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Breakdown properties of aged low voltage cross-linked polyethylene insulated cable

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Abstract. In this study, the electrical breakdown strength tests were performed on low voltage insulation material, crosslinked polyethylene (XLPE) insulated cable rated at 0.6/1 (1.2) kV. In Malaysia, this type of cable was found to have premature degradation within three to five years of service. The objective of this experiment is to study the characteristic of XLPE used as the insulation material of the aged cable. The allowable maximum operating temperature of this cable is at 90 °C. New cables of different manufacturers were tested and a degraded cable taken from field was used as a reference sample. The thermal consequences on each cable were compared. XLPE sheets sliced from the cable insulations were prepared as the test samples. New samples were heated to a temperature of 90 °C to accelerate the ageing process in an oven. An electrical breakdown tests were carried out to assist the evaluation of the degradation on the unaged and aged cables. It has been shown by the experiment that the electrical properties of the aged XLPE of low voltage cable for both manufacturers were greatly affected when exposed to the heat. This can be considered as defect to the manufacturing process because the insulation layers could possibly be made of a substandard material, that fails to perform according to the specification.

1. Introduction

Cross-linked polyethylene (XLPE) is manufactured from polyethylene (PE) plastic with a three dimensional-molecular bond that is created within the structure of the plastic. XLPE is now commonly used in electrical cable construction for a wide range of voltages. Silane cross-linking is the most common practice for manufacturing low voltage XLPE cable (Vandbakk, 2012). Low voltage is defined as a supply system voltage in the range of 50 to 1000 V AC as defined by International Electrotechnical Commission (IEC).

XLPE is favoured over other insulation material such as polyvinyl chloride (PVC), ethylene propylene rubber (EPR) and silicone rubber due to its toughness against temperature. Excellent dielectric strength, high insulation resistance and a low dissipation factor at all frequencies are among other benefits of using XLPE as insulation material.

In Malaysia, the low voltage XLPE insulated cable are available in both single-core and multi-core



form, designated for general use and for underground cabling, where lightness and convenience of terminating are major considerations. XLPE insulated cable also withstands smaller radius bending, allowing for easy and reliable installation. The design of low voltage XLPE insulated cable must conform to IEC 60502-1 and rated at 0.6/1 (1.2) kV. It has plain circular conductors made of compacted stranded copper or stranded aluminium. The XLPE insulation layer is rated at 90°C.

Previous studies and researches showed that XLPE cable has great performance over high temperature and could last 40 years or more (Anwar ul-Hamid et al, 2015). However, there were increments in the number of complaints for insulation failure for less than five years. During installation, cables are subjected to repeated bending or random flexing causing its copper conductors to be stressed. Mechanical stresses during installation are generally more severe than those encountered while in service. Physical damage caused by mishandling of the cables may cause injury to the insulation layer.

One of the issues with XLPE insulation is degradation under service conditions. As much as the advantages of using XLPE is well known, their long-term behaviour is still undetermined. The XLPE cable is constantly exposed to the heat under its operational condition, causing damage and affects the physical properties of the insulation. Being under temperature stress over certain period of time may cause changes to the chemical composition of XLPE. Consequently, the degradation may cause limitations on the effective service life of the cable (Nobrega et al, 2013).

2. Materials and preparation

The materials employed in this study is an XLPE insulated cable with 25 mm² conductor area and 2 mm insulation thickness. Cables are supplied by two different manufacturers, Cable A and Cable B. Both cables comply with the cable requirement according to IEC 60502-1 standard. The cables are rated at 0.6/1 (1.2) kV with XLPE insulated maximum operating temperatures at 90 °C. A degraded cable taken from site is also used in this study. The degraded cable is an XLPE insulated, with 25 mm² conductor area and 2 mm insulation thickness and complied with the IEC 60502-1 standard.

2.1 Thermal Ageing Procedure

The XLPE insulation layer of Cable A and Cable B were heated for this procedure. The heating process was conducted in an air ventilated oven at a temperature of 90 °C for 7 hours a day. This process was repeated for another 7 days and the total heating duration was approximately 50 hours. After the heating process, the samples were left to cool at room temperature.

3. Experimental techniques

3.1 Breakdown test of XLPE insulation

This test was done for the purpose of determining the dielectric breakdown strength of the XLPE insulation. Samples for this experiment were fresh and aged XLPE insulation of Cable A, fresh and aged XLPE insulation of Cable B and degraded sample. Sample were cut into smaller size with length of 2 mm.

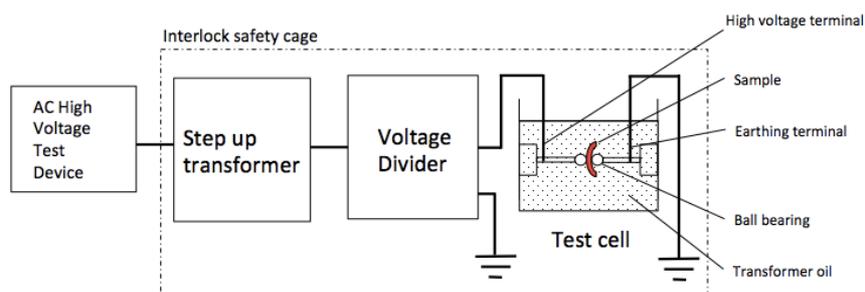


Figure 1. Breakdown test configuration.

Figure 1 shows the main component used in the test. Sample was placed between two steel ball-bearing electrodes before being immersed in transformer oil. The electrode on the left side was connected to high voltage supply while the electrode on the right side was earthed. Voltage of 50 Hz was injected starting from 1 kV and the applied voltage was steadily increased at manually controlled voltage rate until the sample experienced breakdown. Crackling sound could be heard when the XLPE layer began to fail. After the breakdown, the voltage amplitude was reduced immediately by turning the voltage regulator to '0' position. Figure 2 shows the condition of the samples after the test.



Figure 2. The condition of XLPE materials after being injected with high voltage and experienced breakdown.

Test was completed within 5 minutes for each sample. The test was repeated for 5 times for each type of samples (fresh, aged and degraded) and a total number of 25 breakdown test had been performed. The transformer oil was replaced when the oil colour had changed to dark brown with a smell. The readings for each breakdown test were recorded manually and the breakdown field was calculated by dividing the breakdown voltage by the sample thickness. These data were then analysed using two-parameter Weibull distribution (Kwan Yiew Lau, 2013).

3.2 Result and analysis

Figure 3 compare the Weibull plots of the breakdown strength of fresh, aged XLPE insulated layer of Cable A and degraded XLPE insulation. The breakdown strength in Cable A for fresh sample was 174 ± 6 kV/mm and aged sample was 144 ± 8 kV/mm. Figure 4 compare the Weibull plots of the breakdown strength of fresh, aged XLPE insulated layer of Cable B and degraded XLPE insulation. The breakdown strength in Cable B for fresh sample was 166 ± 5 kV/mm and aged sample was 151 ± 10 kV/mm. The breakdown strength in degraded sample was 128 ± 2 kV/mm.

The breakdown field for each cable is tabulated in Table 1.

Table 1. Breakdown strength data.

Sample		Alpha (kV/mm)	Beta
Cable A	Fresh	174 ± 6	24 ± 20
	Aged	144 ± 8	14 ± 11
Cable B	Fresh	166 ± 5	28 ± 19
	Aged	151 ± 10	11 ± 9
Cable Degraded		128 ± 2	58 ± 39

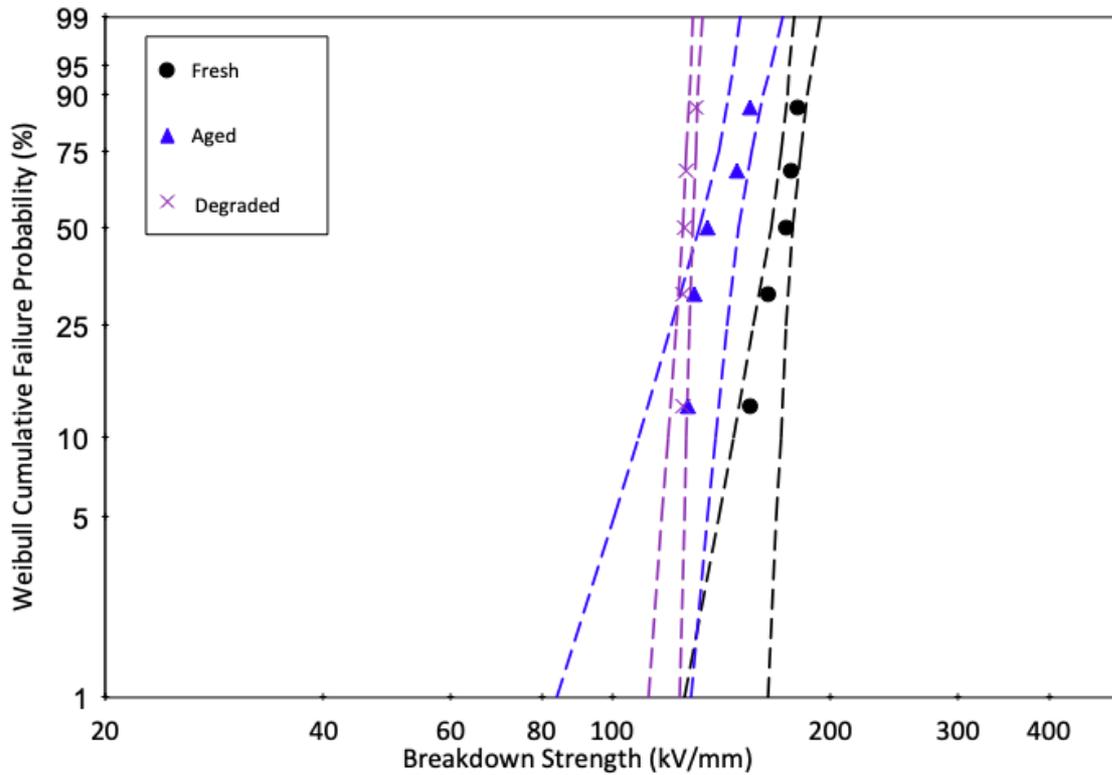


Figure 3. Weibull plots comparing the AC breakdown strength of XLPE insulation layer of fresh and aged Cable A, and degraded cable.

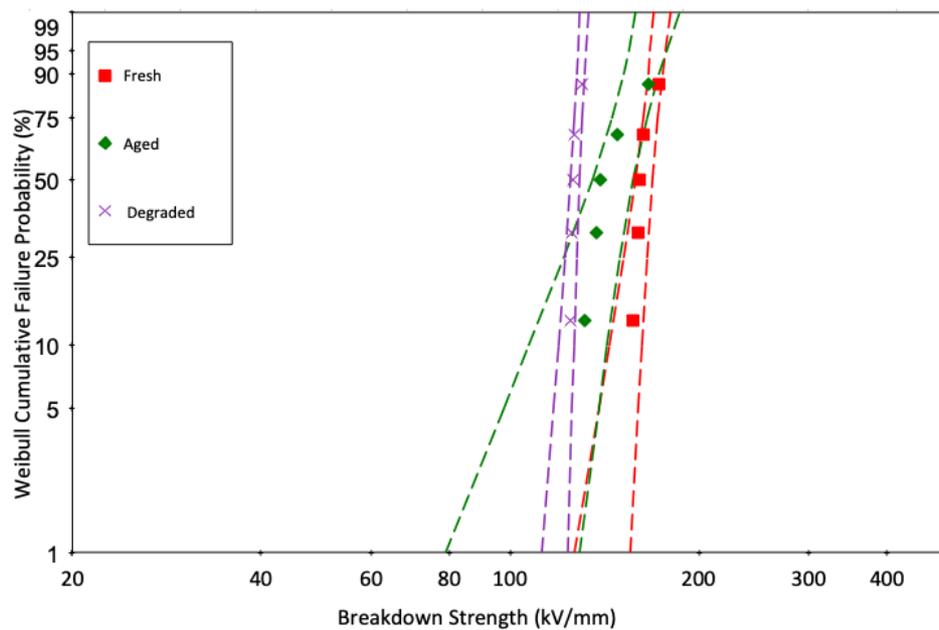


Figure 4. Weibull plots comparing the AC breakdown strength of XLPE insulation layer of fresh and aged Cable B, and degraded cable.

4. Discussion

The fresh sample of Cable A and B were kept at room temperature and the aged sample of Cable A and Cable B had been exposed to the heat at 90 °C for 50 hours. It can be observed that the breakdown voltage in both aged samples were slightly decreasing, where it fell from 174±6 kV/mm to 144±8 kV/mm for Cable A with a decrease in beta value. Similarly, samples of Cable B also show a fall in breakdown strength, from 166 ± 5 kV/mm to 151 ± 10 kV/mm with a decrease in beta value. Thermal ageing appears to affect the breakdown voltage of the XLPE materials for both Cable A and B.

The effect of accelerated ageing is related to the effect of the degraded sample used as the reference. Although in this study, we cannot presume that the thermal ageing is the only factor that cause the degradation in the degraded cable. The lower breakdown strength due to thermal ageing can be considered a significant reliability issue for the insulating material. Through this experiment, the correlation between AC breakdown strength and thermal ageing is in good agreement with most results published (Mecheri et al., 2013; Jong-II Weon., 2014; and Geng et al. 2018).

5. Conclusion

In this work, we investigated the XLPE performance for low voltage XLPE insulated cable. It was observed that the thermal ageing leads to an early degradation of the XLPE materials. Temperature variations had caused a decrease in the electrical properties and affected the breakdown strength. The results confirm the expected correlation between thermal ageing and breakdown strength and clearly demonstrate that thermal ageing lowers the breakdown strength of the XLPE insulation layer. The degraded sample used as reference shows that there is a general trend that the breakdown strength decreases as the cable aged.

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