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Presentation of HVA faults in SONELGAZ underground network and methods of faults diagnostic and faults location

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Abstract— **Power supply networks are growing continuously and their reliability is getting more important than ever. The complexity of the whole network comprises numerous components that can fail and interrupt the power supply for the end user. Underground distribution systems are normally exposed to permanent faults, due to specific construction characteristics. In these systems, visual inspection cannot be performed. In order to enhance service restoration, accurate fault location techniques must be applied. This paper describes the different faults that affect the underground distribution system of SONELGAZ (National Society of Electricity and Gas of Algeria), and cable fault location procedure with Impulse Reflection Method (TDR), based in the analyses of the cable response of the electromagnetic impulse, allows cable fault prelocation. The results are obtained from real test in the underground distribution feeder from electrical network of Energy Distribution Company of Souk-Ahras, in order to know the influence of cable characteristics in the types and frequency of faults.**

***Keywords*— Distribution networks; Fault location method; TDR; Underground cable; Fault detection.**

I. Introduction

The urban zones development and environmental considerations have supported the use of underground power cables instead of overhead lines. Underground cables have many advantages compared to overhead lines. In fact, they practically do not require maintenance and especially are not affected by the unfavorable climatic conditions.

However, when fault happens, the restore time is relatively long due to the various stages of fault identification, classification and location estimation in differed time [1,2].

Then to guarantee the electric power continuity, the electricity companies need to identify and locate rapidly and precisely the faulty segment in order to reduce the interruption duration [2, 3].

Methods based on the principle of pulse reflectometry (TDR: Time Domain Reflectometry or PE: Pulse Echo) [4, 5] are currently used for the location of faults on cables and lines, all types of line disruptions, earth contact of the line, contact among lines, curvatures and unevenness of cables, splitting, penetration of water into cables, etc.

Time Domain Reflectometry (TDR) is a well-known technique that is typically used to measure the impedance of discontinuities as a function of time (or distance) in electronic systems [6, 7].

II. Cable Types and Their Characteristics

Cable types are basically defined as low-, medium- and high voltage cables. According to the cable type, different requirements to cable testing, cable fault location as well as maintenance strategy are defined. The tendency of the last years show the shifting to single-core systems as they are lower in price, lower in weight and cheaper in regards to repair costs. Furthermore oil impregnated or oil filled cables are used less and less, as the environmental sustainability can not be guaranteed. Especially in industrialized countries, these cable types have been replaced and are no more installed.

Today mainly PE insulated cables are used. The improvement of the PE insulation material combined with the modern design of the cable enable to manufacture cables even for the extra high voltage level.

In this following table, we note the different cable types used by SONELGAZ:

TABLE I
CABLE TYPES USED BY SONELGAZ

Voltage	Type of cable	Nature and style of the conductive core	Type of insulating material
10 kV	Unipolar	Aluminum 185 mm² Aluminum 240 mm² Copper 120 mm²	Impregnated paper (IP)
30 kV	three-pole	Aluminum 120 mm² Aluminum 185 mm² Copper 70 mm²	Synthetic Insulation (PRC, PVC, PE)

III. TYPES OF CABLE FAULTS

Cable faults can be categorized into three main types: Open conductor faults, shorted faults, and high impedance faults [8-9].

A. Open Conductor Fault

An open conductor fault is where the conductor of a cable is completely broken or interrupted at the location of the cable fault. It is possible to have a high resistance shunted faults (to ground) on one or both sides of the faulted conductor's location.

B. Shorted Fault

A shorted fault is characterized by a low resistance continuity path to ground (shunted fault). The resistance from the conductor to ground is lower than the surge impedance of the cable for a shorted low resistance fault.

C. High Impedance Fault

A high impedance fault contains a resistive path to ground (shunted fault) that is large in comparison to the cable's surge impedance. This fault type may also demonstrate non-linear resistive characteristics which allow the apparent resistance to vary with the level of applied voltage or current.

IV. IDENTIFY THE TYPE OF FAULT

A multimeter being used as an ohmmeter or an insulation tester is used to determine the type of fault. This is important to help us decide on which method of fault location is best suited.

Tow values of fault resistance R_d are important to know the fault:

TABLE II
VALUES OF FAULT RESISTANCE

Category	R_d value
1	< 100 to 300 MΩ
2	> 100 to 300 MΩ
3	More than some megohm

If the resistance value is situated in category 1, then we can confirm that it is an insulation fault, else if R_d value is situated in category 2 or 3 then we use the prelocation methods.

V. TYPES OF FAULTS DETECTION (PRE-LOCATION METHODS)

The faults occurring in the power lines and cables can be classified into four main categories- short circuit to another conductor in the cable, short circuit to earth, high resistance to earth and open circuit.

Not all approaches work best for each type of fault. Four methods that are mostly used in detecting fault location are described as follows.

- A-frame
- Thumper
- Bridge methods
- Time Domain Reflectometer (TDR)

A persistent short circuit to earth fault can be most easily located using A-Frame method. For high resistance to earth faults. A-Frame method is not always sufficient. In this case, thumper method needs to be used to reduce fault resistance. Thumper method alone may be sufficient for fault location but when applied for a longer duration, it may damage the cable insulation. A-Frame is not useful for locating faults which do not have an earth connection. Time Domain Reflectometer (TDR) is suitable for determining the locations of most of the faults.

A. A-Frame Method

In A-Frame method, a pulsed direct current (DC) is injected into the faulty cable and earth terminal to locate the ground fault. The DC pulse will flow through the conductor and return via earth from the earth fault location back to the ground stake as shown in Figure 1.

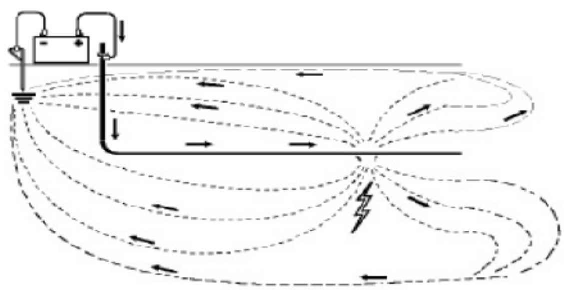

Fig. 1 An A-Frame method of finding cable fault location

The flow of pulsed DC through the ground will produce a small DC voltage. A sensitive voltmeter is used to measure the magnitude and direction of the DC voltage in segments of the earth along the cable route.

Analysing the results of the measuring voltage along the route, the location of the fault in the cable can be pinpointed. A-Frame is an accurate method but it is not the fastest one, since the operator has to walk along the length of the cable from the transmitter to the ground fault.

This method may face a problem if the return DC finds some easier path back to the earth stake of transmitter instead of returning through the ground. If the ground is sandy, paved which provides high resistance and consequently, less current flows through the ground. In that case, the voltmeter fails to measure the voltage and fault detection becomes complicated.

B. Thumper Method

Thumper is basically a high voltage surge generator which is used to apply a reasonable high voltage to the faulty core of an underground cable to generate a high current arc resulting in a loud noise to hear above the ground. This method requires very high current thump at voltages as high as 25 kV to make underground noise loud enough to be heard from the ground.

As the A-Frame method, the thumper method requires an operator needs to walk along the path of the cable and listen for the sound from above the ground. Different ground conditions, nearby traffic and noises may make this sound hard to listen to make a clear distinction.

C. Bridge Method

Bridge methods used for locating faults in underground cables are based on modified Wheatstone circuit where direct current is used to measure the resistance in order to calculate distance of the fault in percentage of the total line length. Murray and Glaser bridges [8] use the similar principal for calculating the distance of the fault. Brief description of these bridges is given as follows.

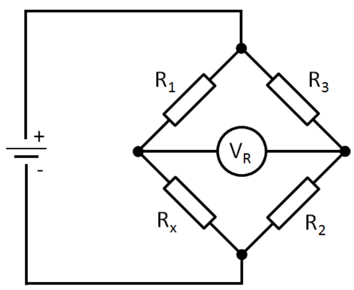

Fig. 2 Basic Wheatstone Bridge

Figure 2 shows the Wheatstone bridge circuit where R1, R2, R3 are the known resistors and Rx is unknown resistor. When the galvanometer represented by the circle in the figure shows zero current flow, the unknown resistor Rx value can be found from the other known resistors value using following equation:

$$R_x = \frac{R_1 \times R_2}{R_3} \tag{1}$$

A variation on the Wheatstone bridge is the Murray Loop Bridge. Figure 3 shows that the adjacent resistances, RC1 of a faulted cable in a loop with RC2 of a good cable can be made to represent Rx and R2 of the Wheatstone bridge. Similarly, corresponding portions of a slidewire resistor RB1 and RB2 can be made to represent the resistances R1 and R3. At balance in the Murray Loop Bridge, RC1/ RC2 is equal to RB1/RB2.

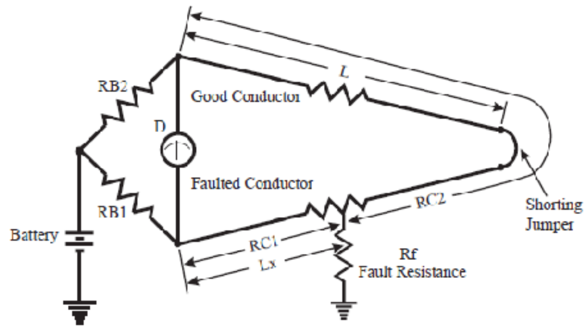

Fig. 3 Murray Loop Bridge application

When it is assumed that the resistance of a uniform conductor is linear and proportional to its length, and the total length of the cable section under test is L, the distance to the fault, L_x, is calculated as follows:

$$L_x = 2L\frac{R_{B1}}{R_{B2}} \tag{2}$$

D. Time Domain Reflectometry (TDR)

The TDR method is the most established and widely used measuring method for determination of:

- the total length of a cable
- the location of low resistive cable faults
- the location of cable interruptions
- the location of joints along the cable

In the Time Domain reflectometry (TDR) method, a low energy signal is sent through the cable where the perfect cable with the uniform characteristic impedance returns the signal within a known time and with a known profile. This time and profile of the signal is altered once the cable has impedance variation due to any fault. The impedance variation causes a portion of the signal reflected back to source.

1) Velocity of Propagation

Certain information must be provided to the TDR before it can provide distance information. Most important is velocity of propagation (VP), the speed at which the transmitted pulse travels down the cable under test. This value is used by the analyser to convert its time measurement to distance.

The approximate velocity of Propagation of cable is given by:

$$V = \frac{V_0}{\sqrt{\varepsilon_r}} \tag{3}$$

Where

V_0 is the light speed: 300 × 106 m/s or 300 m/µs
ε_r is the relative permittivity or dielectric constant of insulating material.

The following table presents the velocity of propagation for different cable types:

TABLE III
Propagation velocity for different types of cables

Cable type	VP m/ µs
Impregnated paper (IP)	140 - 155
Polyethylene (PE)	170
Ethylene propylene (EPR)	136 - 166
Polyvinyl Chloride (PVC)	155

2) Characteristic Impedance

If we consider that a cable is a line with distributed parameters, where:
l: linear inductance H/m
c: linear Capacitance F/m

The characteristic impedance of a cable is given as follows:

$$Z_c = \sqrt{\frac{l}{c}} \quad (4)$$

Characteristic impedance of power cables is generally ranges from 10 to 40 Ω.

3) Reflection factor

A voltage pulse Vi is sent into the cable and it is reflected at any changing in cable impedance (joints, fault, derivation,…)

The magnitude of the pulse reflections depend on how severely the fault impedance (Z_r) differs from the characteristic impedance (Z_c). The reflection can be calculated using the following equation:

$$r = \frac{Z_r - Z_c}{Z_r + Z_c} \quad (5)$$

For a short circuit, $Z_r = 0$ and the $r = -1$ this means that the pulse was reflected in the form of a negative pulse. For an open circuit, Z_r is infinite and $r = +1$, meaning that the pulse was reflected in the form of a positive pulse.

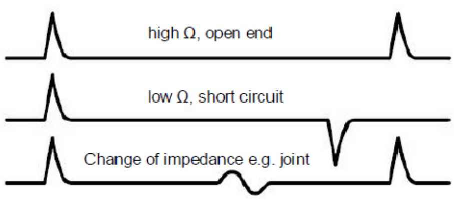

Fig. 4 Schematic diagram of TDR reflection graphs

VI. Locating or Pinpointing Methods

A. Acoustic Fault Location

For pin-pointing of high resistive and intermittent faults in buried cables the acoustic method is used to pin-point the exact fault location. As signal source, a surge generator is used in repetitive pulsing mode. High energy pulses which are released by a surge generator force a voltage pulse to travel along the cable. At the fault the flashover happens. This causes a high acoustic signal that is locally audible. These noises are detected on the ground surface by means of a ground microphone, receiver and headphone. At the fault position the highest level of flashover noise can be detected.

B. Methods of audible frequencies

Approximately 2% of cable faults require such method [10]. We use this method when the resistance fault R_d is less than 5 Ω, and was not possible to locate the cable fault with the acoustic method.

VII. Algorithm for Locating Cable Fault

In this section, we propose an algorithm for different steps of fault location. In figure 5 we present the bloc diagram that we made to follow steps in faulty cables.

We worked with the SONELGAZ, Distribution Company of electric and Gas of Souk-Ahras, we made several tests on many underground cables with different section core and insulation, with two different voltages 10 kV and 30 kV, using the following steps presented in the bloc diagram (figure 5).

The test results are shown in next section.

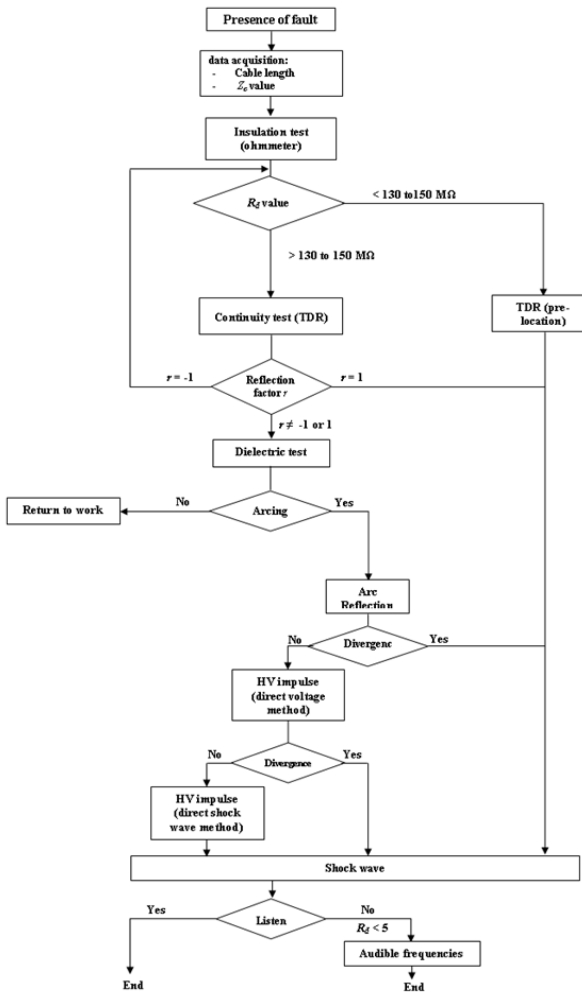

Fig. 5 Block diagram of location algorithm

VIII. Test Results and Discussion

In the first place, and after acquisition data, we show in following table the results of insulation resistance value for different section of cables:

TABLE IV

RESULTS OF INSULATION TESTING

Voltage (kV)	Cable section (mm²)	linear resistance (Ω/km)	linear inductance (Ω/km)	Type of insulating material	Insulating resistant (MΩ)
10	185	0.184	0.100	PRC	**62.79**
	240	0.140	0.100		**110.04**
	120	0.176	0.100		**51.97**
	185	0.184	0.100	PVC	**18.83**
	240	0.140	0.100		**33.01**
	120	0.176	0.100		**15.59**
30	120	0.284	0.100	PRC	**81.10**
	185	0.184	0.100		**49.20**
	70	0.300	0.100		**56.40**
	120	0.284	0.100	PVC	**7.00**
	185	0.184	0.100		**0.678**
	70	0.300	0.100		**18.00**

We note that R_d value is less than norm value, so we confirm that it is an insulating fault (Shorted Fault).

In this case, we use for the next step TDR method to prelocating the fault. On the figure below we see the Reflectogram showing the pulse form in the faulty cable.

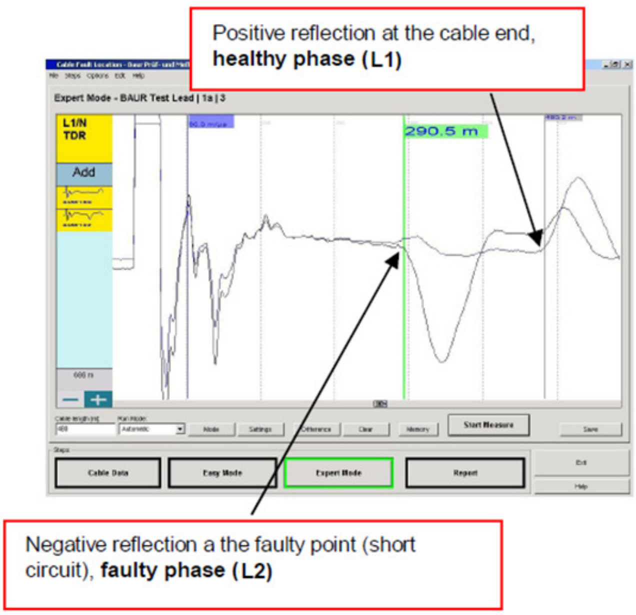

Fig. 6 Reflectogram of test result

IX. Conclusion

This paper explains the importance of locating faults in the distribution network and reviews some of the cable fault locating methods that are mostly used in practical field.

The work that we carried out confirms that TDR technique can detect the far end of the cable and other features along the length of the cable including joints

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