Detection of Underground Power Cable Theft: Strategies and Methods

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***Abstract*— There are many cases in South Africa where power failure is mainly caused by cable theft. Although the power utilities and local municipalities work together, relatively close with communities to promote awareness. But cable theft in majority of urban areas still persists currently. Therefore, this paper proposes a cable theft detection system based on natural frequency disturbances. However, all possible employed methodologies are assessed thouroughly. It is prominent that based on identification of frequency disturbances on an underground cable, it triggers the systems alarm and location of the disturbance is identified within a short period.**

***Index Terms*-- Power failure, South Africa, Cable theft, Frequency disturbances, Theft alarm, Theft location.**

I. INTRODUCTION

Cable and electricity theft are the major role players in economic loss. This strides after it is reported that underground cable theft cost the power utility Eskom an amount close to R15 million to replace the infrastructure stolen underground [1]. Furthermore, the South African Chamber of Commerce and Industry (SACCI) indicated that cable theft cost South African economy five billion annually. Accordingly, in November 2012, R12.2 million was recorded for cable theft replacement cost, whereas December tracked R 12.4 million [2]. Consequently, at Johannesburg, cable theft account for 45% of electricity failure [3]. Cable theft is a major problem to every municipality in South Africa (SA). It is reported that about R 300 000 is spent every two years in the replacement of power cables at King Sabata Dalindyebo Municipality. The municipality proposed the installation of flood lights and to replace underground cables with overhead cables. This is to fight cable theft [4]. In SA, cable theft is a national crisis. This draws implications in the country's economy and security as a whole. Interruptions of essential service deliveries are eminent, which includes; transportation, telecommunications and basic health [5]. Cable theft detection system based on natural frequency disturbance, as a proposed methodology approach against cable theft, prompt to provide ever long awaited solution to cable theft in South Africa and the nation at large. It is however imperative to engage necessary stakeholders in the combat to cable theft national crises. Researchers are at the heart of solutions, however, necessary implementation needs to take place as a matter of urgency. Therefore this paper proposes a cable theft detection system based on natural frequency disturbances. This is done by energizing the cable and investigate its nominal frequency, and disturbing the energized cable in terms of burning and shooting. This paper is organized as follows; Section II Related Methodology Approach, Section III Current Methodologies, Section IV Discussion and Conclusion then followed by Acknowledgement and References.

II. RELATED METHODOLOGY

In [6] a CableGuard is proposed as an anti-theft protection system for underground cables. However, due to its material behaviour over time, absorbtion of moisture causes the system to grab the cable tighter. Thus increasing an additional compression stress at a local point of a cable. Increasing the compression stress on the cable at a local point, these creates a weak link at that point in a cable. Hence an increased skin effect phenomenon at that local point. Figure 1 above shows the CableGuard. Aberdare, the maufacture of transmission and distribution cables, suggested various theft deterrent methods. This methods are quite simple and straight forward, therefore the possibilities that thieves will have the tools to overcome the suggested methods is high (65%). The table below describes the each method used.



Fig. 1 shows the CableGuard as an anti-theft protection system [6].

TABLE I
ABERDARE description of theft deterrent systems [5].

Method no.	Method Description	Description
1	Traceability	Marking of cables at one or multiple sections in/exterrnally .
2	Physical fixing	Securing the cable with clamps.
3	Other conductor material	Use of copper clad steel/ aluminium for earth conductor.
4	Cable design	Difficult to cut and saw.
5	Security	Cable monitoring (fibre cables).
6	Identification	Non-standard sheath colours.
7	Legislation	Categorising copper and classification of cable theft crime.

Cablecroc systems, which are manufactures from galvanised steel and injected moulding from reinforced polymers are said to be used in cable theft prevention. It is said that these systems are cost effective. The cable is attached physically and permanently to randomly spaced achors and protection systems. It is said to provide difficulties to remove underground cables. The force required to remove the underground cable with such solution is more that 56 kN. Figure 2 below shows the picture [7].



Fig. 2 Cable Croc for cable theft prevention [7].

Unit (CATU), which restrain the easy way of stealing suspended, underground as well as data cables. This system interconnect two adjacent cables to each other using clamps. The system has the following advantages;

- Withstand high temperatures and high shock loads.
- Not affected by environmental conditions.
- Provide maintenance free and serve full life of the cable.
- Used in all cables sizes.

The disadvantage that this product entails, is that the pinching force of the system to the cable is unknown as well as the service life. This effect can cause damage to the cable [8]. Across many methodologies provided to cable theft, non at this stage or commercialised system are of electrically designed, but are mechanical systems. The problem faced by mechanical systems is that they have negative impact on response to cable theft incident. The systems are rather found damaged at the time it is recognised that the cable has been tampered with or the cable has been stolen already. Therefore it is imperative to provide a solution with fast response time milli-seconds, thus to provide the response team to act as urgent as possible and prevent the theft. Although a second or few seconds can be enough for the response time, it is eminent not to allow time for thieves to carry their plan within a given period. Figure 3 below shows CATU system deployed on underground cable.

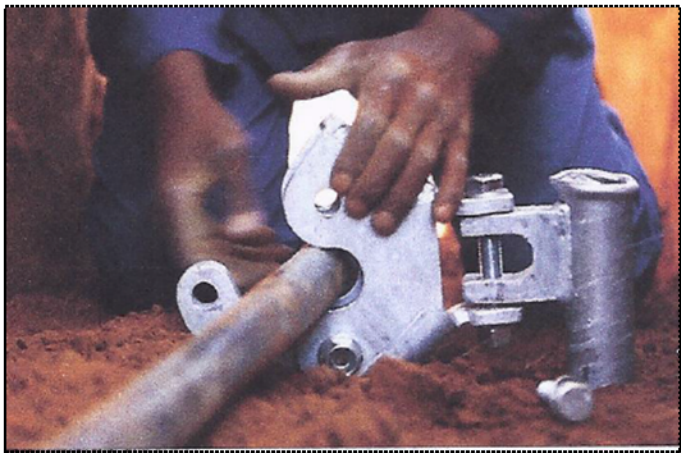


Fig. 3 CATU system installation for an underground cable [8].

III. CURRENT METHODOLOGIES

In [9], an online travelling wave method for fault location is proposed. This was done on a crossbonded cable system with the use of sheath currents. It is stated that the wave travelling method has a disadvantage of noise, and if the signal is not interpreted accurately, it can mislead the location of the fault.

A tool for prelocalization of insulation faults on an underground cable using voltage and current is proposed. However this work was only done at modelling and simulation levels. No practical applications were done or completed to validate the simulation model [10]. An Adaptive Network based on fuzzy Inference System (ANFIS) method to locate the fault in an underground cable is proposed in [11]. However, the system does not clearly state how accurate the system can classify the type of fault and at what point is the fault located.

The Zigbee, GPRs and Power Line Carrier (PLC) system was implemented. It measures the voltage and current of the underground current carrying conductor, thus locating the position of the cable fault. It said that the system send communication via the GPRS in a cable theft incident [12]. No necessary clarification is stated in case where there are current distortions in the line, how the system handle such inconsistency of the current in the cable. Various tools are prone to be used for the determination of cable faults locations, which includes; *Microprocessor devices*, *Short-circuit analysis softwares*, *customer calls* and *visual line inspection*.

Furthermore the requirements for systems used to cable fault are as follows; *speed (10-50 ms), Faults data window*, *Dedicated data communication systems, Accurate phasor calculations* and *high accuracy*. The table II below illustrate the required parameters for different methods applied on cable fault location. It known that this requirements are stated for commercialization purposes, and any defer to the requirements can prone the proposed system to failure. This requirements are mentioned in [13]. The difficulty with the adaption of some of the methods in SA is the lack of fund for manufacturing purposes. South Africa partially uses some of the methods at the power utility (Eskom) power stations.

TABLE II
Parameter requirements for different methods [13].

Method no.	Method Type	Parameter requirements.
1	Travelling-wave.	Substation and Line name, sensitivity, default sample settings, host personal computer, line length and wave velocity.
2	One-ended impedance based.	Phase-to-ground voltage and current, microprocessor based relay, communication interface.
3	Two terminal data based.	Microprocessor based relay, modems and communication equipment's, technical personnel and personal computer, remote communications, correlation of time stamps and phase-ground voltage and currents.
4	One terminal data based.	Microprocessor based relay, modems and communication equipment's, technical personnel and personal computer, remote communications, correlation of time stamps and phase-ground voltage and currents.

The most important part in this section, is to deal with data error. Three different types of errors are used to determine the fault location errror and this includes; a) *Absolute error,* b) *Relative error based on line*-length and *Traditional relative error*. The following are the equations;

$$e_a = | m_m - m_t | \quad (1)$$

Where: e_a is the absolute error, m_m is the measured fault current and m_t is the true fault location.

$$e_l = |m_m - m_t| / L \quad (2)$$

Where: e_l is the relative error based on length, L is the line length.

$$e_t = |m_m - m_t| / m_t \quad (3)$$

Where: e_t is the traditional relative error.

The absolute error gives a certain value regardless of the cable length, thus by understanding the range of errors from the above methodologies in table II, a certain fault location methodology use in a certain power system could provide useful information to the response crew. Therefore, the relative error measurements are useful to compare various faults location methodologies that are independent of the power system. Thus the traditional error measurements are most widely used for pure statistical analysis, and it is less intuitive to practical applications locating faults. Table III describes the pros and cons of each methodology.

TABLE III
Pros and Cons of the methodologies used [13].

Method Type	Advantages	Disadvantages
Travelling-wave	No line parameters are required. Only requires line length and wave velocity.	Requires the line to be energized in order to measure the time of the reflected wave to return to the source. Not always providing accurate results due to effects of pre-insertion resistors and closing point on the voltage signal. Line length calibration is not

		always accurate.
One-ended impedance based.	Phase-ground voltage and currents are used. Not sensitive to the reactance effects.	Inaccurate fault type identification. Influenced by zero-sequence mutual effects. Uncertainty about the line parameters(zero-sequence impedance). Insufficient accuracy of the line model. Load flow unbalanced. Measurement errors. Requires source impedance.
Two terminal data based.	Speed is not critical for human users. Response time of seconds or minutes is acute. It is accurate. Capable of being used with high speed circuit breakers and can perform calculations with half cycle.	One location used to gather and analyze data. Takes long period. Data needs to be synchronised before analysis from each end. Software or analysis tools are required and only take place after the fault has occurred and cleared by the protective relay.
One terminal data based.	Fault type are selected correctly. Reduced reactanced effect error. No zero sequence mutual coupling exist.	Source impedance error can produce incorrect results.
Trace technique	Pin-point	Walking the cable route.

The following are current fault location technologies;

- Restoration through switching.
- Restoration through re-closing mechanism.
- Indication through fuse and fault locator operation.
- Downed wires, customer calls, maps.
- Relay targets.
- DC thumping of underground circuits.
- Smelling burnt cables.

An algorithm for locating incipients faults is proposed in [14], however the algorithm is used on existing data from the utility supply and incorporated into the relay. The methodology approach of the algorithm does not consider the any data produced on the cable fault in terms of shooting or burning of the insulation. Only active and reactive power data is used, thus the formulae does not state how long does it take to locate the fault on underground cables. In [15], a hybrid technic to detect the fault on the underground cable is illustrated. This is done using the discrete wavelet transform as well as feed forward neural network to determine the cable fault. The method is statistically proved to be accurate with a mean average of 0.1%, however the researchers did not specify the lead time to achive all the results stipulated. The investigators in [16] claimes that the methodology approach of simulation model with PSCAD EMTP tool is accurate. Whereas the approach is one of the other method to locae a fault on underground cables is by using Bayesian inference theorem, as illustrated in [17]-[18]. The problem with this method is that, it will take tremendous time to alocate the fault. Hence by that time the perpetrators would have gone already. Therefore a proper method with effective response time is required. Operators at the control room evaluating the signals of cable fault must not be complicated to identify and locate a fault easily on a system. In [19], Hasija *et al.* created a model in Matlab/Simulink for the location and detection of underground cable faults.

Majority of almost every methods used to detect location and faults in underground cable is to use the current and voltage parameter analysis. None of the methods considers the frequency impact of the signals to detect faults and location on distribution networks. Different technics to locate faults in underground cables are discussed in [20]. Table III below describes different technics used.

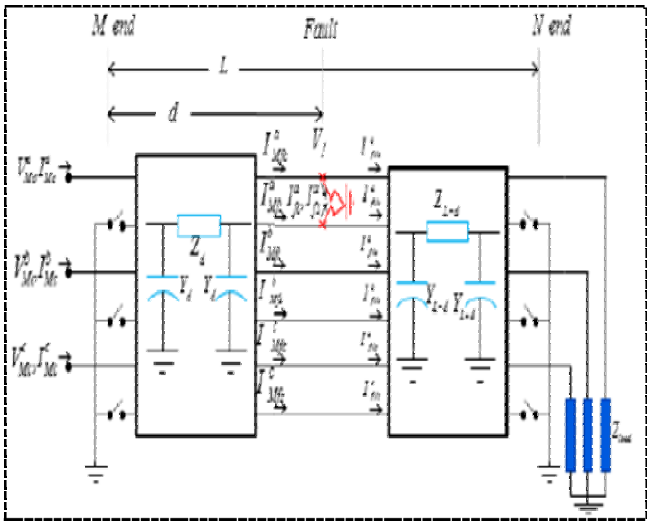


Figure 4 Algorithm used for sheath-ground fault [16].

TABLE IV
Different technics used for the location of underground cable faults [20].

Tech no.	Technic Method	Description
	Pre-locating methods	
1	Multiple Impulse	It uses Time Domain reflectometer (TDR) by sending a low voltage impulse, of which if the re is a fault it is not reflected by the meter. Fault impedance is compared to the insulaton impedance.
2	Impulse Current	TDR is used with impulse generator to create a flashover at the fault point. The current travels back and forth, hence

		determination of the fault point is conducted.
3	Bridge	Use of reflectometry method is applicable. Location of low resistive faults.
Pin-pointing methods		
4	Acoustic	Signal source and surge generators are used. Voltage pulses are sent to travel along the cable, and flashovers are generated at the point of a fault.
5	Step Voltage	Operate with cable sheath fault. Two potential earth propes are utilised together with a receiver. Figure 5 illustrate the method.

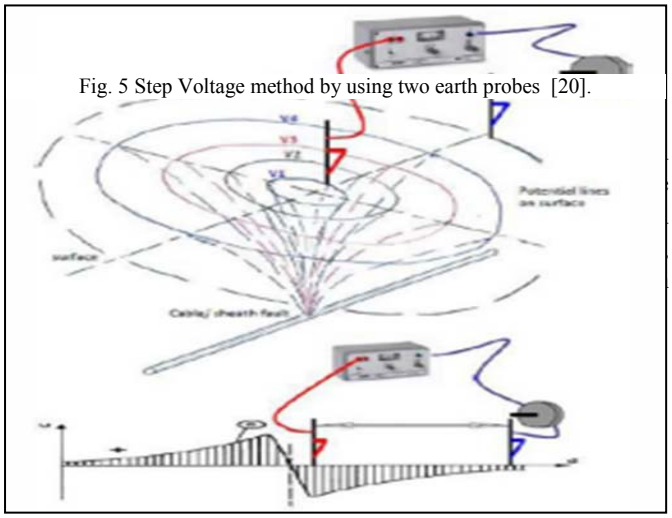


Fig. 5 Step Voltage method by using two earth probes [20].

IV. PROPOSED METHODOLOGY

The review study conducted did not show any frequency analysis as a parameter for fault location on underground cables. Therefore the methodlogy for detecting the location of the cable faults based on shooting and burning is as follows;

- Review study of theory on underground cables.
- Review of operation conditions based in South Africa and other african countries.
- Develop an algorithm based on frequency disturbance criterion for the location of fault on underground cables.
- Development of a simulation model in Matlab/Simulink.
- Experimentally validate the simulation results by evaluating the experimental results.
- Recommendations on how to employ the methodology approach to evaluate cable frequency disturbance.

V. ASSUMPTIONS

The following assumptions must be taken into considerations;

- Cable can withstand variable temperatures from 5-50°C.
- The cable is not touching the ground.
- The cable is new.

VI. DISCUSSION AND CONCLUSION

The current methodology plays a critical role in determination of cable fault locator. In this approach, cable theft is considered as a fault, as the natural frequency is studied on live cables. However this methodology incorporate the classification of the fault. Mainly are electrically classified. None of the methodology discussed classified physical faults in current carrying conductors. Perpetrators use different methodologies to steal underground power cables, below are the known methodology to name a few;

- Cable shooting.
- Burning cable.

Cable shooting: perpetrators use a gun to shoot the cable and the cable create a short circuit and trip the substation. Hence ensuring power failure before sawing the conductors. Whereas with cable burning, the perpetrators dig where the cable is located, create the fire underneath the cable, as the cable burn, an insulation fault occures, thus also tripping the substation and ensuring the existence of power failure just before sawing the conductor.

Cable theft (Short Circuit) detection system based on natural frequency disturbances with the influence of the system requirements based on speed and various operating requirements. It is highly likely that the system will operate efficiently in cable theft location. Thus alerting the control room operator of the location of the theft at high speed (10-50 ms). The system will enable the control officer to inform

central security on duty to the location. This proposed response time is efficient, this is to allow the response crew to arrive at the scene few seconds or minutes before the perpetrators steal the cables. The proposed approach will overcome all the pros and cons listed in Table III of the different methodology approach. The only parameters required to study the natural frequency of the cable will be the voltage and current of the line. Although the capacitance might influence this parameter, it is said to have zero influence on the current flowing through the conductor.

Cable operate at a certain frequency, therefore if the frequency signal change based on the characteristics of fire and bullet, the operator will know how to respond to such incidents. The method proposed will be experimentally investigated with a prototype with the aid of a good signal processing approach.

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