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Technology of partial discharge detection by means analysis of impulse interaction

A Mytnikov and V Strugov
Power Engineering School, National Research Tomsk Polytechnic University, Tomsk, Russia
E-mail:Mytnikov66@mail.ru

Abstract. In this paper the approach based on impulse analysis for partial discharge (PD) control and identification for high voltage insulation are summarized and the experimental research of impulses of different nature for detection some typical PD defects are discussed. Some physical effects at different voltage levels are shown and a method for the representation and characterization of the PD is introduced. Special test cells with different types of defects such as a streamer corona and pore inside oil-paper insulation of condenser type are used for the investigations. The experimental procedure for PD identification by means of impulse form transformation is shown and discussed. Experimental equipment and measurements are described. It is shown that using of impulse of nanosecond duration and commutative impulse allows the characterization and controlling PD in high voltage insulation.

1. Introduction

Partial discharge (PD) can seriously damage the insulation of high voltage power equipment. Power transformers and generators are one of the most expensive and crucial components in any electric power systems, whose reliable operation is most priority for energy generation, transmission sectors and end users. Timely PD control and characterization in inner structure of high voltage insulation is key to stable work providing of power engineering systems [1, 2]. Although many efforts have been concentrated to improve PD control, the failure accidents of high voltage equipment due to insulation damage often take place [3]. Service life of many high voltage apparatus does not reach the designed lifetime. According to a survey [4], it is reported that one third of total transformer failures are attributed to insulation failures. Despite big amount of PD identification techniques, every technology has drawbacks connected with losses problem, complicated measurement process and others. Development PD control technology in high voltage insulation in on-line mode is serious task. Research on the DC voltage-related PD characteristics and PD mechanism has attracted much attention [5]. DC voltage receives special consideration because it has no zero crossing and can cause polarization, there by generating PD characteristics and a PD mechanism that are unique to DC voltage.

It is attractive to use impulse process to control PD in high voltage insulation. These could be external impulses supplying by special generator or switching impulses as result of commutation processes.

The existence in current operation of old and largely worn equipment, simultaneously with new equipment manufactured using present-day technologies and materials, as well as the lack of such modern control technologies for electrical equipment that meet all the criteria and comply with smart grid technologies, causes a decrease in the effectiveness of traditional methods of providing a normal operation of electrical equipment. This factor largely hinders the development of intelligent power management systems.

Due to the aging of a whole generation of power transformers, the present-day electric power industry faces serious problems, since transformer failures, repairs and corresponding costs produce significant economic losses. Transformers have become the most problematic elements of electrical networks. The need for reliable methods of control and diagnostics has led the principal experts in this area to the necessity of developing new technologies that significantly increase the reliability and optimize the performance of each network element. The failure of high voltage insulation of power systems as power transformers or generators often causes accidents with serious consequences. Some of the main reasons for such emergencies are insulation defects caused by PD. The existing diagnostics technologies do not always permit to find out the PD, and hence the number of accidents increases [1–4].

The main purpose of the experiments described in this paper is to study the fundamental possibility of controlling partial discharges (PD) in high-voltage insulation in the ON-LINE mode. The pulse control method for controlling the state of transformer windings, known as the low-voltage impulses, was adopted as the basis for the PD control method.

Attempt to use commutation impulses for PD detection was demonstrated in [6]. It was shown that it is possible to detect PD in insulation of DC motors [6].

Promising results were obtained for winding condition control by using of nanosecond probing impulses [7–9]. This experience is useful to apply impulse processes to PD control. Two ways of controlling the PD were investigated, depending on the form and method of obtaining the pulse. At the first stage, rectangular impulses with duration of 520 and 260 ns were used. These so called external impulses so as they are applied to investigated insulation part from special impulse generator. The second stage of research consisted in the application of inner or switching impulse of a high-voltage network, which was modeled using a circuit based on a pulse capacitor IK-100-0.25. These impulses are generated inside power system due to commutative processes.

2. Experimental research of PD detection in high voltage insulation by means of external rectangular impulses

This approach implies an application of impulse on the part of insulation being under high voltage via the coupling condenser and a pulse signal the containing PD. During the experiments impulses of two different durations 520 and 260 nanoseconds respectively were applied. The cell modeling PD represented the brass sharp inserted into a cell from organic glass. Voltage about 6 kV is applied to a cell from the test transformer. Thus, type PD “incomplete breakdown” on the surface of organic dielectric was organized. Ignition and burning of PD was controlled visually. Block diagram of experiments for PD diagnostics by external nanosecond impulse is shown in Figure 1.

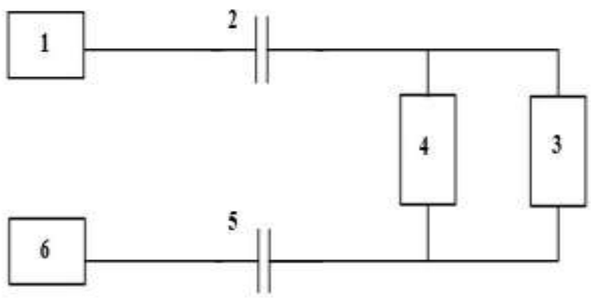

Figure 1. Scheme of experiments. 1 – generator of probing impulses of nanosecond duration, 2, 5 – coupling capacitors, 3 – high voltage transformer, 4 – PD cell, 6 - oscilloscope Tektronix TDS 1012.

Impulse generator forms nanosecond probing impulse which is supplied to detective cell. Oscilloscope measures probing impulse which is applied to cell. At first, probing impulse 520 ns duration is applied to cell without PD. Then cell with PD in streamer corona is placed in the scheme.

Coupling condensers provide safety work of impulse generator and oscilloscope. Waveform of impulse is applied to cell without PD is shown on Figure 2. The same situation with PD as streamer corona is shown on Figure 3.

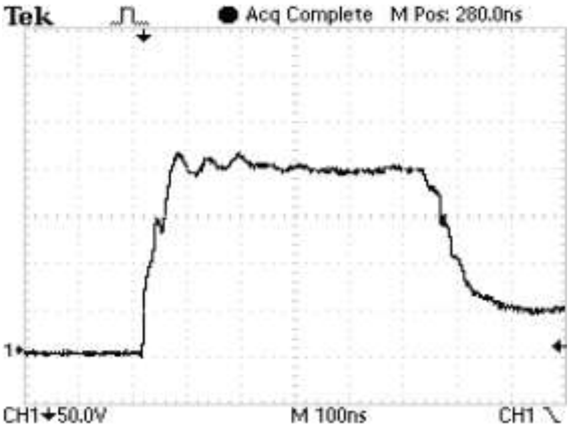

Figure 2. Waveform of impulse 520 ns. No PD.

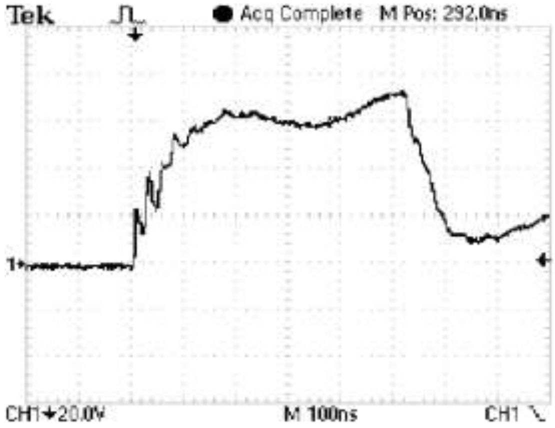

Figure 3. Waveform of impulse 520 ns. PD in streamer corona form is in cell area.

Figures 4 and 5 demonstate waveforms for the same situations, but for impulse duration 260 ns.

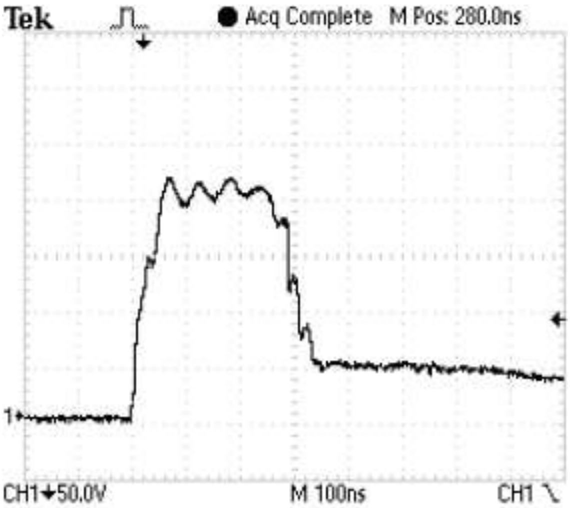

Figure 4. Waveform of impulse 260 ns. No PD.

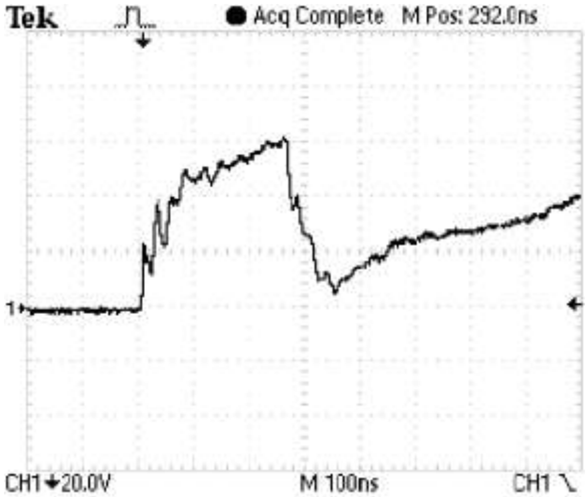

Figure 5. Waveform of impulse 260 ns. PD in streamer corona form is in cell area

Deformation of a form of an impulse comes from an initial form under the influence of PD. The picture observed in experimentscould be explained by following way. A physical basis of similar deformation of a rectangular impulse is interaction of PD pulse waves with the probing impulse ones. Both signals are impulses and contain big amount of high-frequency component. The rectangular impulse at the output of the generator is enriched with high frequencies in the range from hundreds kHz to MHz. The same frequency range has PD arising in internal defects of high-voltage insulation under the influence of operating voltage. Interaction of two frequency ranges when passing an impulse through the part containing PD leads to deformation of an initial form of an impulse and to emergence of the characteristic distortions observed at the Figures 3 and 5. Using a frequency PD-signal analysis is possible to estimate PD level intensity.

3. Experimental research of PD detection in high voltage insulation by means of commutative impulses

The cell of the second type modelled type of PD "PD in Internal Inclusion of Paper-oil Insulation of Condenser Type Bushing". On a metal rod was lapped layers of condenser paper with the leveling plates from thin aluminum foil are reeled up. Two identical cells were made. In one of them the artificial pore with 1mm diameter was made. To model bushing insulation layers of cell were impregnated with transformer oil. The view of a cell is shown on Figure 6.

Figure 6. View of PD cell with pore in high voltage insulation of condenser type.

Common scheme of these experiments were following. Pulsed high-voltage capacitor IK-100-0.25 is charged from a direct current source. Then, when the required charge level was reached (in the range of 2–5 kV), a charged capacitor was switched to a cell with PD. The current in the discharge circuit was measured by a specially designed current shunt. The signal from the shunt was measured by an electronic oscilloscope Tektronix TDS 1012. The shape and amplitude of the signals with and without PD are analyzed and compared with each other at different voltages. Three different waveforms were obtained. Without PD current shunt signal has large amplitude in whole spectrum. Voltage on the cell is 2 kV. At the same conditions, but with PD cell (pore inside), amplitude the waves are diminished. Diminish of wave amplitude in more than 3 times is noted for situation with PD cell and 5 kV. A scheme of experiments is shown on Figure 7.

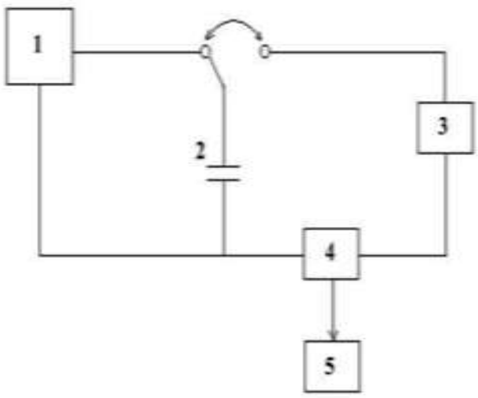

Figure 7. Scheme of PD controlling experiments by means of commutative impulses:1 – charge source of power supply, 2 – high voltage condensor, 3 – PD cell, 4 – current shunt, 5 – oscilloscope TDS 1014.

Experimental situation without PD corresponds to waveform on the Figure 8. The cell is part of condenser insulation without any fail or pores inside. Figures 9 and 10 show the same experimental situation, but the cell contains a pore and voltage on it 2 kV and 5 kV respectively.

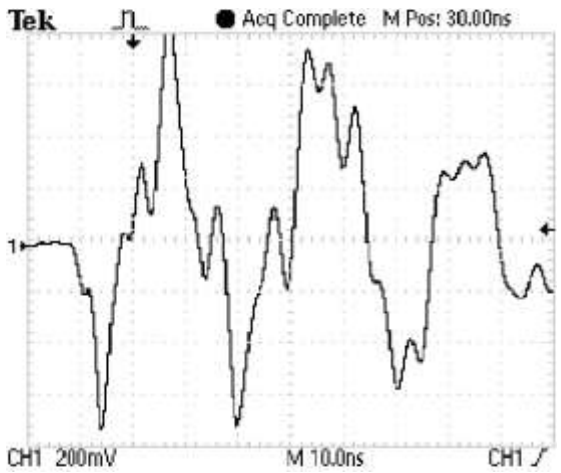

Figure 8. Waveform of current shunt without PD. Voltage on the cell 2 kV.

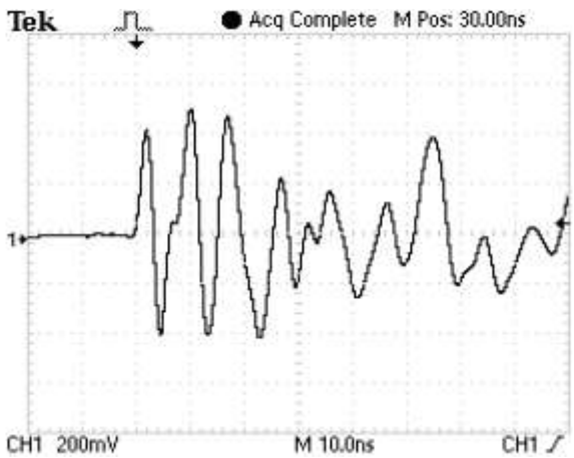

Figure 9. Waveform of current shunt. PD cell contain pore. Voltage on the cell 2 kV.

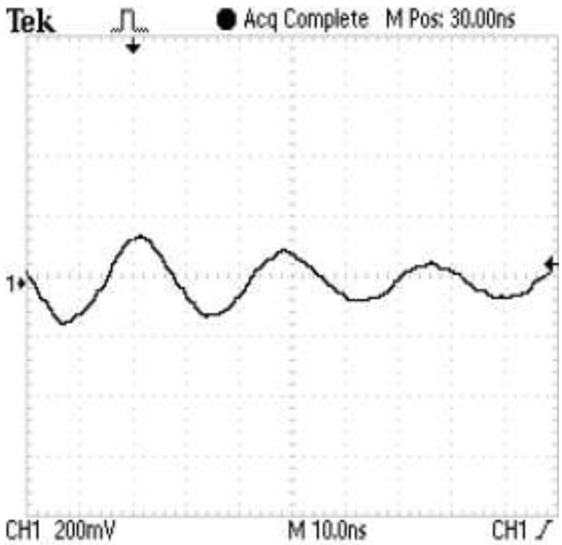

Figure 10. Waveform of current shunt. PD cell contain pore. Voltage on the cell 5 kV.

It is noted that a decrease in the amplitude of oscillations of the current shunt signal is proportional to the intensity of the partial discharge, all other parameters of the measuring system being equal. The decrease is explained by the superposition of the both current PD and initial one.

4.Conclusion

It is established that it is possible in principle to control PD in high-voltage insulation by means of analysis of various types by the impulses. Two different impulses could be appropriate for PD control goal. One of them is impulse of quasi-rectangular form generated by special generator. This PD controlling way is based on technology of consecutive impulse control for transformer winding condition control. Comparison of nanosecond impulses characteristics allows the controlling PD presence on the part on high voltage insulation. Potential application of proposed technology could be realized in ON-LINE regime using measuring sensor of bushing.

Other approach based on using commutative impulses in electric energy system. Consecutive comparison of switching impulses gives information on existence or lack of PD in the investigating high voltage insulation part. In both cases analysis of impulses allow the making of conclusion about presence of absence of PD as well as to make an estimation of PD development degree. Proposed PD-identification could be applied for monitoring for different types of PD - streamer corona, PD in pore in residual atmosphere, PD in inclusion in condenser-type paper-oil insulation.

To fulfill PD control both rectangular pulses created by a special generator and switching pulses of the high-voltage greed can be used. The criterion by which it is possible to state the presence of PD is the reduction of the amplitude of the current signal in the case of switching pulses. When using rectangular pulses, the criterion for assessing the presence and degree of development of the PD is the degree of distortion of the original rectangular shape of the probe pulse proportional to the intensity of the PD.

Potential effectiveness of proposed impulse technology for PD control is high enough, so as it could be used at on-line mode. Analysis of comparison impulse form and amplitude transformation allows the making of conclusion about presence of PD in high voltage insulation. Also, it is possible to make an estimation of PD development degree.

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