

Verification of MATLAB/Simulink Power Cable Modelling with Experimental Analysis

Tze Mei Kuan, Suhaila Sulaiman, Azrul Mohd. Ariffin,

Wan Mohamad Shakir Wan Shamsuddin

Department of Electrical Power Engineering, College of Engineering,
Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Malaysia

Article Info

Article history:

Received Feb 1, 2018

Revised Apr 21, 2018

Accepted Apr 27, 2018

Keywords:

Cable defects

Cables joints

MATLAB/Simulink

Time domain reflectometry

ABSTRACT

Cross-linked polyethylene (XLPE) power cable is commonly used as the medium for transmitting power supply in the power system network. However, frequent exposure of XLPE cable to the high voltage causes its insulation to degrade over time leading to electricity outages. Degradation of cable can be prevented if regular maintenance is performed using the accurate assessment method. This study models and simulates a cable system comprising of three cable sections connected by two un-degraded cable joints. This model aims to assess defect along the tested cable with the application of time domain reflectometry (TDR) technique. A series of simulations are conducted by varying the cable insulation condition to study its influence on the cable joint reflection. These simulation results from MATLAB/Simulink are validated against the actual TDR experimental results. The identical results shown between the simulation and experimental results indicate that the cable model is valid and can be used to assess the condition of a cable.

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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

Power cable is a medium for supplying power to consumers. Thus, it is crucial for power utility to ensure these cables are well maintained to provide a reliable power system. However, frequent exposure of these cables to high voltage causes the cable insulation to degrade over time and finally breakdown occurs resulting in electricity outages. Degradation of cable can be caused by several factors such as partial discharge, voids, water treeing, faulty cable joint and others [1-7]. Hence, performing regular maintenance of power cable is important so that defects in the cable can be diagnosed at the early stage to prevent major outages.

Power utilities have been applying various techniques [8-12] for cable defect diagnosis however, most techniques are unable to pinpoint the defect location along the tested cable and some techniques are destructive [12-14]. Recent studies in [15-18] have suggested that the reflectometry technique is the most suitable approach and is non-destructive. Reflectometry technique works by sending a pulse to the test cable and any reflection noticed along the cable indicates impedance discontinuity which can be due to defect or cable jointing [18]. Thus, with proper recognition of the reflected pulse pattern, the location of the defect can be pinpointed at the point of reflection.

This study aims to assess defect along tested cable with the application of time domain reflectometry (TDR) technique through a cable model built using MATLAB/Simulink. This work is an extension of study in [19]. A cable system comprising of three cable sections connected by two un-degraded cable joints is modelled and simulated using MATLAB/Simulink with the application of TDR technique.

A series of simulations are conducted by varying the cable insulation condition to study its influence on the cable joint reflection. These simulation results from MATLAB/Simulink are validated against the actual TDR experimental results from [20]. Experimental results obtained from study in [20] are measured using Megger Teleflex SX TDR equipment on cable sample of a single core 240mm² 11kV unarmoured XLPE cable (aluminum conductor) with cable length fixed at 300m for all experiments. Hence, all parameters set in the MATLAB/Simulink model are the same as parameters from the experiments conducted to ensure results are validated accurately.

2. METHODOLOGY

2.1. Cable Configurations for MATLAB/Simulink Simulation

This research extends the study in [19] where the previous study compares the simulation results for single cable without joint and cables with a single joint with the experimental results from [20]. Hence, this work further verifies the capability of the cable model built using MATLAB/Simulink in identifying defects along the cable by increasing the number of cable joint. Figure 1 shows the cable configurations of three 100m cable sections connected using two cable joints. The cable joint used in this study is the same as [19] which is un-degraded. Table 1 lists the series of simulations with various combinations of cable insulation condition tested using MATLAB/Simulink. The cable insulation condition is varied to investigate its influence on the TDR reflection result especially at the cable joint reflection.

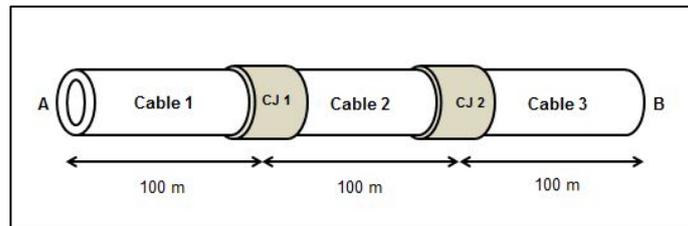


Figure 1. Cable configuration for three 100m connected by two cable joints (CJ 1 and CJ 2)

Table 1. Combinations of XLPE cables for simulation

Simulation	Cable 1 100m		Cable 2 100m		Cable 3 100m
1	Ideal	Cable Joint 1	Ideal	Cable Joint 2	Ideal
2	Ideal		Ideal		Degraded
3	Ideal		Degraded		Ideal
4	Degraded		Ideal		Ideal
5	Degraded		Degraded		Ideal
6	Degraded		Ideal		Degraded
7	Ideal		Degraded		Degraded

2.2. Modelling of TDR technique Cable Assessment System in MATLAB/Simulink

Figure 2 shows the full cable system model built in MATLAB/Simulink for the simulations of three 100m cable sections connected with two cable joints. The cable model in Figure 2 is slightly modified from the cable models in [19] by adding another lumped parameter model to represent the second cable joint which connects test cable 2 and 3. All parameter settings of the pulse generator, cable block diagram and lumped parameter models remained the same as the settings from study in [19].

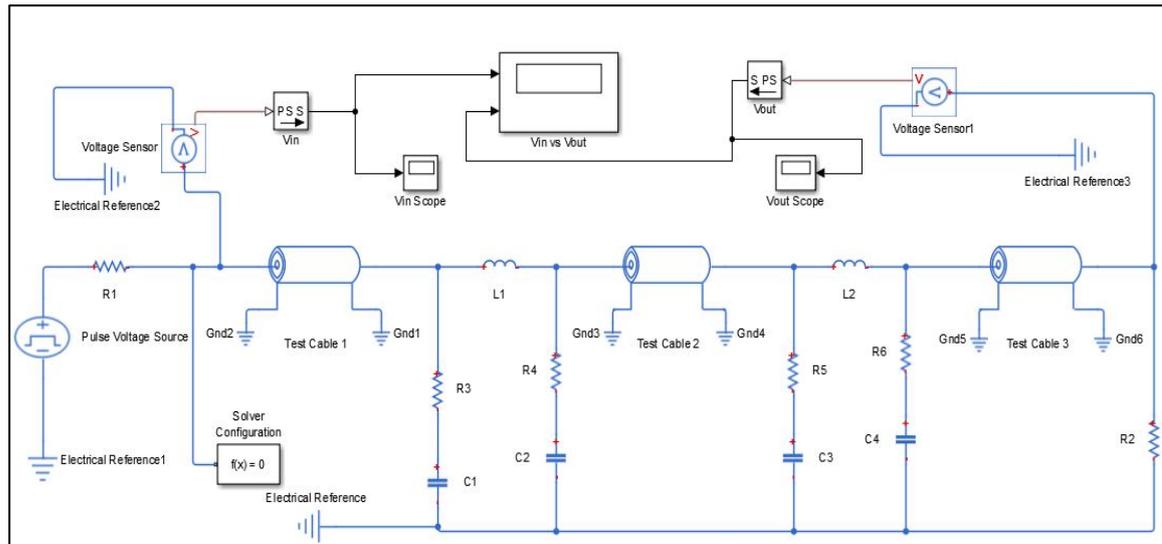


Figure 2. Cable system model in MATLAB/Simulink

2.3. Validation of TDR Simulation

Table 1 simulation results are verified against the experimental results conducted by study in [20] to investigate the reliability of the cable model in producing consistent results with the addition of third cable section and second cable joint.

3. RESULTS, ANALYSIS AND DISCUSSIONS

Cable configurations in Table 1 can be classified into three categories; ideal cable with two cable joints, one cable section degraded with two cable joints and two cable sections degraded with two cable joints. The following sections discuss the results and analysis from these three categories.

3.1. Ideal Cable with Two Cable Joints

Figure 3 shows simulation 1 result using the MATLAB/Simulink cable model in Figure 2 where all three cable sections are in good conditions including the two cable joints. Four reflections are observed from Vin. The first reflection at the starting point denotes the injected pulse from the pulse generator while the other three are reflected at $1\mu\text{s}$, $2\mu\text{s}$ and $3\mu\text{s}$, respectively. As explained in [19], the x-axis in MATLAB/Simulink is limited to time parameter only. However, this can be translated to cable length by using the time delay equation [21]. By applying the time delay equation, the reflections at $1\mu\text{s}$, $2\mu\text{s}$ and $3\mu\text{s}$ represents the reflections at cable length of 100m, 200m and 300m, respectively. This indicates that the second reflection refers to the first cable joint since it is located between the first 100m cable and second 100m cable. The third reflection is detected at 200m which indicates the reflection from the second cable joint since it connects the second 100m cable and third 100m cable. The fourth reflection is identified at 300m which denotes the endpoint reflection of the whole 300m tested cable.

It can be observed that the two cable joints reflections identified at 100m and 200m show a pair of positive and negative reflections with same magnitude each which is consistent with the hypothesis made in [19] where a good joint connecting two good cables shows a pair of reflections with same magnitude. In order to verify this simulation result, it is compared to the experimental result as illustrated in Figure 4. It is clearly observed that the experimental result show similar reflections as the simulated result.

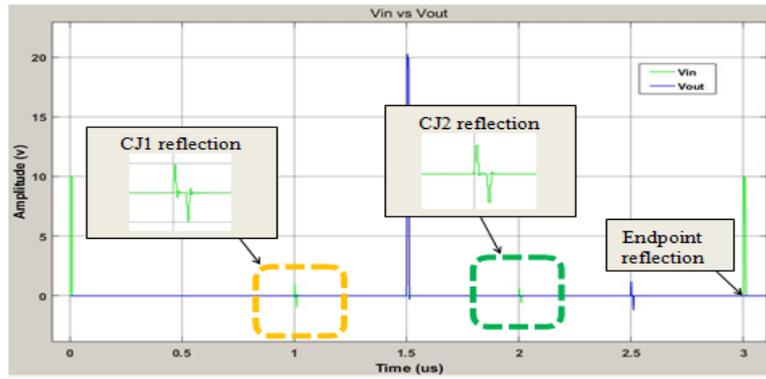


Figure 3. Simulation 1 result

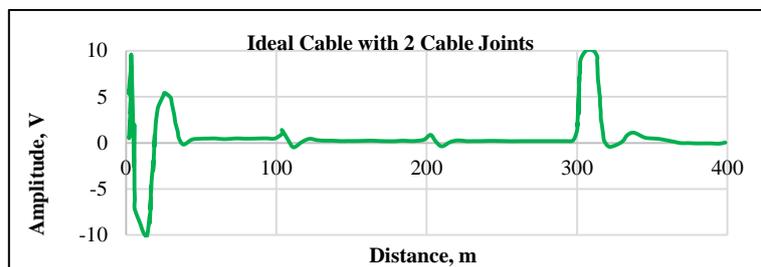


Figure 4. Experimental result for ideal cable with 2 joints [20]

3.2. One Cable Sections Degraded with Two Cable Joints

Simulations 2 to 4 are cable configurations with only one of the three cable sections is degraded. According to the hypothesis made in [19], in the occasion where a cable section is degraded, the cable joint reflection closest to the degraded cable will show higher magnitude compared to its pair. All three results from simulations 2 to 4 are found to have similar characteristics as the hypothesis made in [19]. The endpoint reflections for these simulations are also observed to be slightly delayed since a cable section is degraded. Figure 5 shows simulation 3 result where the second cable section is degraded. Since the degraded cable is located between two cable joints, hence the closest cable joint reflections which are the negative reflection from the first cable joint and the positive reflection from the second cable joint show higher magnitude than its respective pair. Validating this result with the experimental result from Figure 6, it is clearly noticeable that the cable joint reflections characteristics are identical.

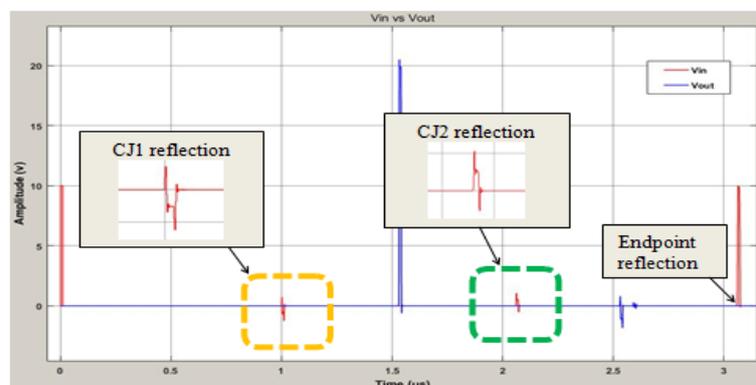


Figure 5. Simulation 3 result

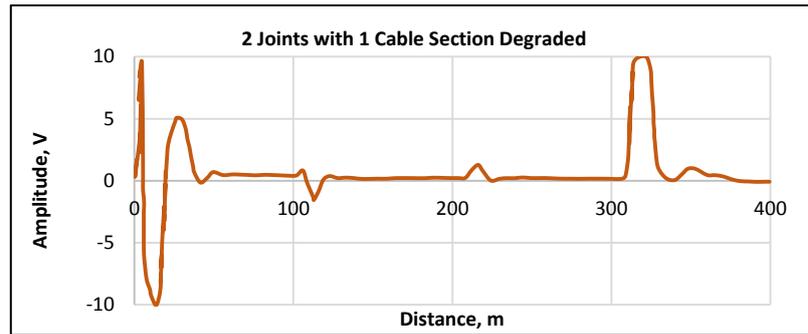


Figure 6. Experimental result for 1 cable section degraded with 2 joints [19]

3.3. Two Cable Sections Degraded with Two Cable Joints

Simulations 5 to 7 from Table 1 are cable configurations with two of the three cables in degraded condition connected by two good joints. The MATLAB/Simulink simulation results have shown same characteristics which also satisfies the hypothesis discussed in section 3.2. This can be illustrated by Figure 7 which shows the result of Simulation 7. Simulation 7 comprises of two degraded cables which are located at the second and third cable sections. With the hypothesis from section 3.2, the negative reflection from the first cable joint shows higher magnitude compared to its positive reflection since the negative reflection is closest to the degraded cable at the second cable. The second cable joint reflection however shows both positive and negative reflections with same magnitude. This is because the third cable is having the same degraded condition as the second cable. Hence, same magnitude is observed. Although the magnitudes are the same, the cable can still be identified as degraded due to the delay observed by the reflections of the second joint which is located after $2\mu\text{s}$ while the endpoint reflection is recorded with a delay twice the delay observed at the second cable joint. Thus, it can be concluded that the second and third cables are degraded.

Results from simulations 5 to 7 are also verified against the experimental results from [20]. From the comparisons conducted, the characteristics of the cable joint reflections from MATLAB/Simulink simulation results are still showing consistent results with the experimental results in [20]. For instance, simulation 7 result in Figure 7 can be compared to Figure 8 experimental result which show identical reflections. Thus, it can be concluded that the cable model in Figure 2 is valid and can be used for further investigations on cable defect assessment.

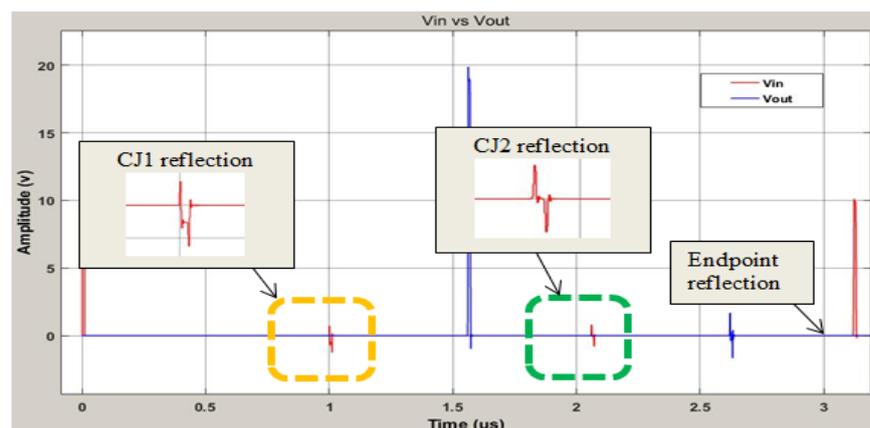


Figure 7. Simulation 7 result

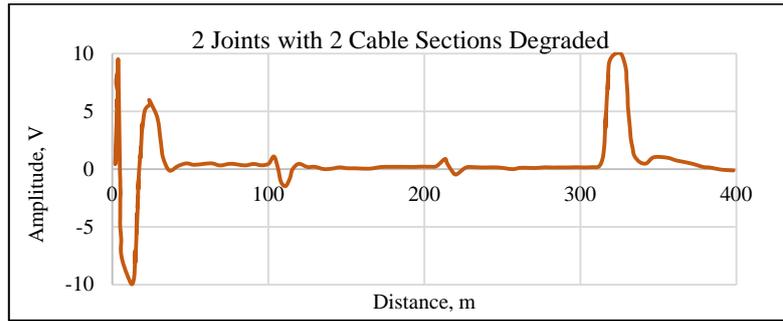


Figure 8. Experimental result for 2 cable sections degraded with 2 joints [16]

Table 2 summarizes the comparisons between MATLAB/Simulink simulation results and the experimental results from [20] which shows the changes in the cable joint reflections with different cable condition connected to the joint.

Table 2. Comparisons of cable joint reflection between MATLAB/Simulink simulation and experimental results

(a) Observation at Cable Joint 1 (CJ 1)			
Simulation	Cable Joint 1 (CJ 1) Reflection		Observation at CJ 1
	Simulation Result	TDR Experimental	
1			Symmetrical pulse
3			Asymmetrical pulse with higher negative pulse amplitude
7			Asymmetrical pulse with higher negative pulse amplitude

(b). Observation at Cable Joint 2 (CJ 2)			
Simulation	Cable Joint 2 (CJ 2) Reflection		Observation at CJ 2
	Simulation Result	TDR Experimental	
1			Symmetrical pulse
3			Delayed asymmetrical pulse with higher positive pulse amplitude
7			Delayed symmetrical pulse

4. CONCLUSION

This research extends the cable model verification from study in [19] where this study models a cable system with two joints using MATLAB/Simulink. A series of simulations are conducted by using various combinations of cable conditions to replicate actual cable with defects along the cable. The methodology of simulation is divided into three categories where simulation is performed first on cable configuration having all three cables in ideal condition as a benchmark to compare with results from cable configurations with degraded cable later. Next category of simulations is conducted on cable configurations with one degraded cable section and lastly, simulations are done with cable configurations having two cable sections in degraded condition. These simulation results are compared to the experimental results from study in [20] to verify the accuracy and reliability of the cable system model for defect assessment.

Simulation results obtained in this study have shown the same characteristics of cable joint reflections as the hypothesis made in previous study [19]. Comparison of results between simulation and experimental results also show consistency where the characteristics of cable joint reflections are identical for both cases. Therefore, it has been validated that the cable system modelled in MATLAB/Simulink is as accurate as the actual cable condition and hence, the MATLAB/Simulink model can be used for further studies in assessing defects in cables. In addition, this cable model can be investigated further by modelling a degraded joint and be validated against the experimental results since this study only emphasizes un-degraded cable joint.

ACKNOWLEDGEMENTS

The authors would like to thank the Ministry of Education, Malaysia for funding this project under the Fundamental Research Grant Scheme (20140121FRGS) and the High Voltage Diagnostics team from TNB Research Sdn. Bhd. for their full support in laboratory facilities, technical support and cable samples.

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