ISSN (Print) : 2320 – 3765

ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Issue 6, June 2017

Identification of Faults in Medium Underground Cables System: Rwanda Case Study

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Abstract: Electric power systems are gaining progress all over the world which results in increase of cables in operation and their total length. Underground cables have been widely implemented since long time ago due to reliability and environmental concerns. To enhance the reliability of a distribution system, proper identification of a faulted segment is required in order to reduce time interruption during fault current conditions. Fast and precise fault location play important roles in accelerating system restoration, reducing power outage time, and reduce financial losses, which significantly improve system reliability. This article is a report visit at Rwanda Energy Group, Section of Transmission and distribution, it describes a review on underground faults identification and location then fault identification and location estimation methods based on Centric System for medium distribution voltage in Underground cables being used in Rwanda was explored and then improvement suggestions were recommended at the end of this report.

Keywords: Underground cables; Fault location; Fault identification; Wavelet transform

I. INTRODUCTION

Faults are among major disturbance to power systems [1]. Hence there is a need to locate the faulty point in an underground cable in order to facilitate quicker repair, improve the system reliability and reduced outage period [2]. Power cable fault location techniques are used in power system for accurate pinpointing of the fault positions. The benefits of accurate location of fault are (a) Fast repair to restore back the power system, (b) Improve the system availability and performance, (c) Reduce operating cost and save the time required by the crew searching in bad weather, noisy area and tough terrains. One of the definitions of a fault is a physical condition that causes a device, a component, or an element to fail to perform in a required manner; for example, a short circuit or a broken wire. A fault always involves a short circuit between energized phase conductors or between a phase and ground. A fault may be a bolted connection or may have some impedance in the fault connection. The term “fault” is often used synonymously with the term “short circuit” defined as an abnormal connection (including an arc) of relatively low impedance, whether made accidentally or intentionally, between two points of different potential (Note: The term fault or short-circuit fault is used to describe a short circuit.). Distribution faults occur on one phase, on two phases, or on all three phases and Single-phase faults are the most common. Almost 80% of the faults measured involved only one phase either in contact with the neutral or with ground [3] (Table 1).

No	Fault	Percentage
1	One phase to neutral	63%
2	Phase to phase	11%
3	Two phase to neural	2%
4	Three phase	2%
5	One phase on ground	15%
6	Two phase on ground	2%
7	Three phase on ground	1%
8	Other	4%

Table 1: Percentage of fault as announced by EPRI.

As another view point, measurements on 34.5 kV feeders found that 75% of faults involved ground (also 54% were phase to ground, and 15% were phase to phase). Most faults are single phase because most of the overall length of distribution lines is single phase, so any fault on single-phase sections would only involve one phase. Also, on three-phase sections, many types of faults tend to occur from phase to ground. Equipment faults and animal faults tend to cause line-to-ground faults. Trees can also cause line-to-ground faults on three-phase structures, but line-to-line faults are more common. Lightning faults tend to be two or

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ISSN (Online): 2278 – 8875

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three phases to ground on three-phase structures.

II. SYMMETRICAL AND ASYMMETRICAL FAULT

Symmetrical or balanced fault is defined as the simultaneous short circuit across all the three phases while asymmetrical fault is when the fault is no longer balanced. In practice, most faults in power systems are unbalanced and asymmetric faults are difficult to analyse. The common types of asymmetric faults are single phase to ground fault, line to line fault, double line to ground fault.

2.1. Fault Types

Faults are either temporary or permanent. A permanent fault is one where permanent damage is done to the system. This includes insulator failures, broken wires, or failed equipment but virtually all faults on underground equipment are permanent. A temporary fault does not permanently damage any system equipment. If the circuit is interrupted and then reclosed after a delay, the system operates normally. Temporary faults cause sustained interruptions if the fault is downstream of a fuse, and fuse saving is not used or is not successful. For temporary faults on the feeder backbone, all customers on the circuit are momentarily interrupted. Faults that are normally temporary can turn into permanent faults [4]. If the fault persists too long, the fault arc can make permanent damage to conductors, insulators, or other hardware.

The most common types of cable fault are either contact faults or breaks. The contact fault is described as a short or shunt fault and is a connection or part of connection between core and core or between cores to sheath. The value of fault resistance varies from zero ohms to many mega ohms. On the other hand, break or also called an open circuit or series fault can be a clean break in a conductor, with infinite or very high resistance reading across the break and to adjacent metal. There can also be a dirty break where there is a measurable resistance across the gap and to adjacent meta. A partial break can occur when some of the strands of a conductor are broken or burnt.

Another type of cable fault is flashing fault. This type of fault does not manifest itself at lower voltages but flashes over at a certain higher voltage threshold. This may be several hundreds of Volts or several kilovolts up to a maximum which is the accepted dc test voltage for the cable. Such fault is acting like a spark gap. Lastly is the ingress of moisture. Moisture usually produces a contact fault involving all cores. Water enters in a cable at some point of damage and may reside in one limited stretch or it may spread many meters along the cable, typically as far as next joint [5] (Figure 1).

Figure 1: Example of underground cable fault.

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2.2. Method of Fault Classification in Underground Cable

Wavelet based method:

The wavelet based approach for fault classification is implemented using multi resolution analysis (MRA) of voltage and current signals. MRA is the process of decomposing a signal into different levels of resolutions. Initially, the signal is passed through two discrete wavelet transform (DWT) filters – high pass (HP) filter and low pass (LP) filter. The samples of output signal from the HP filter are known as detail coefficients, and those from the LP filter are known as approximated coefficients. This is considered as the first level. Next, the obtained samples from LP filter (first level approximated coefficients) are further processed through HP and LP filters to form the second level. In this way, the original signal can be processed through many levels depending on the need of resolution of signal.

Discrete wavelet transforms:

A signal is split into two parts, usually the high frequency and the low frequency part. This splitting is called decomposition. The edge components of the signal are largely confined to the high frequencies part. The signal is passed through a series of high pass filters to analyze the high frequencies and through a series of low pass filters to analyze the low frequencies. Filters of different cutoff frequencies are used to analyze the signal at different resolutions. Suppose that x[n] is the original signal, spanning a frequency band of 0 to πrad/s. The original signal x[n]is first passed through a half band high pass filter g[n]and a low pass filter h[n]. Then after the filtering, half of the samples can be eliminated according to the Nyquist's rule. Since the signal has the highest frequency of π/2 radians instead of π radians [6].

$$\text{yhigh} = \sum x[k]h[2k-n]n$$

$$\text{Ylow} = \sum x[k]h[2k-n]n$$

where yhigh [k] and ylow[k] are the outputs of the high pass and low pass filters, respectively, after subsampling by 2. This procedure can be repeated for further decomposition and then outputs of the high pass and low pass filters are called DWT [7].

Theory of Wavelet Analysis

He name 'wavelet' comes from the requirement that they should integrate to zero, "waving" above and below the x-axis. The diminutive connotation of wavelet suggests that the function has to be well localized. Other requirements are technical and needed mostly to ensure quick and easy calculation of the direct and inverse wavelet transform. There are some important differences between Fourier and wavelet. First Fourier basis functions are localized in frequency but not in time. Wavelets are localized in both frequency and time. Wavelets can provide multiple resolutions in time and frequency [8].

Method of Fault Location

After fault classification, the next step is to determine the fault location. The fault location identifies the physical position of fault in the power system. This information is very useful for isolating the fault and restoring the power immediately. There are two major methods for determining the location of fault namely (a) Circuit theory based method and (b) Traveling wave theory based method [9].

Circuit Theory Based Method

The circuit theory based method locates the fault using voltage and current values and impedance changes. After finding the fault type, fault voltage and current values are used to calculate apparent impedance based on the equation of apparent impedance. Depending on the fault type, specific voltage and current values are selected to find out the apparent impedance. The equation of apparent impedance consists of unknown terms like fault resistance and distance of fault. By separating the apparent impedance equation into real and imaginary parts, the fault location is calculated. In this method, the equations are shown only for a line-to-ground fault but a similar analysis can be performed for other types of faults. Instead of eliminating the fault resistance, the equation of fault's distance is expressed as a function of fault resistance. As the equation is in the form of a square root of quadratic equation, the minimum value of fault resistance is calculated and substituted in the equation of distance of the fault to find the location of the fault. The fault location is estimated by comparing the reactance of different sections of line with apparent

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ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

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Vol. 6, Issue 6, June 2017

reactance. For balanced systems, the sequence components of phase voltages, phase currents and impedances are used to form a quadratic equation in terms of fault distance and fault resistance. Unknown fault resistance is calculated by the imaginary part of this equation and the fault resistance is substituted in the real part of the equation to obtain the fault location. For unbalanced systems, direct circuit analysis is used to form a quadratic equation in terms of fault distance and fault resistance [10]. Matrix inverse lemma technique is used for calculating inverse operations of matrices. Then, the quadratic equation is solved to find the fault location.

Traveling Wave Theory Based Method

The traveling wave theory based method uses the information of voltage and current traveling waves for locating the fault. At the point of fault location, voltage and current waveforms get suddenly disturbed. Such disturbance causes them to propagate through the power system. Based on the total length of the faulted line, propagation velocity and time of waveforms, the location of fault can be obtained. This technique is mostly used for extra high voltage transmission lines than in distribution lines because distribution system contains many subsections such as laterals and feeders [11]. These subsections may create disturbances for the traveling waves on the lines. It includes two methods:

1. The single ended method.
2. The double ended method.

In the single ended method, only one fault locator is installed at one substation. Depending on the arrival time of waves at that substation, the location of the fault is estimated [12]. In double ended method, there are two fault locators installed at two substations and depending on the arrival time of waves at both stations, the fault location is calculated. This process involves using costly equipment such as GPS (Global Positioning System) to record the exact arrival times. The double ended method found to be better than the single ended method when applied to a distribution system wavelet transform is used to analyse the recorded waveforms at one end or both ends of the line. For double ended method, wavelet transform is used to examine the waveforms with a better resolution that are recorded at two ends. Then, based on the velocity and arrival times of waves, fault location is found. A similar approach is used for the single ended method, but due to the problems in reflected waveforms, separate approaches are derived for non-grounded and grounded faults [13]. Another traveling wave theory approach in locates the fault by using the high frequency components in the recorded waveforms of voltages and currents at the substation. The recorded waveforms are decomposed into a particular level of wavelet coefficients. The level is decided based upon the selected high frequency. By examining the wavelet coefficients, the faulted section in the distribution system is identified. Then, based upon the equivalent impedances of the remaining sections, an equivalent system is modelled, and the apparent impedance based technique explained in is used for locating the fault.

III. FAULTS LOCATION AND CLASSIFICATION IN MEDIUM UNDERGROUND CABLES SYSTEM: RWANDA CASE STUDY

Rwanda Energy Group Limited uses CENTRIC system which uses DC voltage test for underground faults location and this system has been used since 1955 till now. With the Centrix Diagnose, SebaKMT (company that offer all equipment of centric system) offers as a combination with the Centrix cable fault location system as additional functionality of fully integrated solution in the range of testing and diagnosis (Figures 1 and 2).

It contains main parts such as Control Unit (IPC, Command elements, VI unit and monitor), Cables and Megometer. The monitor display all information about faults such as fault distance, fault location, reistance of phases (normal or not). Cables are very long so that they can reach where the test is being done. There are three cables first cable for grounding system, the second for neutral and the third for carrying the signals. Megometer is used to measure the resistance of each phase (Figure 3).

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International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering
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Vol. 6, Issue 6, June 2017

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Figure 2: Centric system van for underground system cables faults.

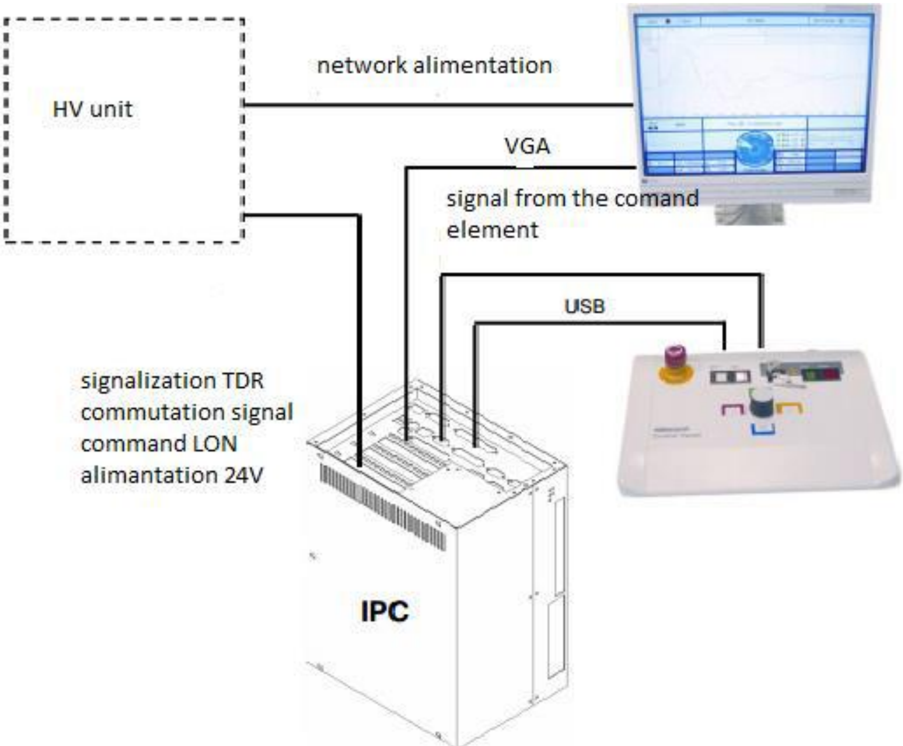

Figure 3: Control unit of centric system.

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3.1. The Process of Finding Fault

At the first time you have to measure the resistance of the phases according to the voltage level. The system maximum voltage that can achieve by this CENTRIC system in Rwanda is 80 kV. The sample (Kicukiro district) was chosen for this study was 1 in 30 districts, for the statistical power probability to be 0.05. A significance criterion states how unlikely a result must be if the null hypothesis is true, to be significant. For the criterion of 0.05, probability of attaining observed effect, must be less than 0.05 for the null hypothesis to be true. Therefore, the Frequentist approach to inference was invoked because the Bayesian approach allows probabilities to have interpretations, which represent the researchers beliefs that given values of the parameters are true [14]. Then a fault location was done at SONATUBE KICUKIRO on 15 kV distribution line where the nominal current was found to be equal to 700 µA. By Ohm's Law**:**

R = V/I
R =15 kV/700 Ma
R =21.42 × 10^6Ω = 21.42 MΩ

The resistance must not be under 21 MΩ, if the resistance is under this value at 15 kV it means that there is a fault somewhere in that line.

Phases	Resisitance	Comments
Phase 1	40 MΩ	No problem
Phase 2	22 MΩ	No problem
Phase 3	0.8 MΩ	Problem

Table 2: Resistance value measured by megometer at sonatube, kicukiro.

With this Table 2, it is clear that Phase 3 has a resistance which is under 20 MΩ which indicate that it is faulted then a prelocation started by sending a signal in the cable having the problem ie that has 0.8 MΩ, the computer displayed the fault voltage which is 3.31 KV and fault current equal to 37.1 mA. The length of the cable, computer displayed 74 m and the distance at which the fault is located, displayed 24 m from the connection cable testing. Then after pinpointing will start, which is the process of finding reallocation of fault. At this process the signal was sent with high energy of 2560J in the cable. When the signal reaches a point of fault, there will be a production of sound with high energy. As someone who is looking where the fault is you have to go at estimated distance and use your ears to understand the sound (Table 3).

Test voltage	Fault voltage	Current voltage	Real distance	Fault distance	Initial time	Final time
16 kv	3.31 kv	37.1 mA	74 m	24 m	0	2
16 kv	3.1 kv	30 mA	74 m	15 m	0	2
16 kv	2.6 kv	32 mA	74 m	18 m	0	2

Table 3: Voltage and distance values measured by centric system.

IV. RECOMMENDATIONS

Since this visit had only focused on distribution level of voltage, it is recommended that further visit and studies can be carried out on variety level of voltage in power system. More studies can be done on the effect of cable aging on fault location and for locating faults in a combined overhead transmission line with underground power cable. Another point is that, as Rwanda is country which is developing compared to other countries in Africa, and still using centric system (DC test) for locating fault distance. This method is designed in the way that when there is a fault far away the road, it is not easy to handle it. So, we recommend them the use portable system for locating fault distance in whole country. Rwanda Energy Group (REG) uses a Centric system Van which carry a system of locating fault, and this van is not portable, we recommend them to use TDR Technology which is portable and easy to carry everywhere (hills, mountains and son on).

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ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Issue 6, June 2017

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