IMPROVING TDR MEASUREMENT IN MULTI-JOINT CABLE NETWORK

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ABSTRACT

Underground cables are widely used in the UK for electricity distribution. Additionally, many of the cables are approaching the end of their design-life. Distribution Network Operators (DNOs) will normally keep these aged cables in service to extend their service lifetime. However, the aged cables are prone to develop faults, which result in loss of power supply. This leads to customer minutes lost -- a parameter that is monitored by the Electricity Regulator (ER). Hence, it becomes desirable to know where in their power network, a fault might be developing. Time domain reflectometry (TDR) is mainly used to pre-locate faults in low voltage underground cable network. However the success of TDR to address faults relies on the simplicity of the cable circuit being diagnosed. This is because T-joints in a cable network and parallel circuits at the diagnostic point could result in acquisition of a complicated waveform and therefore inducing inaccuracy in pre-locating. Hence current technologies for identifying and locating fault either require access to residential homes or use of a heavy blocking inductor to ensure that only a particular circuit is being investigated. Neither way is preferred by ER. This paper analyses existing limitation posted by current TDRs and proposes some techniques to address the limitations.

INTRODUCTION

Time Domain Reflectometry (TDR), which is also known as Cable Radar, is a technique utilizing transmission line theory and pulse reflection principles to detect impedance changes along a cable. It works similar to the principle of radar; by transmitting a pulse down a cable circuit and looking for receive signals.

TDR technique has been well refined in medium voltage cable and overhead transmission line applications [1-4], however, it posts some restriction on underground cable networks. This is due to multiple T-joints in the structure of underground cable networks.

P.F. Gale has described a TDR based method [2], but it use current pulse rather than voltage pulse to address the faults, and requires experienced engineers to interpret of the results. The system developed by Komoda et al. can address the cable network with three-phase tees [3], but without investigating with single-phase tees. Magnago et al. further enhanced the TDR based on wavelet transforms and analysed the fault, however it considered only the case of 345kV transmission line without tees [4]. The technique presented in [5] and [6] is TDR based with novel combined logic. This system is further developed [7] and refined based on experimental result [8]. However the approach is concentrated on the use of post-processing tool to overcome the restriction of TDRs.

Underground cables are constructed by at least two parallel conductors, therefore underground cables can also be classified as transverse electromagnetic (TEM) transmission lines [9]. A TEM transmission line can be modelled with a well-known lumped-element model, which containing four basic elements, R', L', G', C'. Hence the cable impedance Z_0 is known as:

$$Z_0 = \sqrt{\frac{R' + j\omega L'}{G' + j\omega C'}} \qquad (\Omega)$$

For any point of a TEM transmission line, the ratio of amplitude of reflected voltage wave to incident voltage wave is known as voltage reflection coefficient Γ.

Assuming the impedance before a point of interest in a cable is Z_0^-, accordingly the impedance after a point is Z_0^+, it is known that:

$$\Gamma = \frac{V_0^-}{V_0^+} = \frac{Z_0^+ - Z_0^-}{Z_0^+ + Z_0^-} = |\Gamma| e^{j\theta_r}$$

where

$|\Gamma|$ is the magnitude of Γ, $|\Gamma| \le 1$

θ_r is the phase angle

The equation shows reflection is directly associated with characteristic impedance changes. A voltage wave travelling along a cable will be reflected back if there is impedance change along its path. Two extreme case would be an open circuit ($\Gamma = 1$) and short circuit ($\Gamma = -1$).

In an ideal lossless transmission line, Z_0 is real hence Γ is also real within any point of that transmission line, however, in many cases, the transmission line must be modelled as a lossy line and Γ is a complex number. This results in high distortion to signals especially high frequency (narrow) pulses.

The voltage reflection coefficient in a T-joint could be calculated as:

$$\Gamma_{\text{T-Joint}} = \frac{Z_{00} \| Z_{01} - Z_{00}}{Z_{00} \| Z_{01} + Z_{00}}$$

where

Z_{00} is the impedance of main cable

Z_{01} is the impedance of branch cable

For example, a single T-joint with same cables has a reflection ratio $\Gamma = -\frac{1}{3}$, this is significant and can be regarded as a short.

Thus another limitation of TDR is caused by the T-joint of cable circuit. The T-joint will introduced a high attenuation and cause unnecessary negative reflections.

To improve the TDR measurement, it is necessary to increase the power of the transmitting pulse, whilst reduce the reflection from the unnecessary branch. Additionally, if the measurement is taken when the circuit is energized, the TDR system is also required to be immune from noise.

INCREASE THE DISTANCE

TDR or simple pulse radar operating with narrow pulse widths have many advantages, including better range resolution and accuracy, and small blind and minimum range[10]. A TDR pulse has to carry sufficient energy to cope with the attenuation of cable and T joints. While maintaining the narrow pulse width, the energy of the pulse may be increased by increasing the amplitude. However this high voltage pulse may present reliability problems and safety issues.

With the use of modern signal processing techniques, alternative ways of getting around this problem may be possible. The project is currently investigating various innovative techniques that are widely used in data communications and imaging to overcome this problem.

Furthermore, most of these innovative techniques are capable of superior noise rejection ability, and this allows the TDR system to work in a noisy circuit. For example a computer with PWM power supply may generate wideband noise to the power network, and the noise will significantly affect the TDR waveform.

REDUCE UNNECESSARY REFLECTION

Whilst increasing the TDR distance, it is also preferred to isolate the branch that is not of interest. A blocking inductor is designed for this purpose. Blocking inductors are required to carry current of a particular subcircuit, therefore they are normally large, heavy, and expensive.

It is desired to replace the use of blocking inductor by an easier and more convenient way.

Ferrite bead is a special type of electronic choke and widely used for suppress high frequency signals.

Fig 4 shows the characteristic impedance of a typical ferrite bead manufactured by Fair-Rite, part number 0431164951 [11]. This ferrite bead has a maximum attenuation at about 100MHz.

As the frequency of TDR pulse could be designed to about tens of MHz, ferrite bead could be used for suppression of the pulse into the circuit that is not being investigated.

Fig 5a shows a normal pulse TDR waveform of 60ns transmitted down a 30M waveform cable. Fig 5b is the voltage waveform with a ferrite clamped in the sending end, while Fig 5c is one with 2 ferrites clamped in the sending end. This figure provides the indication of performance of a normal ferrite.

Use of ferrite bead has many benefits including low cost and easy installation.

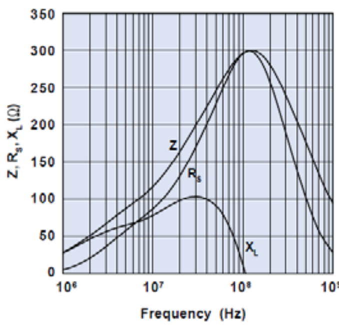
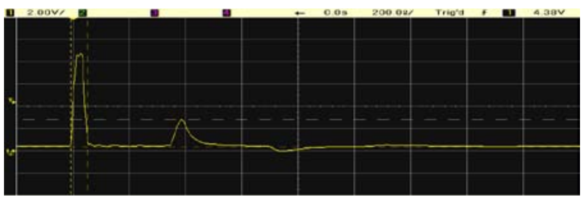
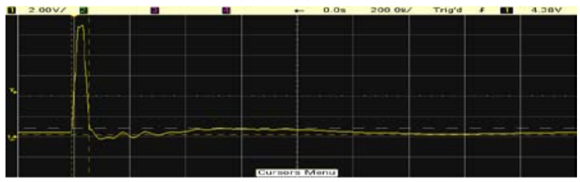


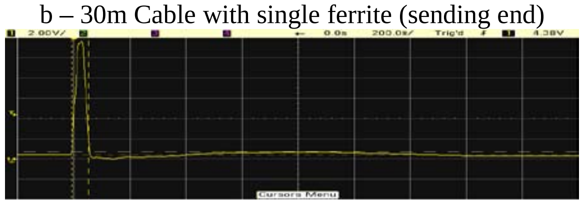
FIG 4: IMPEDANCE CHARACTERISTIC OVER FREQUENCY



a – 30m Cable without ferrite



b – 30m Cable with single ferrite (sending end)



c – 30m Cable with double ferrite (sending end)

FIG 5: TDR MEASUREMENT OF A CABLE WITHOUT AND WITH SINGLE/DOUBLE FERRITE

CONCLUSIONS

Underground cables could be modelled by TEM transmission line.

Reflection of TEM transmission line depends on the characteristic impedance change.

An improved TDR system with innovative techniques can overcome the restriction of pulse width and detecting range problem posted by conventional TDR. And this system can be work on a noisy online cable circuit, which further reduce the need of power cut on user's ends. Disadvantage of improved TDR system include added cost and complexity to transmitter and receiver.

Ferrite bead provide an alternative solution to blocking inductor, and reduces the cost of measurement. It could be installed in the user's end of cable in order to isolate the effect of user's load from TDR measurement.

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