{1}$$

where U_0 is the step voltage value and C_0 is the capacitance of the calibrator capacitor.

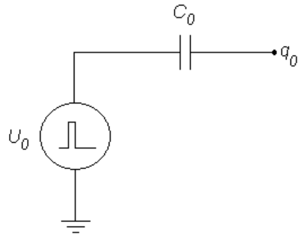

Figure 1. Basic structure of PD calibrator

Received on: 05.06.2015
Accepted on: 21.11.2015

In this case, by using step voltage pulses, bipolar PDs are generated (both negative and positive), however in this study, we aimed to generate unipolar PD pulses, hence fast rising and slow decaying pulses are used.

Equation (1) indicates that if value of C_0 is constant and value of U_0 is variable, then q_0 charge value is totally dependent on the value of U_0. In order to achieve this, voltage level of the step voltage generator should be adjustable.

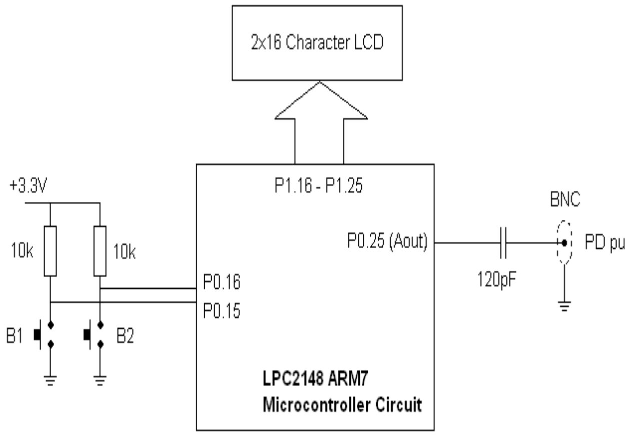

Figure 2. Block diagram of designed PD calibrator

LPC2148 microcontroller which is manufactured by NXP (formerly Philips Semiconductors) was used in this study. The microcontroller is based on a 32 bit ARM7 core with real-time emulation and embedded trace support that combines the microcontroller with embedded high-speed flash memory of 512 kB [8]. It is also having an internal 10 bit fast digital to analog converter (DAC). By using this internal DAC, it is possible to generate U_0 step voltages at different levels.

Block diagram of designed PD calibrator is shown in Figure 2. Step voltage generated by DAC is transmitted to the BNC output connector through 120 pF capacitor. This is a CK05BX type ceramic capacitor. B1 and B2 buttons are used to set the level of step voltage generator. Thus, PD level (charge value) can be changed by these buttons. User interface was designed by using 2x16 character LCD to show the charge value.

Embedded code which is running in microcontroller was written in Keil uVision3 development platform. Flow chart of the code can be seen in Figure 3.

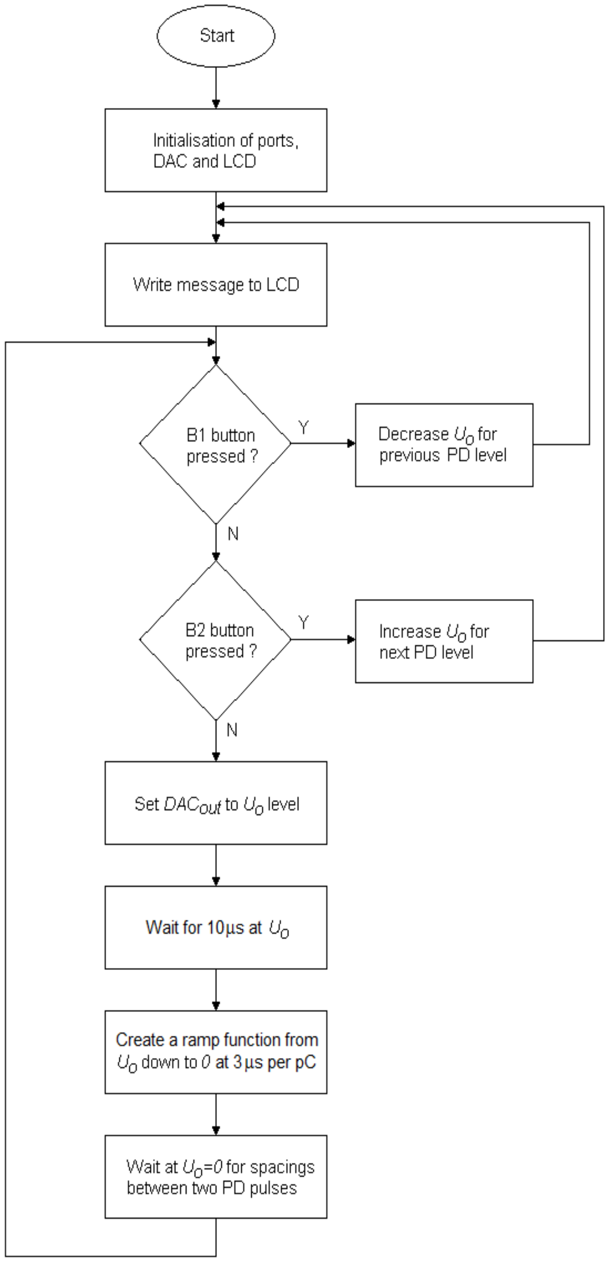

Figure 3. Flow chart of the embedded C code

Working principle of the code may be described briefly as follows; a digital data is sent to the DAC. This data generates an U_0 voltage at the output of the DAC. After waiting 10 µs at that level, output is decreased to zero by a descending ramp function (3 µs per pC). To obtain a defined pulse repetition frequency, microcontroller waits at zero level for a short time period (total loop time is 2 ms). After these steps, output is set to the U_0 voltage again and this process is repeated continuously. At each starting point of the loop, state of B1 and B2 buttons are checked by microcontroller. If any pressed, microcontroller changes the U_0 voltage level to adjust the PD level. The waveform generated by DAC is shown in Figure 4. Pulse repetition frequency of the PD calibrator was selected to be 500 Hz.

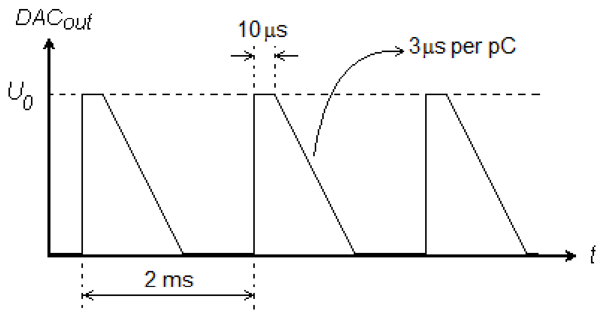

Figure 4. Step voltage pulses generated by DAC

Designed and constructed PD calibrator has five output levels. These levels which can be selected by B1 and B2 buttons are 5 pC, 10 pC, 20 pC, 50 pC and 100 pC. Selected PD level is also shown on LCD. Mechanical construction of the PD calibrator can be seen in Figure 5. It has been housed in an aluminium box and has been powered by a 9 V battery.

Figure 5. Mechanical construction of the PD calibrator

3. Evaluation of Performance

Performance test and calibration of the PD calibrator can be performed by several methods [3,9,10,11]. Applied methods and measurement results are described in the following sub-sections.

3.1. IEC 60270 Annex A (A.3 Alternative Method)

This method is defined in IEC 60270 Annex A chapter A.3. Schematic illustration of method is shown in Figure 6 and application of method is shown in Figure 7. Because of the PD pulse is an *i(t)* current pulse, it can be applied to the resistor R_m and can be converted to the $U_m(t)$ voltage pulse. This voltage pulse can be sampled by digital oscilloscope and charge value q can be calculated by numerical integration. Influences of the resistor R_m and the numerical integration to the results should be taken into account [12].

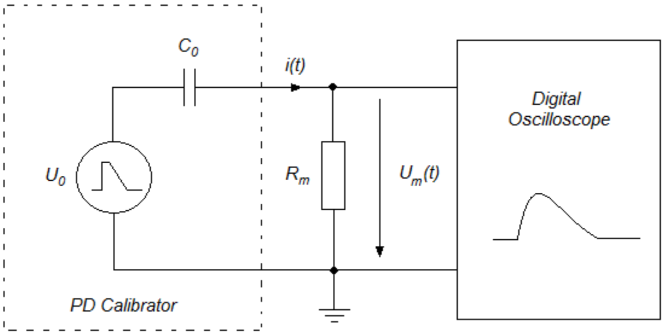

Figure 6. Calibration with numerical integration method

Equation (2) shows the calculation of the charge value q from sampled $U_m(t)$ voltage pulse.

$$q = \int i(t)dt = \frac{1}{R_m}\int U_m(t)dt \qquad (2)$$

Some of the digital oscilloscopes can calculate the numerical integration from sampled data. Another way is transferring the sampled data from oscilloscope to the personal computer. In this way, calculation of numerical integration can be performed in mathematical programs like Matlab.

According to the IEC 60270 standard, value of R_m should be selected between 50 Ω and 200 Ω. In this work, 200 Ω resistor was used for R_m in measurements. Results are shown in Table 1.

Table 1. Results with numerical integration method

Applied (pC)	Measured (pC)	Rise time (ns)	Pulse repetition frequency (Hz)
5	4.80	18.1	500.02
10	9.79	19.7	500.03
20	19.4	22.4	500.03
50	49.4	39.4	500.03
100	101.2	51.1	500.05

The summarized uncertainty analysis is shown in Table 2. The expanded uncertainty of the PD calibrator was determined by multiplying the combined uncertainty with coverage factor $k = 2$ corresponding to a coverage probability of approximately 95 %.

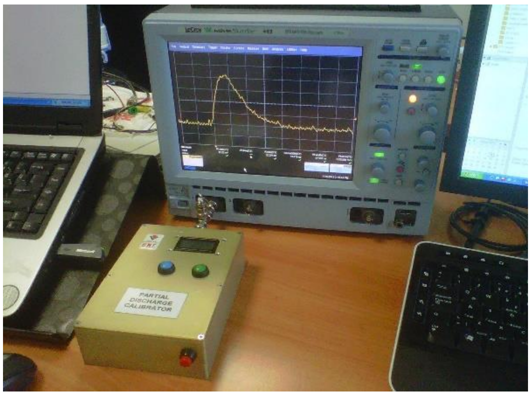

Figure 7. Numerical integration using digital oscilloscope

Table 2. Uncertainty analysis of PD calibrator (at $k = 2$)

Source of error	Type	Uncertainty in %
Standart deviation of the mean	A	1.7
Uncertainty of R_m resistor	B	0.1
Uncertainty of oscilloscope	B	0.5
Uncertainty of the integration	B	1.0
Total uncertainty	A and B	2.3

Table 3. Measurement results with LDT-5 and LDS-6

Applied (pC)	Measured with LDT-5 (pC)	Measured with LDS-6 (pC)
5	5.1	5.0
10	10.2	10
20	20.0	21
50	50.2	51
100	100	102

3.2. Measurement with LDT-5 and LDS-6

Another option to the test of the PD calibrator is using the commercial PD test and measurement devices. LDT-5 PD calibrator tester and LDS-6 PD detector devices (produced by Doble Lemke company) were used for this purpose. LDT-5 PD calibrator tester is an electronic type direct measurement device for PD calibrators. LDS-6 is an IEC 60270 compatible PD detector which is used for PD measurement of high voltage devices. Measurement with LDS-6 was performed by using high voltage coupling capacitor. Thus, calibration pulses generated by PD calibrator should be applied to the LDS-6 through coupling capacitor. Measurements with LDT-5 and LDS-6 can be seen in Figure 8 and Figure 9, respectively.

Figure 8. Performance test with LDT-5 PD calibrator tester

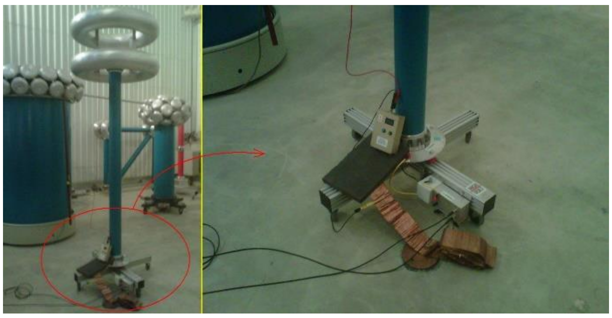

Figure 9. Performance test with LDS-6 PD detector

Measurement results with LDT-5 and LDS-6 are shown in Table 3. It is clearly seen that results taken from both systems are very close to the applied value from PD calibrator.

4. Conclusion

Results revealed that the designed, constructed and calibrated PD calibrator is compatible with IEC 60270 standard. It is highly convenient to use this calibrator for test and calibration purposes in partial discharge studies. It has five PD levels (5, 10, 20, 50, 100 pC) and has 500 Hz pulse repetition frequency. Total uncertainty of the PD calibrator is 2.3 %. Also besides its good performance, the total cost of the calibrator is 75 €.

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