FAULT LOCALIZATION IN CABLES AND ACCESSORIES BY OFF-LINE METHODS

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Abstract - **Many of accidental interruption that occur in electrical energy distribution networks are caused by insulation breakdown of cables and their accessories (joints, terminals).**
To reduce the losses and damages produced, the main responsibility of service team is localization and fast removing of faults in cables and accessories. A careful inspection of new installed cables and wear grade determination, insulation ageing of cables under service by periodical examination during scheduled revisions became essential components of an efficient management, too.
So, this paper presents some off-line methods for determination and localization of faults in cables when fault has been already installed and can determine or had already caused the cable insulation breakdown.

Keywords: *power cable, partial discharge, acoustic emision, apparent load*

1.INTRODUCTION

Off-line methods - refer to the methods used to localize damaged area when electrical cables are disconnected.
These methods are applied in cable testing process, in special laboratories, in manufacturing factories before cable delivery to beneficiary or on-site before cable commissioning and especially in practice activity for localization and removing of fault area.
On-line methods - refer to the methods used for determination, localization and monitoring the partial discharges (PD) happened in electrical cables and their accessories during operation of underground distribution networks of electrical energy
Two other great groups are distinguished within these methods, namely:

- non-electrical methods
- electrical methods

Off-line methods for determination and localization of faults in electrical cables and their accessories are presented and analyzed further on .

2. NON – ELECTRICAL METHODS

2.1 Acoustic Method

In principle, this method is based on pick-up of acoustic signal at ground level by means of a microphone and an amplifier, the fault area being associated with section where the maximum acoustic intensity seized is recorded.
Mainly, the method requires a shock wave generator consisting of a pulse condenser fed by a high voltage generator and a discharger acting like a switch by which the condenser load is directly transfered in fault cable. Where cable insulation is weakened or damaged, a breakdown or a discharge is generated. Acoustic wave associated with discharge is seized at ground surface by a sensitive acoustic device [1].
A shock wave generator is connected typically to the tested cable as shown in fig. 1 [1].

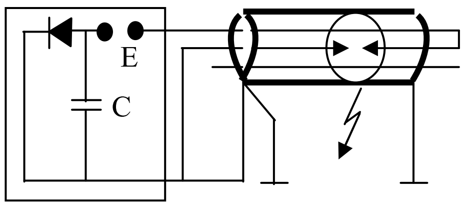

Figure 1: A shock wave generator connection

where: C = condenser battery (pulse condenser)
E = discharger

Pulse-generated energy is given by the expression:

$$W_c = \frac{1}{2} C U^2 \qquad (1)$$

Where: U = voltage , in kV;
C = condenser capacity, in μF;
W_c = energy, in Ws

For a more precise pozitioning of fault area and because acoustic signal time is very short, of milliseconds order, a device for maximum value storage is typically used.

2.2 Visual Method

This method is based on visual supervision of bright phenomena occurring in fault area during cable testing operation. These estimations are done in a dark room by a specialized personnel who is accommodated to indoor dark, using performant optical devices (high resolution binoculars) [2] . During tests performing, photo records may be achieved with performant cameras.

3. ELECTRICAL METHODS

3.1Time Domain Reflectometry (TDR)

It is used to detremine and localize some faults already happened in cables and accessories insulation.
Principle of PD pulse propagation in a power cable is shown in fig. 2 [3].

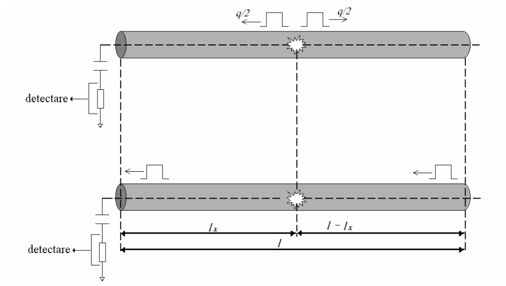

Figure 2: Principle of PD pulse propagation in cable

The first pulse appears after a time t_1 and reflected pulse after time t_2, the difference of time being [3]:

$$\Delta t = t_2 - t_1 \qquad (2)$$

Distance from fault area up to cable distant end is detremined by expression [3]:

$$l_x = v_p \cdot \frac{\Delta t}{2} \qquad (3)$$

where Δt = time, in µs;
v_p = propagation speed, in m/ µs;
l_x = length, in m

Period of time necessary that impulse covers the distance from reflextion place up to the cable beginning is measured by a reflectometer. It is obviously important to know the total length, l, of tested cable.

3.2 A.C. Methods

3.2.1 Classical Electrical Method

PD measurement in power cables using this method applied frequently in test laboratories is based on detecting of current and voltage pulses occurring in fault area.
The method is correlated with electrical load, q, corresponding to discharges, but is not similarly with load discharged in cavity, so called *apparent load* [4,5].
This apparent load value in case of an air cavity with spherical shape may be determined by expression below [6]:

$$q = \frac{1{,}64 \times 10^{-8} \varepsilon_r L^{5/2} p^{1/2}}{R \ln\left(R_s / R_c \right)} .... \qquad (4)$$

where: L = cavity depth; p = pressure;
R_s = cable radius; R_c = conductor radius;
ε_r = relative permittivity

Diagrams for PD direct measurement are shown in fig. 3 [4,5].
Meter, M, is measuring or can record, after case, the voltage drop on impedance Z_m . Shape and duration of measured pulses are determined by impedance Z_m and by C_x and C_k.
Voltage drop taken over from measurement impedance terminals is processed by meter that indicates an amount proportional to apparent load, q, [4,5].

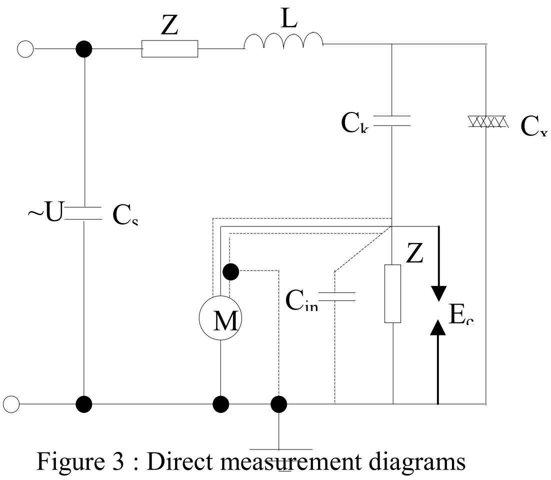

Figure 3 : Direct measurement diagrams
Where:
- C_x = tested object;
- C_k = coupling condenser;
- Z_m = measurement impedance;
- M = meter;
- E_c = protection discharger;
- L = filtration inductance;
- Z_s = source internal impedance

During measurement operations, a voltage component with frequency of 50 Hz appears, reason for which the meter must be provided with a filter designed to take opver only high frequency pulses.
To localize exactly PD area in cable insulation, the pulses shape and position given the applied voltage will be studied. So, measurement diagrams are supplemented with scanning oscilloscope set at a voltage with the same frequency like the supply voltage.
Some figures of various shape known as Lissajous figures are displayed on oscilloscope dial their interpretation allows a better localization of PD [4].

3.2.2 Continuous Rating Method

This method is based on A.C. low frequency voltage generated in order to determine and localize the faults in power cables, using one of the following methods:

- at network frequency – supply by a transformer from network of 50 Hz supply by a resonant circuit at network frequency with high voltage adjustable coil
- at variable frequency(20-300) Hz – power converter and resonant circuit with high voltage coil – fixed inductivity

From above methods, the resonant circuit with variable frequency method can be adapted and easily applied for examination the cable insulation (PD determination) on site; although its working frequency depends on capacitive load, it may be achieved from constructive point of view in a compact portable equipment .
Block diagram of a such equipment is shown in fig. 4 [7]

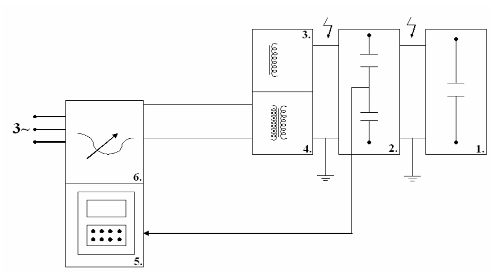

Figure 4: Block diagram of cable test system fed by a variable frequency resonant circuit

1.testing object;2.voltage divider;3.fixed reactor;
4.excitater transformer;5-6 control and supply unit

From constructive point of view, the high voltage unit is designed and manufactured as capsulated type with oil impregnation paper insulation and natural oil cooling.
By applying a such system, as presented in fig.4, PD with values below 10 pC can be determined.

3.2.3 Oscillating Wave Test System (OWTS)

Mainly, it consists in generating a damped A.C. voltage with frequency ranging between 50 and 500 Hz.
A cable test diagram using OWTS method is shown in fig. 5 [8].

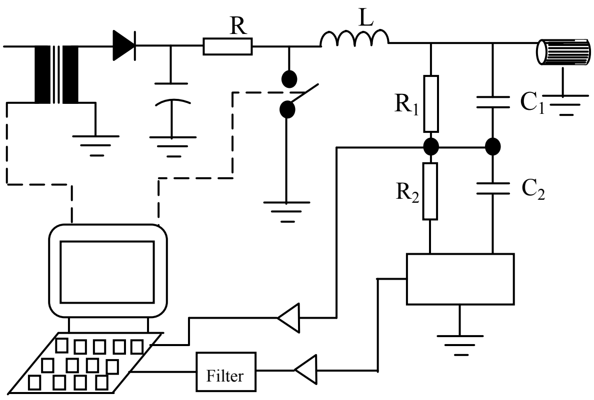

Figure 5 : OWTS method diagram for PD measurement in cables

The system is fed by a D.C. variable voltage source supplying the tested cable for time t_1 of seconds order, with an increasing voltage up to the value of tested cable.
After test voltage value is reached, a special short-circuiter, whose closing time is very short, is connected to the tested cable by means of an air-core solenoid,L. From this moment, various damped voltage oscillations are produced at circuit proper frequency, f.
Oscillation frequency is determined by expression [8,10]:

$$f = \frac{1}{2\pi\sqrt{L \cdot C_{cable}}} \quad (5)$$

4. EXPERIMENTAL DETERMINATIONS OF PD IN CABLES AND ACCESSORIES

This section covers the practical results obtained in PD level determination in some mean voltage power cables using electrical method.The tests have been performed in LIT Test Laboratory within ICMET Craiova.
These tests have been effected in strict accordance with IEC 60270 recommendations.
Samples of tested cables have been initially subject to some previous preparation operations (ones with known faults and intentionally created, others free of known faults) and equipped with accessories (terminals) produced by ENERGOCOM Bucharest.

Technical characteristics of MV cables subject to laboratory tests are presented in Table 1 [12].
Circuit diagram used for cables and accessories test is presented in fig. 6.

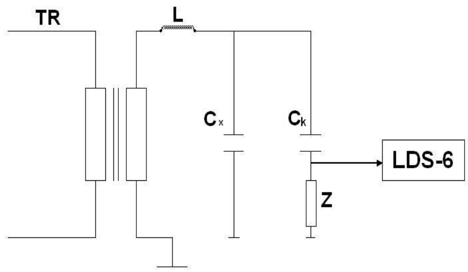

fig. 6
Measurement diagram

Equipment used for tests consisted of: test transformer 200 kV; capacitive divider MCF75/350P type; coupling condenser 1.000 μF; measurement impedance H-253/1; coaxial measurement cable. The device used for PD detecting and measurement was of LDS-6 type produced by Lemke Diagnostics GmbH.
Initial calibration of the system was done by a special device PET 2-1.
Results of these tests are presented in Ttable 2 [12].

5.CONCLUSIONS

In actual conditions, localization and fast removing of faults occurring in power cables and accessories became a priority in electrical networks maintenance because the main accent is put on increase of efficiency and diminish of losses caused by accidental interruptions in electrical energy distribution.
An advantage in determination of faults in power cables and accessories using off-line methods refers to the fact that disturbances level which could distort and affect the correctness of measurement is small enough because tests are performed with power cables disconnected.
Acoustic method is applied for fault localization in power cables or joints when the fault has already caused the insulation failure or breakdown. It is widely applied being used in localization of about 80% of the faults happened in power cables.
In case of fault localization by TDR method, an increased sensitivity and accuracy are obtained when less PD areas are found in the respective cable; there is a simple explanation, namely, in case of more PD areas, the individual pulses and/or reflected ones are overlapped and they appear as a mean value. Also, the length of cable is a characteristic which imposes certain limits as regards utilization of this off-line method and evidently the measurement precision decreases when the cable length increases [6].
By OWTS method, after measurements and detreminations made on-site, special data are obtained about some important parameters available for valuable information on cable general condition; these parameters may be grouped as follows [8,9]:

- primary (base) parameters: PD level depending on time; initial voltage value (PDIV); extinguishing voltage value (PDEV):
-secondary (derivate) parameters: curve q-U; PD level depending on phase, etc.

This information about PD may be determined for various values of voltage, reaching up to 2Uo, obtaining a lot of PD characteristics called PD “fingerprints” for the tested cable.
OWTS method provides for tested cable the same determination conditions of partial discharge initial voltage (PDIV) similar to those obtained at 50 Hz, so that PDIV, PD level and PD appearance phase are specific and relevant information for determination the fault in power cable. This method proved to be convenient for diagnostic of power cables and their accessories on-site.
Tests performed at A.C. voltage are important for inspection, execution and correct connection of power cables and their accessories on-site [11].
Off-line methods, both electrical and non-electrical ones, became indispensible working tools for all specialists acting in mainetance domain of electrical energy distribution underground networks and in fast and sure intervention domain for faults removing.

Table 1: Technical characteristics of cables

No.	Cable	Cable type	Voltage (kV)	Equipment	Length (m)
1	A	A2XSy 1 x 150 mm^2	12/20 (24)	- terminal SILCOTIS 20 kV - terminal TI with deflector cone of electro-insulating tapes 20 kV	2,5
2	B	A2XSy 1 x 150 mm^2	12/20 (24)	- 2 terminals TI 20 kV with prefabricated deflector - joint with electro-insulating tapes, in the middle	5,5
3	C	A2XSy 1 x 150 mm^2	12/20 (24)	- 2 terminals SILCOTIS 20 kV - joint with electro-insulating tapes, in the middle	5,5
4	D	A2XSy 1 x 150 mm^2	12/20 (24)	- terminal SILCOTIS 20 kV - terminal SILCOTIS 20 kV	2,5
5	E	A2XSy 1 x 150 mm^2	12/20 (24)	- terminal SILCOTIS 20 kV - terminal 20 kV with prefabricated deflector	2,5

Table 2: Results of tests

Cable	Pre-stress voltage (kV)	Test voltage (kV)	PD value (pC)	Calibration value (pC)
A	20,7	18 20 24 18	30 – 40 42 120 – 150 0	500
B	20,7	20 18	600 –1200 at t =0 sec - 400 t =1 min - 200 t = 2 min - 400 t = 3 min - 300	100
C	21	21 18 17 16	at t = 0 sec -100-120 t = 1 min - 90 63 30 at t = 0 sec - 11 t = 1 min - 4	20
D	24	24 20 18	28 18 9	5
E	21	15 21 18 15	50 700 – 800 350 125	100

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