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Cable Test and Breakdown Voltage Determination of Joysense Cable Insulation

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Abstract

Cross-linked Polyethylene (XLPE) has been used as the insulation for polymeric power cables for its superior advantages. This type of cable insulation are famously known and used for their good dielectric properties, mechanical properties, thermal properties, and probability to be utilized at high temperature. This study is of four (4) parts; designing suitable method for cable test, accelerated testing procedures applied to XLPE insulation for high voltage cables, online partial discharge determination, and aging test. To study the insulation durability to AC high voltage operation, the breakdown strength and aging were investigated under different setting of temperature. The breakdown voltages of XLPE were measured at different temperatures of 300C, 500C and finally at 700C. Lastly, the aging effect of cable insulation was observed by conducting the AC breakdown voltage test after the aging process. Results showed that the breakdown voltage and aging of XLPE cables will decrease with increase of temperature setting.

Keywords*Cable Test, AC Breakdown voltage, Aging effect, Thermal stress, Partial Discharges*

1. Introduction

Cable plays a vital role to transmit electricity from the generation part to distribution network. The transmission and distribution networks are using specific cables to distribute the supply to fulfill the consumers demand [1]. There are many types of cables used in the power networks. Those cables will be diverse according to their variation of size, length, and usage at different level of voltages. In fact, cables also have various type of insulation. The usual types of insulation used in industry nowadays are Polyvinyl chloride (PVC), Polyethylene (PE), Cross-linked Polyethylene (XLPE), Ethylene Propylene Rubber (EPR) and paper/oil. PE material was changed by XLPE as a new alternative way [2]. Each of them have their own special characteristics that later will be chosen by consumers based on their specifications. XLPE cables can operate at conductor normal temperature of 90^0C, with 130^0C being the emergency condition, and 250^0C for short circuit condition [3]. However, the cable insulation may deteriorate due many factors such as electric stress and thermal stress over the lifetime that can reduce the dielectric strength.

High Voltage (HV) cable is the most significant equipment in transmission line and distribution network. Thus, the high voltage cable must always be in good condition. They must have strong durability to withstand stress and should not be torn in short period of time [4]. High voltage industry now is frequently facing problem to determine the suitable strength capability of cable to be used at proper place. Researches have been conducted by many groups on developing the different techniques and tests on testing the properties of cables before the cables are being installed in the industries, in operating condition of cables in the industries or in field tests and during the post mortem of cables with failures. The tests have been conducted to improve the quality and prolong the time services of the cables. This test leads to the better quality of cables and services in the industries in the future.

Mohammed Hanif proposes “Principles and Applications of Insulation Testing with DC” where ihe discussed and described the common insulating materials, their application and desirable properties [5]. The project used several types of test such as Time-Resistance Test, Step Voltage Test and Discharge Based Test. All of the tests that have been conducted are to determine and analyze the basic initiators of insulation degradation, to identify the causes and

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effects of insulation failures and to test the qualities of the cables insulations. The project shown that the tests can be used to improve the system performance, system safety, system reliability and economic asset management although the results shown that the insulation degradation cannot be eliminated.

Yigang Liu, Chang Xue and Gang Liu, in their paper "Analysis for AC Voltage Withstand Test of HV XLPE Power Cable" discussed on how effective the AC voltage withstand test were on exposing all potential defects in cables [6]. The projects were working on to find and analyze any defect that may be able to occur during the operating, and increasing voltages are being injected into the cable samples. M.Shafiq, M. Lehtonen, M. Isa and L. Kutt have designed some tests for their "Online Partial Discharge Diagnostics in Medium Voltage Branched Cable Networks" project where the project presented a technique on localizing partial discharge for branched cable network [7]. Due to advance equipment, the project has conducted a test that was able to detect the location of the partial discharge along the branched cable network. This project showed that the online discharge determination can be used as a preventative maintenance tool for cable system.

Cable tests are solutions that deliver information and data from analysis of the cables that measure the condition of the cables whether the cables are in good condition to be used in the transmission of electrical power. Hence from this point of interpretation, the breakdown strength of XLPE insulation type of cables are to be investigated in order to specify the dielectric strengths and breakdown voltages under different setting of temperature.

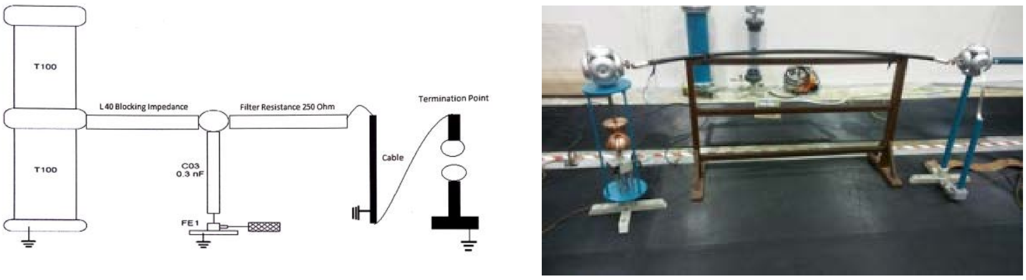
This research and study could provide many potential benefits especially to high voltage industry. It will benefit the industry mostly on economical aspects that will give enhance profits to the industry, when the cable's durability and aging conditions were obtained, so they can make prediction on the cable's life expectancy. Other than that, the findings of this research could provide baseline information to future researchers on the properties of breakdown strength of XLPE type of insulation cable in regard to the aging of these cables. This study will help them reveal problems and solutions that most of the other researchers were not able to discover.

To make this study successful, there are 4 goals that must be achieved at the end of study. First is the cable test designed to be effective to test the breakdown strength of cable samples. Secondly, to determine the breakdown strength of XLPE insulation type of high voltage cables under different temperatures, and to determine the aging effect of XLPE insulation of high voltage cables [8]. Theories stated that the decrease in breakdown voltage for XLPE cable samples as temperature keep increasing is generally assumed to be the effect of dwindling aging in XLPE insulation samples. Lastly, the value of partial discharges was determined during the breakdown tests of the cables.

2. Research Method

2.1 Experiment 1: Cable Test

The cable samples used in the cable tests were Joysense Rare Earth Aluminium XLPE cables sized 240 mm^2 and 195 mm^2 single cored unarmoured, rated at 0.6/1 kV. The length of the cable samples were 2 m long. A cable test technique was designed in the High Voltage Laboratory, Faculty of Electrical Engineering, UiTM, Shah Alam. The AC insulation cable test was carried out to determine the breakdown voltage or the dielectric strength of the cable insulation when increasing voltages were injected to the cable sample. In this experiment, the whole 2 m cable was used.



(a) (b)

Figure 1. (a) Schematic diagram of Cable Test set up in High Voltage Laboratory
(b) Actual Cable Test set up in High Voltage Laboratory

The starting AC voltage was 5 kV with increment of 1 kV every 10 seconds until breakdown was reached. This test was performed on the 240mm^2 cable and repeated with the 195 mm^2 cable. Results were tabulated.

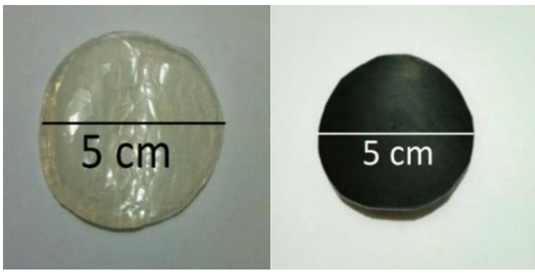
The online partial discharges test is a technique for measuring the damaged that has taken place in the insulation of the cable when the insulation reached its maximum breakdown voltage. The sample cable that was injected with increasing voltages until its breakdown voltage reached has been tapped with earthed wire on the outer insulation, and the online partial discharges reading can be recorded at the exact moment of the breakdown of the insulation of the cable. The reading of the online partial discharges will determine whether the cable is qualified for the real operation in the distribution network.

2.2 Experment 2: Separate Insulation Test at Different Temperatures

The Joysense Rare Earth Aluminium 11 kV XLPE cable sample was used in this insulation test. The insulation of the 11 kV cable was cut into 5 cm long sections. Then, the PVC outer cable was removed first followed by the aluminium shield, semi-conductor layer and conductor. Only the insulation layer and conductor shield was left.

Next, the samples were placed in hot press machine for 5 minutes at pressure of 1000 Psi and temperature setting of 90^{o}C. This procedure was performed at Polymer laboratory of Faculty of Chemical Engineering, UiTM. After the process ended, all of the samples changed from cylindrical shape to plate-like shape.

Next, the samples were placed at hot press machine for 5 minutes at pressure of 1000 Psi and temperature setting of 90^{o}C both of them was trimmed by using knife. There are four samples overall which can be categorized into two. First category is the stand alone XLPE (Sample 1) while the other is the XLPE sample with PVC cover (Sample 2).



(a) (b)

Figure 2. (a) XLPE cut sample (Sample 1), (b) XLPE with PVC cover cut sample (Sample 2)

Sample 1 and Sample 2 required a special dielectric test. Since the experiment required both electrical stress and temperature stress, a suitable AC breakdown test was used for the experiment. The samples were warmed up to 30^{o}C, 50^{o}C and 70^{o}C. While waiting for the sample to reach specific temperature value, the preparation of AC breakdown test was performed. Once it had reached the required temperature, the sample was brought directly to perform AC breakdown test. All of the procedures were performed at High Voltage laboratory.

Figure 3.Preparation Before Conducting AC Breakdown Test of the samples

All the samples in AC breakdown voltage test were to be conducted by using special equipment preparation. A point-plane electrode and two guard rings including screws were used. The point-plane electrode was attached on top of the sample and being sandwiched by the guard rings and then screwed up to ensure there are no excess air flow at the sample.

The time for voltage injection was set to 15 seconds for every increment of 1 kV to ensure the proper voltage transfer through the sample. Sample 1 and Sample 2 were subjected to combination of electrical stress and thermal stress. The measurements were conducted at 30oC, 50oC and 70oC accordingly. The AC breakdown voltage data under different temperature were recorded and analysed.

Thermal aging procedure had to be performed on all of the samples with duration of three days. The Temperature (and humidity) Chamber, Platinous J series type was used to conduct the aging test. Various temperature setting can be set in a day. The chamber was set at 30oC for the first six hours and being increased in three hours to reach 60oC. Then, the temperature was kept steadily at 60oC for another six hours. Then the temperature was reduced to 40oC at a steady rate within three hours and kept constant for another six hours. The cycle was to be repeated for another two days. The same AC breakdown test was performed on the samples after the three days aging process, and the results were recorded and analyzed.

3. Results and Analysis

Results of the research from the above experiments were tabulated and analyzed and discussed.

3.1. Experiment 1: Cable Test Results

Table 1 show that the breakdown voltage of the cable had decreased as the test was repeated. This happened when the earthed wire was placed at the same position throughout the test. When the earthed wire was tapped at the different parts of the outer insulation of the cable (for example, at the middle of the cable), the breakdown voltage of the insulation remained the same value, which was around 21 kV.

Table 1. AC cable test breakdown voltage result

Test	Sample 1 (KV)	Sample 2 (KV)
1	21.35	20.6
2	20.52	19.77
3	19.68	18.53
4	14.00	13.76

Sample 1: 240 mm^2 0.6/1KV single core unarmoured cable with XLPE, binding tape and outer sheath insulation
Sample 2: 195 mm^2 0.6/1KV single core unarmoured cable with XLPE, binding tape and outer sheath insulation

Table 2 showed the readings of the online partial discharge measured. All the readings were taken during the breakdown voltage of each test. The highest partial discharges readings were recorded at the first test for both cables with 279 pC for the sample 1 and 280 pC for the sample 2. As the tests were repeated, the readings of the online partial discharges were observed to be decreasing slightly with the lowest reading being 266 pC for sample 1 with the breakdown voltage recorded at 14.00 kV, and 265 pC for sample 2 at 13.76 kV.

Table 2. AC cable Partial Discharge result

Test	Sample 1 (pC)	Sample 2 (pC)
1	279	280
2	270	270
3	269	268
4	266	265

It can be seen that the online partial discharges can be said to be the same for both samples through the experiments and the values lie between 280-265 pC. These values provide a good indication of the cable insulation, as the limit values of acceptable level of partial discharges were way below 500 pC for low to medium voltage cables [9].

3.2. Experment 2: Separate Insulation Test at Different Temperatures Results

AC breakdown voltage was affected by variation of temperature setting. Breakdown voltage will decrease if the temperature is increased [10].
Table 3 below presents the measured AC breakdown voltage data of all the Sample 1 and Sample 2 with different setting temperature. The results are shown graphically in Figure 4.

Table 3. Measured AC Breakdown Voltage data at Different Temperatures

Temperature (^oC)		30	50	70
Breakdown Voltage (kV)	Sample 1	19.2	18.2	17.2
	Sample 2	21.2	20.5	19.2
Breakdown Field Strength	Sample 1	9.6	9.1	8.6
(kV/mm)	Sample 2	10.6	10.25	9.6

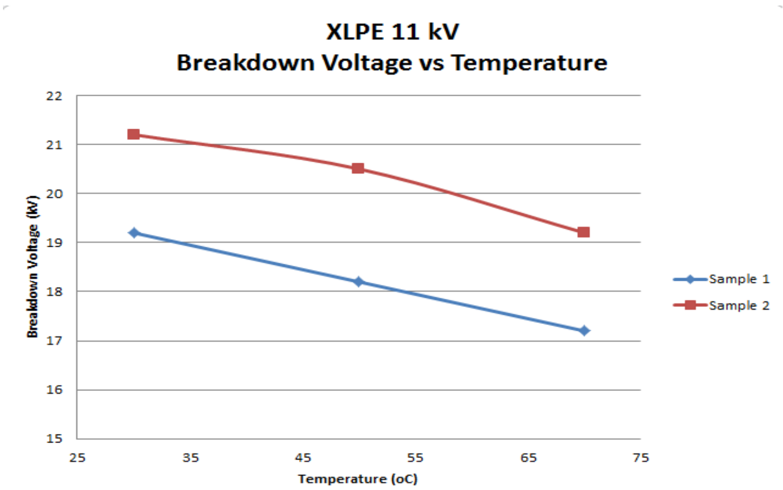


Figure 4. AC Breakdown Voltage vs Temperature for Samples 1 and 2

For Sample 1, the value of AC breakdown voltage was 19.2 kV at 30^{o}C while at 50^{o}C, the breakdown voltage decreased to 18.2 kV, and to 17.2 kV at 70^{o}C. Meanwhile, for Sample 2, the value of AC breakdown voltage at 30^{o}C was 21.2 kV. The value then decreased at 20.5 kV at 50^{o}C, and further decreased at 70^{o}C to 19.2 kV.

Table 4. AC breakdown voltage after three days thermal aging

	Before aging Breakdown Voltage (kV)	After aging Breakdown Voltage (kV)
Sample 1	19.2	17.2
Sample 2	21.2	19.2

The AC breakdown voltage reading before and after thermal aging was observed and compared. The result showed a declination in value of AC breakdown voltage after thermal aging process. AC breakdown voltage test was conducted on all of the samples before the aging process started and the values were 19.2 kV and 21.2 kV respectively for Sample 1 and Sample 2.

Meanwhile, the values of AC breakdown voltages for Sample 1 and Sample 2 were slightly decreased to 17.2 kV and 19.2 kV respectively after the aging process being performed. The result showed a reduction of 2 kV for both the samples.

4. Conclusion

Tests have been performed on the Joysense Rare-Earth High-Iron Aluminium Alloy power cables. Technique for a regular cable test was designed in the High Voltage Laboratory in UiTM Shah Alam. The results show a positive outcome where the cables which are rated 0.6/1 kV have breakdown voltages of around 21 kV. This is way beyond the insulation strength designation for a 1 kV cable.

Samples of the insulation materials of the 11 kV Joysense Aluminium power cable were cut and removed, and tested for its AC breakdown voltage with different temperatures.

The AC breakdown voltage with different temperature showed that the strength of breakdown voltage will decrease when the temperature was increased, which was between 21.2 kV to 19.2 kV (Sample 2), which looked consistent with Experiment 1, the cable test.

The same goes to AC breakdown voltage after thermal aging of three days which experienced reduction in AC breakdown voltage value showed that the breakdown voltage decreased by only 2 kV compared to original insulation before thermal aging.

It can be seen that the online partial discharges were the same for both samples through the experiments and the values lie between 280-265 pC. These values provide a good indication of the cable insulation, as the limit values of acceptable level of partial discharges were way below 500 pC for low to medium voltage cables.

As a conclusion, Joysense Rare-Earth High-Iron Aluminium Alloy power cables are excellent quality Aluminium alloy cables suitable for use in distribution system, and commercial and domestic electrical installations such as high-rise condominiums.

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