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Power Cable with Two Joints Experimental Analysis for Defect Assessments

Tze Mei Kuan, Azrul Mohd. Ariffin
Department of Electrical Power Engineering, College of Engineering, Universiti Tenaga Nasional,
Jalan IKRAM-UNITEN, 43000 Kajang, Malaysia

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ABSTRACT

Time domain reflectometry (TDR) is an easy technique that provides quick response which is ideal for power utility companies to conduct cable diagnostics on-site. Electricity disruption due to power cable failure is a major challenge for power utility companies due to the long length of cable installed with joints. The long time taken to diagnose the defect along the cable before electricity can be restored has not only jeopardized the reputation of power utility companies but also brings losses to the economy. Hence, this study conducts experimental analysis on cable with two joints with the application of TDR technique to reduce the electricity disruption time. This research is divided into two stages where stage 1 conducts experiments on cable with one degraded section while stage 2 looks into cable with two degraded sections. The TDR reflection characteristics are studied from stage 1 experiments and applied to stage 2 experiments to verify the consistency of the TDR reflection characteristics. The cable conditions of stage 2 experiments are predicted using the reflection characteristics from stage 1 observations and are then validated by comparing these predictions with the actual cable configuration. Results obtained from these experiments have proven that the TDR reflection characteristics are consistent and accurate which can be used to sectionalize the degraded cable section. Detail findings of all experiments conducted with the TDR application are discussed in part three of this paper.

Corresponding Author:

Tze Mei Kuan,
Department of Electrical Power Engineering,
College of Engineering, Universiti Tenaga Nasional,
Jalan IKRAM-UNITEN, 43000 Kajang, Malaysia.
Email: tzemei@uniten.edu.my

1. INTRODUCTION

Electricity disruption due to power cable failure have been reported from around the globe over the years [1-5]. Power utility companies often face challenges to diagnose defect along the cable due to the long cable length installed with joints. Power cable is an important asset to power utility companies as it is the only medium to supply electricity to the consumers. There are many factors that contribute to power cable failure such as faulty cable joint, manufacturing defects and cable insulation degradations such as partial discharge, voids in the insulation and water treeing [6-9]. Due to the vast factors contributing to power cable failure, cable diagnosis on-site requires time to locate the fault leading to long duration of electricity disruption time. Hence, it is crucial for a fault localization technique which is able to sectionalize the defect cable section in a short time. Thus, this research applies the time domain reflectometry technique which is an easy technique that provides quick response.

Reflectometry techniques can be categorized into three main techniques which are the time domain reflectometry (TDR), frequency domain reflectometry (FDR) and joint time-frequency domain reflectometry

(JTFDR) techniques [10-15]. Studies in [14-15] have proposed the JTFDR due to its good resolution and accuracy in detecting faults in the cables. However, the JTFDR can only be applied to cable length shorter than 100m which is not suitable for power utility companies to conduct the test on-site. FDR on the other hand provides good resolution for longer length cables, however FDR incurs high cost and it is unable to distinguish the exact fault [15].

Study in [15] have suggested that TDR is easy and non-destructive technique which is suitable for locating faults in long cables up to 30km. TDR uses the radar principle by sending a pulse into the cable and reflections are easily detected when there is any impedance mismatch along the cable. Therefore, this study conducts experimental analysis on cable with two joints with the application of TDR technique. As the TDR technique is able to provide quick response, any defect along a cable which creates an impedance mismatch will be able to be identified and cable replacement can be done quickly to reduce the electricity disruption time. This principle is investigated by conducting a series of experiments on various combinations of cable insulation condition with two joints using the TDR application to prove the practicality of this technique in sectionalizing degraded cable.

2. METHODOLOGY

This study performs two stages of experiments to investigate the accuracy of TDR technique in locating the defect cable section along a cable with two joints. Figure 1 illustrates the connections of three 100m long cables with two un-degraded/good joints which are used in all experiments. A total of seven experiments are conducted with various combinations of defect cable location along the cable as listed in Table 1. Experiment 1 which has a cable with all three cable sections in good condition is used as a benchmark to compare with TDR results from other cable configurations which has degraded cable. Stage 1 experiment comprises of three experiments where each has a cable with one degraded cable section while stage 2 experiment consists of another three experiments with each experiment having two degraded cable sections. Results from experiment 1 and stage 1 experiments are studied to understand the characteristics of TDR reflections along a cable with two joints and one degraded section. These characteristics are then applied to stage 2 results which has two degraded cable sections to predict the condition of cables for every experiment. These predictions are then compared to the actual cable configuration in Table 1 to investigate the consistency of the TDR reflection characteristics.

All experiments are conducted using Megger Teleflex SX TDR equipment on single core cable samples with the dimension of $240mm^2$ 11kV unarmoured XLPE cables (aluminum conductor). Two conditions of cable insulations are used in this study where the good cable (GC) has a clean XLPE insulation without any defect while the degraded/bad cable (BC) is defected with semiconductors in the XLPE insulation.

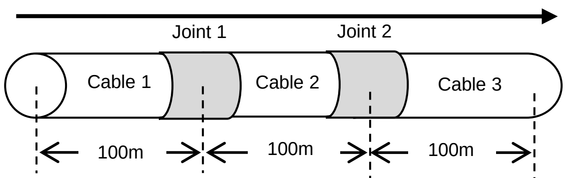


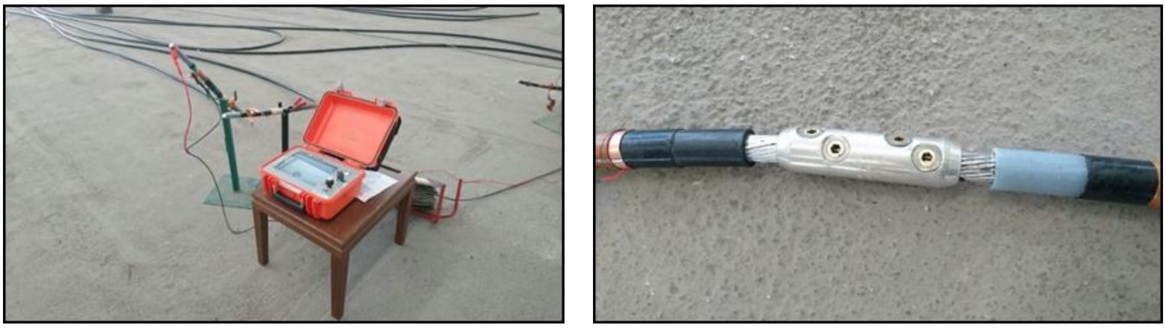
Figure 1. Illustration of cable connections with two joints

Table 1. Cable Configurations

Experiment	Cable 1	Cable 2	Cable 3
1	Good	Good	Good
Stage 1 Experiments			
2	Good	Good	Bad
3	Good	Bad	Good
4	Bad	Good	Good
Stage 2 Experiments			
5	Good	Bad	Bad
6	Bad	Good	Bad
7	Bad	Bad	Good

3. RESULTS, ANALYSIS AND DISCUSSIONS

Figure 2(a) shows the TDR experimental set-up where the Megger Teleflex SX is connected to one end of the cable and the other end of the cable is left open while Figure 2(b) depicts the example of the straight through joint used for connecting the cables in all experiments.



(a) (b)

Figure 2. (a) TDR experimental set-up (b) Example of straight through joint

Figures 3 to 5 illustrate the results of experiments in stage 1 while Figures 6 to 8 display the results of experiments from stage 2 of this study. As experiment 1 comprises of all good cable conditions connected with two good joints (GJ), it is taken as a benchmark to compare its result with other experiments in stage 1. Therefore, experiment 1 result is plotted against every other experiment result to compare the differences in the reflections.

Figure 3 displays the results of experiment 1 and experiment 2. Experiment 1 which has all three cables in good condition shows reflections at 100m, 200m and 300m. As the experiment applies TDR technique, reflections are detected due to impedance difference between two mediums when signal propagates through the cable. The first reflection observed at 100m records a pair of reflections which comprises of a positive peak followed by a negative peak with the same magnitude. As reflection is observed to due impedance difference, the difference in medium at 100m refers to the connection of the first 100m cable and the first joint. Therefore, the positive peak recorded shows the impedance of joint is higher than the impedance of a cable which creates the positive difference. As the signal propagates further, it leaves the first joint and enters the second cable section where another difference in impedance is detected. Since the impedance of cable is lower compared to the joint, hence a negative reflection having the same magnitude as the positive reflection is observed. Both reflections are seen to have the same magnitude since both cables connected before and after the joint are in the same condition where impedances are the same and hence, they give the same level of impedance difference.

A second reflection detected at 200m also shows a pair of reflections comprising of a positive peak and then a negative peak. Similar to the first reflection at 100m, the positive peak in the second reflection is due to the impedance difference between the second cable and the second joint while the negative peak is reflected due to the impedance difference between the joint and the third cable section. Since both cables are in the same good condition, thus, the second pair of reflections records both peaks with same magnitude. The third reflection identified at 300m indicates the cable endpoint reflection. The endpoint reflection records a much higher magnitude due to the impedance difference between the third cable and the open end which has a high impedance due to the open circuit. These three reflections have indicated that the TDR technique is able to pinpoint the location of joints along a cable which is represented by a pair of reflections due to the impedance difference between the joint and the connected cables.

Experiment 2 result in Figure 3 also shows three reflections detected at 100m, 200m and slightly further than 300m since the cable configuration is similar to experiment 1. As the first two cable sections are in good condition, the first reflection observed at 100m still shows a pair of reflections with same magnitude. However, the second reflection detected at 200m shows a higher negative magnitude compared to the positive reflection. As discussed earlier, reflection is observed due to impedance mismatch between two mediums. Since the third cable section in experiment 2 is degraded, its impedance becomes lower compared to the good cable. The lower impedance of a degraded cable creates a higher difference in impedance between the joint and the degraded cable compared to the joint and the good cable. Hence, a higher magnitude in the negative reflection is observed. The cable endpoint reflection is detected later than 300m compared to the cable in experiment 1. This is because wave propagates slower in a degraded cable, thus it takes a longer time to reach the end of the cable causing a delay in the endpoint reflection.

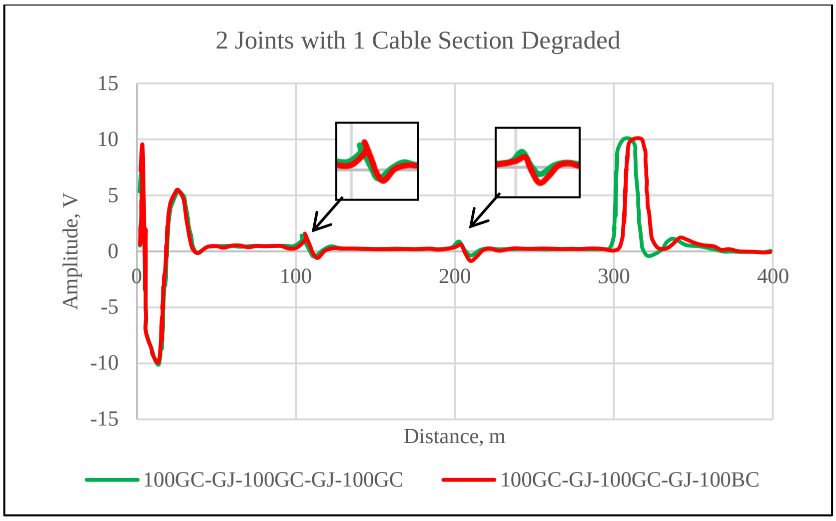


Figure 3. Results for Experiment 1 versus Experiment 2

Figure 4 compares the results from experiment 1 and experiment 3. The second cable section is degraded in experiment 3 while first and third cable sections are in good condition. The result still shows three reflections caused by the impedance difference at the first and second cable joints, and at the cable open end. Similar to the observations in Figure 3, the degraded cable at the second section in experiment 3 causes the negative peak reflection at the first joint to have a higher magnitude compared to the positive peak. At the same time, the positive peak at the second joint reflection records higher magnitude compared to its negative peak reflection. The bigger difference between the impedance of the joint and degraded cable compared to the difference between the joint and good cable causes the difference in magnitude at the joint reflection. Besides that, the second joint reflection is recorded slightly later than 200m with a delay as compared to experiment 1. This is again due to the slower propagation of signal in a degraded medium. Due to this delay, the same delay is observed at the cable endpoint. There is no further delay observed since the third cable section is in good condition.

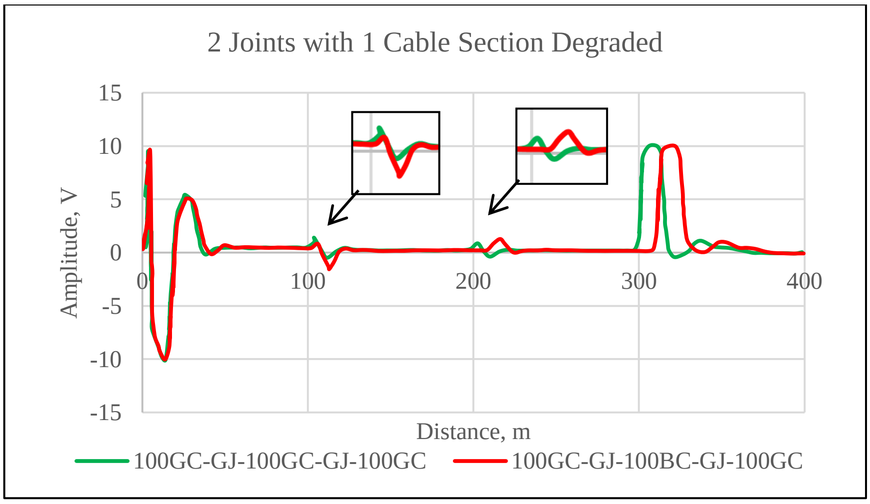


Figure 4. Results for Experiment 1 versus Experiment 3

The characteristics of TDR signal reflections from experiments 1 to 3 can be applied to analyse the result from experiment 4 in Figure 5. Three reflections are detected from experiment 4. The first joint reflection shows a higher positive peak which implies that the first cable is degraded while the second cable is in good condition. Due to the degraded cable in the first section, the first joint reflection records a delay. This delay has caused the second and third reflections to be delayed with the same amount of time. Second joint reflection has the same magnitudes for both positive and negative peaks indicating that both second and third cables are in the same condition since the impedance differences are the same. Therefore, the third cable is predicted to be in good condition. These predictions on experiment 4 cable conditions are found to be accurate as compared to the actual condition of the cable listed in Table 1.

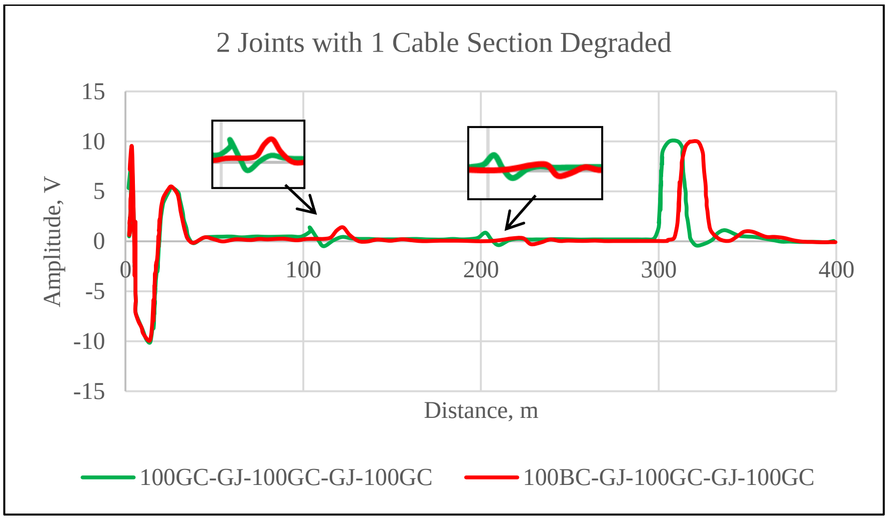


Figure 5. Results for Experiment 1 versus Experiment 4

The TDR reflection characteristics from experiments in stage 1 are used to analyse the results obtained from stage 2 experiments. Figure 6 shows the result from experiment 5. The first joint reflection shows a higher negative magnitude compared to its positive peak reflection. This indicates that the first cable is in good condition while the second is in degraded condition the second joint reflection shows both positive and negative peaks are having same magnitude. Therefore, it can be predicted that the second and third cables are in the same condition. hence, the third cable is also degraded. Due to the degradation in second cable, the second joint reflection is slightly delayed. Since the third cable is also degraded, the endpoint reflection shows a reflection with bigger delay. Comparing these predictions with the actual cable configuration from Table 1, these predictions are proven to be correct.

The TDR reflection characteristics are verified further on cable from experiment 6. The experiment 6 result in Figure 7 is still showing three reflections. The first joint reflection with a slight delay clearly shows a higher positive magnitude than the negative which implies that the first cable is degraded while the second cable is in good condition. The second joint reflection records a higher negative peak compared to its positive peak. This indicates the third cable is degraded while consistently showing the second cable to be in good condition. Due to the two degraded cables, the endpoint reflection is observed with a higher delay. These predictions are again proven to be accurate when compared to the real cable configuration in Table 1.

Experiment 7 is conducted to further validate the consistency of the TDR reflection characteristics. Figure 8 shows experiment 7 result where three reflections are observed. The first joint reflection is delayed with same magnitude for both positive and negative peak reflections. The delay shows that the first cable is in degraded condition and since the joint reflection comprises of both positive and negative peaks with same magnitude, therefore the second cable is predicted to have the same condition as first cable which is also degraded. Due to the first two cables in degraded condition, the second joint reflection is detected with higher delay. The positive peak records a higher magnitude compared to its negative peak indicating the third cable to be in good condition. Since the third cable is in good condition, no further delay is observed at the endpoint reflection. These predictions are verified with the actual cable configuration in Table 1 and they are again accurate. Thus, the characteristics of TDR reflections are found to be consistent for cable with two joints and more than one degraded cable sections.

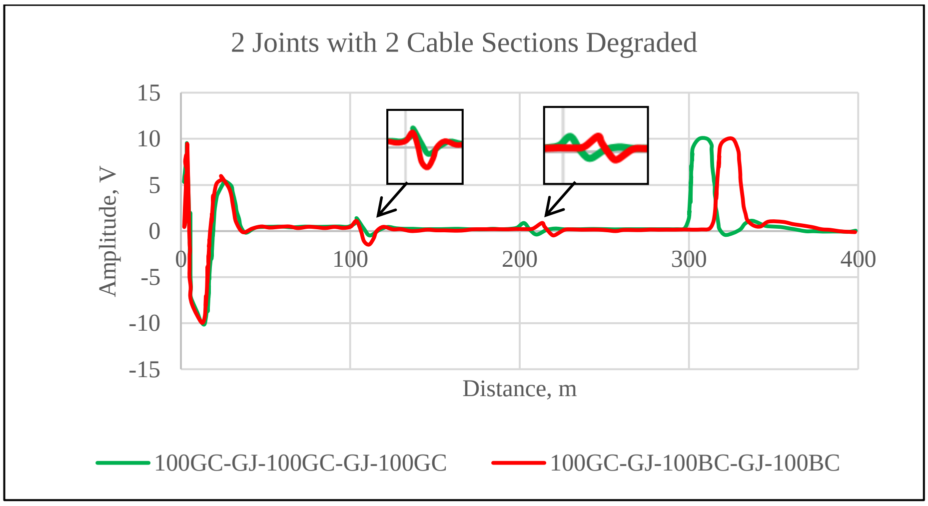


Figure 6. Results for Experiment 1 versus Experiment 5

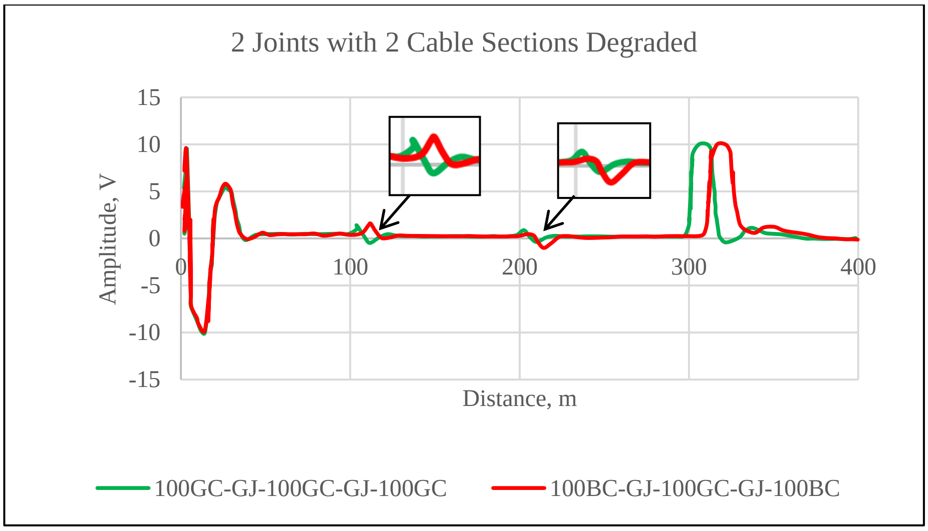


Figure 7. Results for Experiment 1 versus Experiment 6

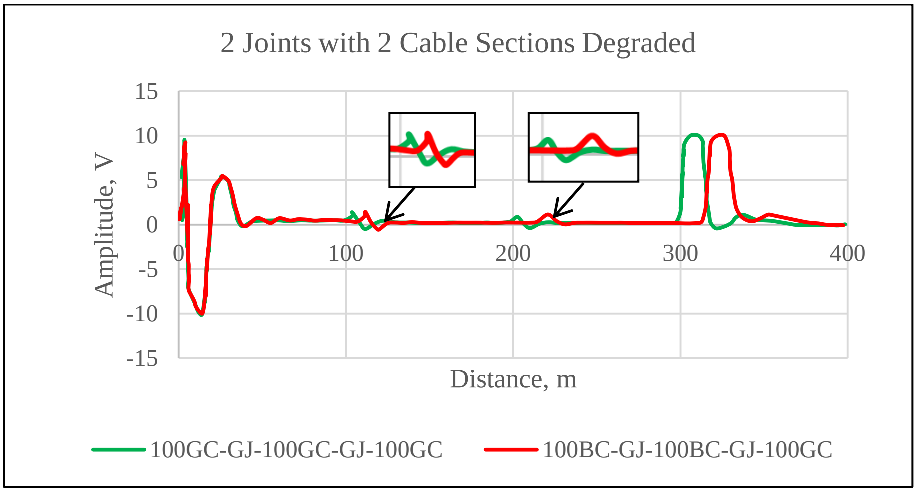


Figure 8. Results for Experiment 1 versus Experiment 7

4. CONCLUSION

This research studies the characteristics of TDR reflection in locating the defect cable section along cable with two joints. Two stages of experiments are carried out. Stage 1 experiments investigate the characteristics of TDR reflection on cable with one degraded section. Further verification is conducted by executing stage 2 experiments where the characteristics obtained from stage 1 are used to predict the cable condition in stage 2 and then compared to the actual cable configuration to check the accuracy of the predictions.

Stage 1 results show that a degraded cable section can be indicated at the joint reflection. Since the impedance of a degraded cable is lower than a good cable, the impedance difference between the joint and degraded cable records a higher magnitude compared to the magnitude of reflection between the joint and a good cable. As wave propagates slower in degraded cable, a delay is observed at the reflection which allows the degraded cable section to be identified easily. These reflection charcteristics when applied to stage 2 experiments which consist of cables with two degraded sections are found to be consistent. The degraded cable sections are located accurately upon comparing with the actual cable configuration in Table 1.

The analysis of results from all experiments in this study have shown that the degraded cable section along a cable with two joints can be identified using the TDR technique. More verifications of TDR reflection characteristics can be done on cable with additional joints and combinations of both good and degraded joints.

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