NEW ASPECTS REGARDING THE EVALUATION OF MEDIUM VOLTAGE CABLE INSULATION

Mircea Emilian ARDELEANU*, Lucian MANDACHE* Andrei MARINESCU**

**University of Craiova, Romania, mircea_emilian@yahoo.com;*
*** INCD ICMET Craiova, Romania, amarin@icmet.ro*

Abstract – **As part of maintenance practice of electrical distribution networks, it is important to evaluate the aging of electrical cable insulation during periodical revisions or re-operation after some accidental or planned interruptions. DAC - Damped AC Voltage method, known primarily for off-line measurement of partial discharges (PD) can be used to asses the aging of insulation, providing data on insulation resistance and loss factor. This paper presents a new concept of numerical simulation of MV cables behavior during damped oscillating voltage tests, with assessment of insulation quality parameters. The concept allows finding the useful quality parameters of the insulation based on the damping factor. In this manner, the application area of the Damped AC Voltage method in the cable testing is considerably enlarged. Numerical simulation uses a time domain analysis, performed with SPICE and the results are interpreted using a MATLAB application. It was designed from the perspective of the maintenance practice for MV cables. Our numerical simulation results are a start point for on-site practical experiments. Such testing method could become of wide interest for industrial applications.**

Keywords: *MV cable insulation, partial discharges, loss factor, damping factor, insulation resistance, numerical simulation.*

1. INTRODUCTION

One of the main goals of the maintenance practice of distribution networks is to maintain optimum operating parameters for equipment components. Permanent knowing of cable insulation condition is of great importance.
These goals have led in recent years to modernize, optimize and improve sensitivity of fault detection equipments for cables and accessories and increase the accuracy of insulation condition assessment.
Using Damped AC Voltage is a modern method of evaluation off-line PD levels in cables and it can be used successfully in determining the extent of wear of the MV cables insulation by determining the tan δ and insulation resistance.
This paper proposes a new approach to evaluate the quality parameters of MV cable insulation based on numerical simulation of the behavior test-damped oscillating voltage.

2. DAC METHOD PRINCIPLE

In principle this method consists in the generation of a damped AC voltage. (DAC – Damped AC Voltage) with a frequency ranged within 50 – 500 Hz. Fig.1 [1] presents the cable test equipment using the DAC principle.
The system is supplied by a variable DC voltage source providing to the test cable a voltage rising up to the test voltage value for a time period *t*. The time period can be determined using [2]:

$$t = \frac{U_{\max} C_{cable}}{I_{loading}} \quad (1)$$

where: $U_{\max}$ is the voltage delivered by the DC supply; C_{cable} is the cable capacitance; $I_{loading}$ is the cable current.

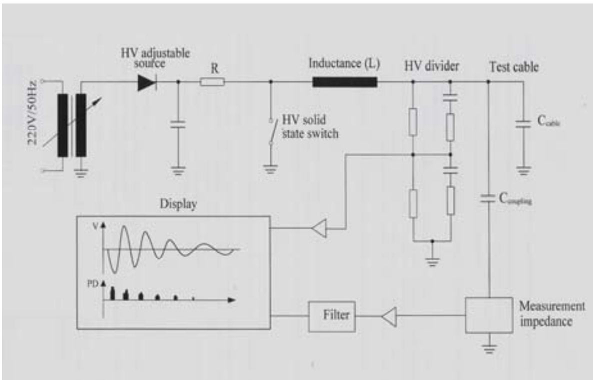

Figure 1: DAC use diagram for PD measurement in cables.

When the test voltage value is reached the test cable is connected by means of an air core coil *L* of a special short circuiting device with very small closing time. From this moment, a series of voltage oscillations damped on the circuit frequency *f* are generated. The oscillation frequency is determined with [3,4]:

$$f = \frac{1}{2\pi\sqrt{L \cdot C_{cable}}} \quad (2)$$

The air core coil with low losses makes the resonance frequency vary from 50 Hz to a few hundreds of Hz so that the tested cable section is supplied with a low damped sine wave form. The quality factor Q_c characterizing oscillation damping has relatively high values (30-100) due to the losses in the tested cable and has the expression [2]:

$$Q_c = \sqrt{\frac{L}{C_{cable} \cdot R_a^2}} = \frac{1}{R_a}\sqrt{\frac{L}{C_{able}}} \tag{3}$$

where R_a is the equivalent total resistance of the circuit.
A high value of Q_c has the advantage that on-site PD measurements can be made for damped alternating voltages having a frequency slightly different from the power frequency, and consequently providing non-disturbed measurements.

3. DAMPING FACTOR, LOSS FACTOR AND INSULATION RESISTANCE

3.1. Damping factor

Damping factor (attenuation coefficient), K_{am}, defined with reference to a damped oscillating signal, is the subunit ratio of two local maximum values, consecutive (Fig. 2):

$$K_{am} = \frac{A_{k+1}}{A_k} \tag{4}$$

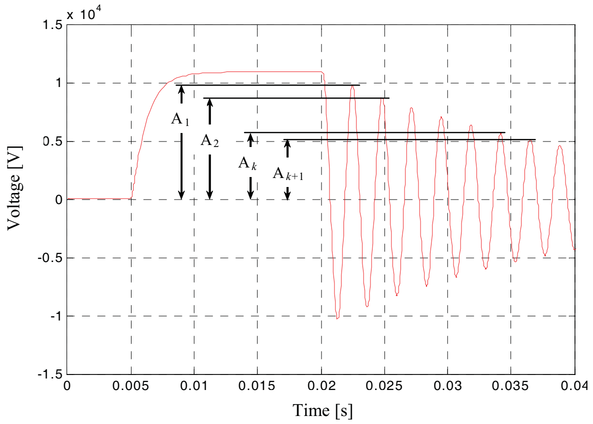

Figure 2: Figure explanatory regarding damping factor definition.

3.2. The loss factor

Air gaps and inclusions, impurities, gases or other faults may appear in the insulating materials used in MV cables and accessories construction, both during manufacturing time and their mounting and operating, leading to progressively decrease of insulation degree and, as consequence, to the insulation breakdown.
In the case of a new cable, faults free (trees phenomenon, inclusions, impurities, air gaps etc), this seams to have the properties of an ideal condenser, with very low dielectric losses, but the occurrence of some faults or insulation ageing lead to insulation resistance decrease and tan δ increase.
By measuring the cable loss factor, tan δ, it can be determined the presence or absence of gas inclusions in cable insulation, dielectric ageing degree due to gas inclusions existence which cause gradually the insulation damage.
Thus, tan δ becomes an important parameter in assessing the cable insulation quality, making possible to establish a correspondence relation between insulation resistance and tan δ and the possibility to evaluate the remaining service life.

3.3. Insulation Resistance

Insulation resistance is determined as the ratio of DC voltage applied between two electrodes which are still in contact with dielectric and total current that runs through all that.
In practice, the value determined experimentally on commissioning is considered as a reference for electrical cable insulation resistance (R_{izPIF}).
Values measured at different time intervals and on different occasions (accidental interruptions, revisions etc.) are reported in percentage units relative to the baseline, acceptable values being standardized depending on cable life (since the commissioning). These values are set for a maximum life of 40 years, the value allowable at the end of life being approximately 50% of baseline [5].

4. INSULATION CONDITION EVALUATION USING DAMPED AC METHOD

To assess the degree of aging of solid insulation of a MV cable using DAC method, the relationship between damping factor of the voltage wave and insulation parameters: tan δ and insulation resistance was determined.
Study was carried out for a 12/20 kV cable segment, having the cross section $S = 120\,\text{mm}^2$, length $l = 600\,\text{m}$, capacity $C = 0.138\,\mu\text{F}$, considering the insulation resistance to commissioning, $R_{izPIF} = 150\,\text{M}\Omega$, insulation resistance when testing, $R_{iz} = 100\,\text{M}\Omega$ and 12 years of operation time.
To simulate the DAC cable testing, the SPICE program was used, the simulation diagram being presented in Fig. 3 [6].
Circuit load capacitor is modeled by an independent source of DC voltage V1 (12kV) and load resistance R1 (10kΩ). The short-circuiting device is modeled by a relay controlled by a voltage step V2 that imposes the switching moment.

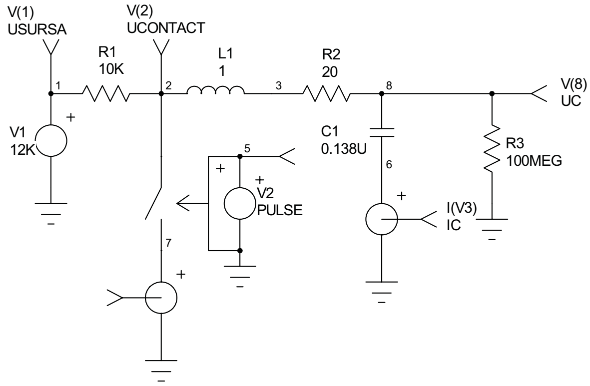

Figure 3: Diagram of functional model.

Discharge circuit, which is damped oscillating voltage, is modeled by the group L1-R2 ($L_1 = 1\text{H}; R_2 = 20\Omega$) and C1-R3 shaping cable test. C1 is the capacity of the cable ($C_1 = 0.138\mu\text{F}$) and R3 is its insulation resistance.

As a result of the time-domain analysis, the voltage across the test terminals is obtained – see test-point V(8), represented in Fig. 4. It is obviously the aperiodic loading process of the capacitor C1 and damped-oscillating discharge initiated by closing of the short-circuiting device. Voltage wave was stored for further processing.

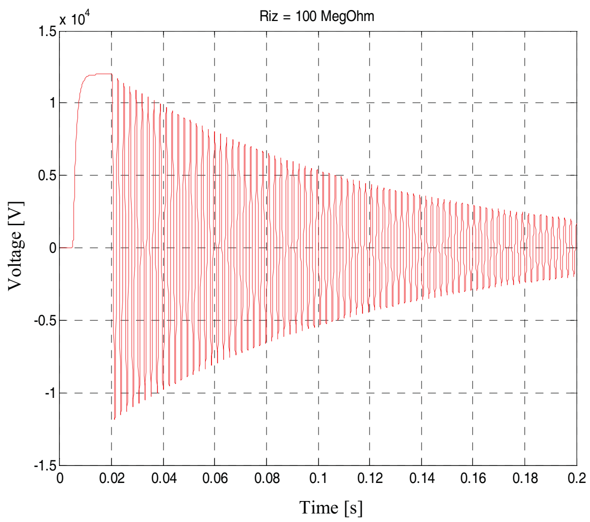

Figure 4: Shape of damped voltage obtained by insulation resistance R3-100MΩ.

Simulation described above was repeated to generate a family of damped voltages, the reference parameter being the insulation resistance R3, with values between $(1 \div 0.5)\, R_{izPIF}$.

To analyze the simulation results, a MATLAB application was conceived, having the following functions: calculate damping factors and loss factors ($\tan\delta$) for the whole family:

$$tg\delta = \frac{1}{2\pi C_{cable} R_{iz}} \quad , \qquad (5)$$

dependence $K_{am} = f(\tan\delta)$ being presented in a suggestive graphical form (Fig. 5).

It is noted that between K_{am} and $\tan\delta$ is a linear dependence and the decreasing of insulation resistance up to 50% given R_{izPIF}, associated with a lifecycle of 40 years, corresponds to a variation of only 0.005% of damping factor, which requires a high accuracy of the survey.

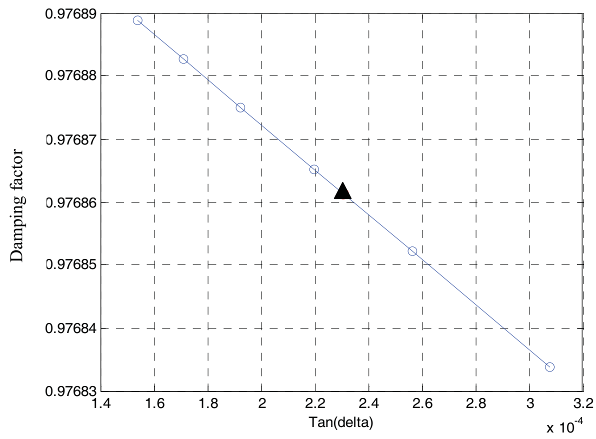

Figure 5: Variation of damping factor depending on tan δ.

Starting points obtained by simulation and direct calculation, using a linear interpolation can cause loss factor corresponding to any value of damping factor. Thus, for the cable considered, the value $\tan\delta = 2.306\,\%$ is obtained, marked with a triangle on Fig. 5.

From calculations, using expression (5), it results $R_{iz} = 100\,\text{M}\Omega$, a value similar to that seen for test cable and higher than acceptable for a minimum lifetime of 12 years [5], $R_{iz\min} \cong 0.6 R_{izPIF} = 90\,\text{M}\Omega$.

5. CONCLUSIONS

To know the insulation weariness degree it is very important and in the permanent attention of the maintenance supervisor for cable and accessories in the electric power distribution networks.

DAC method is one of the most modern methods for off-line and on-site MV cable testing.

This method has the following advantages:

- it is a non-destructive diagnosis method;
- at any on-site test performed along time on the same cable, the same oscillation frequency will be obtained with the same equipment;
- it can easily discover faults generated by the wrong

mounting of cables, sockets and terminals ever since the putting into operation;
- the loss factor (tan δ) can be determined from oscillation damping; one can determine the strength of cable insulation.

Results from the assessment method described, based on numerical simulation and automatic data processing, using dedicated simulator SPICE and MATLAB programming environment, revealed the possibility of determining both the insulation resistance and the $\tan\delta$, important parameters in determining the extent of MV cable insulation aging.

Theoretical observations resulted form a valuable information base which is to be validated by experimental testing.

In combination with software tools mentioned above, the DAC method, used in practice for assessing the DP level, is important in current maintenance of electrical distribution networks and can provide complete data on the condition of insulation (PD level, insulation resistance, $\tan\delta$). For this purpose it is necessary to provide the test equipment with a classic method of calculation using a specialized software complex calculation based on the principles outlined in the paper. As a consequence, it results the decrease of maintenance operations involving the evaluation of cables and reducing costs.

Test Tool is designed from the perspective of professionals responsible for the maintenance activity and the cable insulation condition based maintenance (CMB) is of great importance in decision-making by state.

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