Abstract. In power transmission system union of the electric power cables are necessary for the safety purpose. For identifying defects before it occurs and locating defects a method is required. This paper introduces an approach for a diagnostics of electric power lines. The TDR model and its function is simulated by resolving the finite differential time domain equations with MATLAB Simulink. The shown results gives that most satisfying method to assure safety of operation is TDR based diagnostic.

Keywords: electric power cables, TDR, MATLAB Simulink

I. Introduction

A TDR is the most convenient method to find shorts and opens in cables where there is no associated path to ground that can be used for ‘A-frame’ type locating. A TDR may also be more accurate for cables in duct where the path to ground may not be at the point of the fault but rather at an unrelated duct damage (crack, joint, etc.) [1].

The speed and accuracy of the TDR makes it today’s preferred method of cable-fault location. Although today’s instruments are more user friendly, a good understanding of the basic principles and applications of a TDR is essential to successful troubleshooting.

The pulse generated by the TDR takes a certain amount of time, and thus distance, to launch. This distance is known as the blind spot. Any faults that may have been hidden in the blind spot can now easily be located (however, remember to take the length of the jumper cable into account). The main focus is efficient modeling, which yields sufficient accurate results for the application while covering the relevant range of operating conditions.

From the well known governing equations of time domain transmission line of the voltage and current, in differential form and one dimensional finite differential time domain may be solved via MATLAB Simulink methods to yield appropriate values for reference parameters [10]. Using these parameters an efficient diagnostic is carried out. Modeling and results for electric power cables used in cable parameters are presented. Diagnostics of cable as a function of impedance and inhomogeneity are studied.

II. Theory

The working of a TDR depends on the impedance of the transmission line. Impedance is described as the resistance offered by an electronic circuit to an electrical signal.

Impedance can be described in two fashions: 1) circuit impedance “Z” (load); 2) characteristic impedance “Z0” (transmission line). Circuit impedance is the result of the interaction between the resistive, capacitive, and inductive portions of the electronic circuit. Both the capacitive and inductive portions of circuit impedance depend on the frequency of the AC signal applied to the circuit. Electronic circuit impedance (Z) can be expressed as:

$$|Z| = \sqrt{R^2 + (\frac{2\pi f L - 0.5 \pi C}{2})^2}$$

Where, $R$ =DC Resistance, $C$ = capacitance, $L$ = Inductance and $f$ = Signal Frequency.

Characteristic impedance is defined as the ratio of voltage to current of a wave moving down a transmission line. The resistance of a transmission line is typically small enough to be neglected. For a lossless line $Z_0$ can be expressed by:

$$Z_0 = \sqrt{\frac{L}{C}}$$

When mismatching of impedance occurs, results in electromagnetic discontinuity. The TDR signal’s velocity of propagation $v$ is related to the relative dielectric permittivity $\varepsilon_r$ of the medium, which is assumed to be lossless (or at least with negligible conductivity), and the relative magnetic permeability $\mu_r$, by the following equation:

$$v = \frac{c}{\sqrt{\varepsilon_r \mu_r}}$$

Where $c=3\times10^8$ m/s, which is the velocity of light in vacuum, while the relative magnetic permeability is unity in most materials, such as liquids.

Velocity of propagation in terms of velocity of light is given as:

$$v = \frac{1}{\sqrt{\varepsilon_r}}$$

When an impedance mismatch occurs, a part of the incident pulse is reflected back toward the step generator. The ratio between the reflected signal amplitude and incident pulse amplitude gives the reflection coefficient $\rho$. 


The reflectivity change at the defect or impedance mismatch between material interfaces can be related to the reflection coefficient through the equation:

$$
\rho = \frac{V_{\text{reflected}} - V_{\text{incident}}}{V_{\text{incident}}} = \frac{Z_L - Z_0}{Z_L + Z_0}
$$

(5)

Furthermore, in the case of a TDR probe traversing from the front end to the far end of a cable consists of conducting material filled with a similar material or different material area or length D, the dielectric constant of the cable tested can be evaluated as:

$$\varepsilon_r = \left(\frac{D}{\varepsilon_0}\right)^2$$

(6)

Where D is the distance of the signal from the first point of discontinuity to the new mismatch point (this is typically a short or open circuit terminating the probe), and D₁ is the corresponding apparent distance in air, measured by the TDR set-up.

the second mismatch occurs can be measured, as:

$$D = \frac{D_1}{\sqrt{\varepsilon_r}}$$

(8)

Measuring the reflection coefficient (ρ) and the apparent length of the cable (D₁) we can simultaneously measure the length of the cable, and also evaluate the nature of defect in that cable.

Also, the delay experienced by a wave in a cable and the length of the defect are related as:

$$d_{\text{min}} = \frac{c + \varepsilon_r}{4\varepsilon_r}$$

(9)

Where c is the velocity of propagation of the signal, in terms of c, i.e. the velocity of light in free space.

The spatial resolution is the ability of the TDR to distinguish between closely spaced anomalies. It depends on the rise time of the TDR. Two discontinuities are indistinguishable if separated by less than the rise time. Hence, faster the rise time of the TDR, sharper its spatial resolution. The spatial resolution d_{\text{max}} is related to rise time t_{\text{rise}} of the TDR as:

$$d_{\text{min}} = \frac{c + \varepsilon_r}{4\varepsilon_r}$$

(10)

Where c is velocity of light in vacuum and εr is relative dielectric permittivity of the medium.

III. SIMULATION

The Simulink model is based on signal flow diagrams. Gain parameters of each block is calculated and set in the MATLAB code. The back end of the MATLAB program is a Simulink model of the TDR. This model is a signal flow diagram of the TDR. The signal flow graph is used in many different applications. It is a way of describing transitions with block diagrams. The transmission line is a perfect feedback system with the signal flow point of view. The following examples illustrate the usage of the signal flow graph.

As shown in Fig 1, the TDR tester sends out a voltage signal down the transmission line. The reflection created can be neglected if the characteristic of tester’s impedance matches that of the transmission line (Z₀=Z₁). The magnitude of the reflected signal can be calculated as

$$\Gamma_0 = \frac{Z_L - Z_0}{Z_L + Z_0}$$

(15)

while the magnitude of the transmitted signal is

$$T_{\text{01}} = 1 + \Gamma_0$$

(16)

![Fig. 1. Initial Reflection and Transmission Coefficients](image1)

Most of the reflectometers have the detector/sampler installed inside the tester. The signal flow graph of the system can be represented as shown in Fig 2.

![Fig. 2. Initial Response](image2)

With some time delay that is proportional to the cable length, the wave propagates further to the end of the cable and reflects back to its original junction at the tester with another time delay that is equivalent to the forward delay.

![Fig. 3. Delay behavior and reflection at the end of a cable](image3)

![Fig. 4. Response with delays](image4)
For simplicity, the responses have been pretty ideal so far. The basic model shown in Fig 7 can be further developed in order to simulate behaviors in the real world situation. Attenuation for example, can be added within or after the delay box. Filtering effect, for another example, can be included in the block diagram as well. For some application specific configurations (i.e. aircraft environment), the noise or vibration effects may be critical, thus, can be added to the basic block diagram shown above.

With a two-section transmission line configuration shown in Fig 8, the signal flow becomes more difficult to keep in track. This is where the easiness of the bounce diagram method starts to fade.

For the basic signal flow graph of a single section transmission line shown in Fig 6, we can easily expand the model to simulate multiple sections. Let’s assume the impedance of the tester matches the first section of the transmission line. We can remove the initial reflection \( \Gamma_0 \) from the graph. The resulting signal flow graph is shown in Fig 8, where \( L_1 \) block represents the first section while \( L_2 \) represents the second section. Comparing the blocks \( L_1 \) and \( L_2 \) we noticed that they are functionally identical. By representing them as big boxes with two pairs of IOs, we can greatly simplify the signal flow diagram as shown in Fig 9.

Similarly, we can further cascade the configuration to \( N \) sections as shown in Fig 10. The ability of cascading block diagrams as connecting sections of transmission lines makes this method easy to use and more flexible. The properties of the transmission lines can be built-in each block and the users only need to connect them together. This is especially useful for concurrent GUI programming languages.

**IV. RESULT**

TDR is an instrument which uses a pulse to detect impedance changes along a transmission line. It is mainly used to test for faults in cables. The output of the TDR is a graph on which the locations of impedance anomalies are seen as deflections in the signal. The nature of the anomaly can also be inferred from this graph. TDR consists of a) Pulse generator b) Broad band oscilloscope. The pulse generator generates either short
pulses or step pulses and the pulses are send down the cable under test.

![Block diagram of TDR](image)

**Fig 12. Block diagram of TDR**

The results are given in Figure 13-15. Fault in the cable or change in medium implies an impedance mismatch. When the pulse reaches a discontinuity, some energy is reflected back. The reflected signal is superimposed upon the incident signal. A mismatch is seen as a step-up or a step-down in the resultant signal. The studies were carried in data of RG58 (5m, 50ohm, VOP-0.66) and RG62 (2.2m, 93ohm, VOP-0.84) coaxial cables and used a TDR tester (50 ohm) to the coaxial cables in series or shunt.

The low voltage signal pulse send through the TDR tester to the coaxial cables, if there is any fault in a cable (i.e. variation in impedance), then the pulse will reflect back on the line to the source so that the time delay between the incident and reflected pulses is used to determine the round-trip distance, to the point of impedance change on the line. The amplitude of the reflected waveform can be used to measure the impedance of the defect, and the time delay of the reflected waveform can be used to locate it (Fig 13-15). The reflection will not occur if there is no impedance discontinuity. Calculate the reflection coefficient values and simulate the diagram in MATLAB/Simulink. Run the simulation and get the output waveform, and then convert that output graph into amplitude Vs distance curve to locate the fault.

![Output for single section](image)

**Fig 13. Output for single section**

![Output for Two sections](image)

**Fig 14. Output for Two sections**

![Output for Three sections](image)

**Fig 15. Output for Three sections**

**IV. CONCLUSION**

Using the Matlab Simulink tool, we have simulated the TDR short pulse from pulse generator and captured the reflected signal using scope. The main electrical inputs to this model is pulse width, rise time and conductor impedance, were it is used to simulate the relation of the time domain. In addition to that the determination of defect in the cable is obtained as a function time domain. The simulated impedance mismatch is introduced in simulink model, which led to changes in reflectivity and resistance. It is inferred from the results that simulation can be used for power transmission cable diagnostics in overhead power cable and underground electric cable by incorporating actual data. Thus, the diagnostic
monitoring approach can be used to qualify power cables and also help to ensure lossless and cost-effective power transmission.

This paper introduced the application of TDR in an electric cable diagnostics system. Small faults occurred in large cables are identified using this technique. The technique uses injection of successive pulses with sharp rise and fall times, and with higher pulse spans of up to around 10 nanoseconds into the cable, in order to detect small faults over longer distances. Thus, it holds promise in helping create for our built environment a more sustainable future.

For immediate deformation determination, the location of any movement is determined immediately at the site. Convenient, results are obtained with TDR monitoring systems for finding the fault in power cable.

REFERENCES


