Usage of Heat Treatment to Rejuvenate Retired Power Cables

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Table of Contents

Abstract……………………………………………………………………………………3

Introduction………………………………………………………………………………..3-4

Materials…………………………………………………………………………………...4-5

Method....………………………………………………………………………………..5-7

Results……………………………………………………………………………………..7-9

Discussion………………………………………………………………………………….10-11

Conclusion………………………………………………………………………………….11

References………………………………………………………………………………….12

Abstract

Throughout this lab, three retired 110 kV AC cables were used to determine which would be the ideal annealing temperature for the process of rejuvenation. The cables used in this experiment respectively had service years of 0, 15 and 30. Each cable was 5 meters long and equally cut into five sections; one section remained the control variable, while the other four sections were annealed at temperatures of 90, 95, 100, or 105 ◦C. In order to properly test the cables, the insulation layer was peeled off to expose the metal conductor. The DC conduction current and dielectric breakdown strength were measured using the fourier transform infrared spectrometry (FTIR) and differential scanning calorimetry (DSC). Eventually, it was determined that the highest dielectric breakdown strength and lowest electrical conductivity occurred in the inner, middle, and outer positions; however, the temperature that worked ranged from 95 ◦C to 105 ◦C. Although the thermal annealing did not affect the molecular chains. Therefore, it was concluded that the optimum annealing temperature that allows for retired cables to be rejuvenated through the use of heat treatment, is 95 ◦C.

Introduction

In New York, there has been a high demand for additional energy; however, the cost of maintaining the power grid alone has been about $17 billion in the past ten years. Even utility companies have been attempting to upgrade the state's transmission lines but the cost for new cables are extremely high (Campbell, 2016). By rejuvenating retired cables, not only will New York companies restore old materials but they will save money from the reduced production of new cables.

The hypothesis in this experiment is that the optimum annealing temperature that will rejuvenate retired power cables is below 100 degrees Celsius because cables operate under mild conditions with relatively low current and temperature in the insulation. If the temperature were to exceed 100 ◦C, it is believed that it will overheat the cable instead of rejuvenate it.

In high-voltage cables, there is an insulation material known as cross-linked polyethylene (XLPE) which contains good electrical properties. After a long period of time, these cables experience insulation degradation and cables, such as 110 kV cables, can only last for about 30 service years. Despite that, these retired cables still contain a good amount of electrical properties. The temperature in the metal conductor within power cables is a huge factor. This is due to the fact that cables are used under light conditions with low temperatures, which indicates that the metal conductor doesn't surpass a temperature of 90 ◦C, allowing it to still contain electrical properties. There have been studies in which retired cables have possessed better thermal and electrical properties when compared to new cables. The reason behind that is due to the fact during the cable operation, these cables were exposed to higher temperatures which increased the molecular chain movement. In addition to that, in another study XLPE sheets were exposed to thermal annealing temperatures at approximately 90 ◦C and the outcomes were enhanced thermal and electrical properties. Due to this, there was a lower chance of failure and longer service years (Xie et al., 2020).

Materials

- ➢ Three retired 110 kV AC cables (5 meters long)
    - ○ Cable 1 - 0 service years
    - ○ Cable 2 - 15 service years

  - Cable 3 - 30 service years

- A small circuit
- A current generator (AHY-3000, IUXPOWER, China) with copper connectors
- Metal frames
- A spectrometer (Bruker 77)
- A scanner (Q200)
- A pair of copper plate electrode
- Silicone oil
- An electrometer (Keithely 6517B, Tektronix)

Method

There were three cables used in this experiment; one cable had 0 service years, another cable had 15 service years, and the last cable had 30 service years. Before continuing with the experiment, one had to gather information on the insulation degradation of the cables. In this case, there was no physical damage on the outer portion, the cables were never in a state of overheating , therefore it's gathered that the insulation layer was always below 90 ◦C (Xie et al., 2020).

Note: This information is important to obtain because insulation degradation of a cable is a hazard and could cause a short or start a fire.

Each cable was 5 meters long, and was cut into 5 equal segments. At approximately 15 cm, the outer casing and insulation layer of both ends of each segment were peeled away in order to expose the metal conductor and proceed with the testing. Although each cable was cut into five segments, only four segments were tested, while the last one remained as the controlled variable. The first segment was connected to a current generator (AHY-3000, IUXPOWER, China) with copper connectors, and then was positioned on top of metal frames for stability. The first part of the process was the heating phase, in which a fairly large current, labeled as C_1, was applied to the cable. The heat that was produced within the inner conductor, resulted in the temperature increasing from room temperature to the preset temperature in a matter of 12 hours. The second part is when the applied current decreases to certain value, labeled as C_2, which allowed for the holding phase, when the preset temperature remained the same for approximately 2 hours. Lastly, the cooling phase, when the current decreased to 0 and the cable cooled back down to room temperature(Xie et al., 2020).

There are five segments for each cable, each cable was annealed at the preset temperatures of 90, 95, 100, and 105 ◦C. Therefore, each segment was annealed at a different preset temperature, while the fifth segment didn't undergo any form of annealing process, and remained as the control. The process each segment underwent is known as a thermal cycle, which is also described by a consistent heating, holding, and cooling phase. This cycle was repeated 20 times for each segment(Xie et al., 2020).

In order to test the results of the heat treatment process, a section of approximately 15 cm was cut from the middle of each segment. In addition, the effects of the annealing process on the cable insulation also had to be measured, this was done by peeling the XLPE from three different positions within the insulation layer; the outer, middle, and inner position. The portions that were peeled away were labeled by the position they came from and the service years of the cable they were peeled from.

There are three things that were being investigated from this experiment; the change in molecular chain, the thermal performance, and the electrical performance. First, the change in molecular chain was measured using a Bruker 77 to test the Fourier Transform Infrared

Spectroscopy(FTIR). The scanning was repeated five times to ensure the accuracy of the results. Next, the thermal performance was determined by measuring the differential scanning calorimetry (DSC) using the Q200, a scanner. The scanning was repeated twice with a sample weighing 5 mg in each measurement. This process occurred by first heating the sample from 25 to 140 ◦C for 5 minutes at a rate of 10 ◦C/min. After, the sample was cooled to 25 ◦C at a rate of −10 ◦C/min. Lastly, the electrical performance was determined from the DC conduction current and dielectric breakdown strength. The DC conduction current was measured using an electrometer (Keithely 6517B, Tektronix). Meanwhile, the dielectric breakdown strength was measured by inserting the sample between a pair of copper plate electrodes and then submerging them in silicone oil. Approximately 50 Hz of voltage was applied to the electrodes in order for the sample breakdown to occur. This process was repeated 15 times.

Results

Table 1:

Important Factors Within the Heat Treatment

T_{pre}**(◦C)**	t_h**(h)**	t_c**(h)**	C_1**(A)**	C_2**(A)**
90	12	14.3	1200	1060
95	12	15.9	1240	1090
100	12	17.1	1280	1110
105	12	17.6	1310	1150

Note: This graph demonstrates the T_{pre}*(preset temperature in celsius), the* t_h*(heating time), the* t_c*(cooling time),* C_1*(current in heating phase), and* C_2*(current in holding phase)(Xie et al., 2020).*

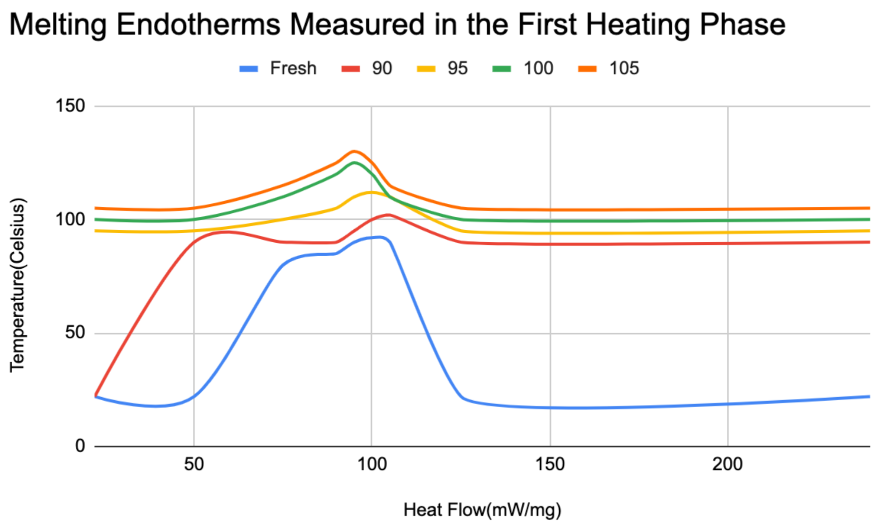

Figure 1. This figure displays the results from the heating process as the cables were annealed at different temperatures(Xie et al., 2020).

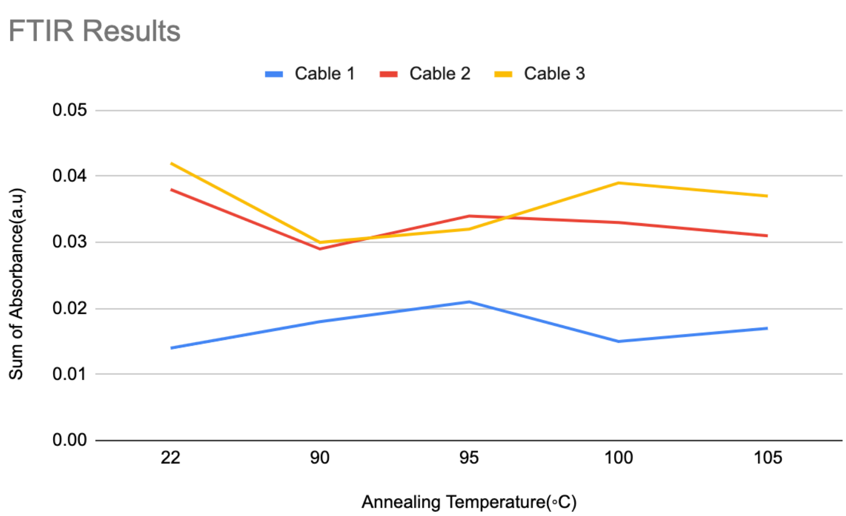

Figure 2. This figure displays the FTIR results. The blue line represents Cable 1, the red line represents Cable 2, and the yellow line represents Cable 3(Xie et al., 2020).

Figure 3. This figure displays the electrical conductivity that resulted from the annealing temperatures at different positions. The yellow line demonstrates cable 1(XLPE-15), the blue line represents cable 2(XLPE-0), and the red line represents cable 3(XLPE-30)(Xie et al., 2020).

Discussion

The results from the experiment concur with the previous hypothesis that was made, stating that the optimum annealing temperature that will rejuvenate retired power cables is below 100 degrees. Firstly, Figure 1 demonstrates the melting endotherms that were being observed from the cables during the heating phase. Although the data was collected of three different cables, the data presented in Figure 1 displays the information gathered from those three cables combined. The reasoning for this is because the results were fairly the same, the five melting curves demonstrate a similar melting point and endotherms for each temperature, this may be because the same crystal structure appeared after the cooling stage. During the heating process, the original crystal structure melted and then reemerged during the cooling phase, which demonstrates that the various temperatures didn't damage the molecular chain.

Figure 2 displays the FTIR results, which basically measures the molecular chain damage. From these results, it's further elaborated that since XLPE-15 and XLPE-30 have a higher absorbance than XLPE-0, then those two cables have more severe insulation degradation. In figure 2, one can see only minimal changes which demonstrates that there was no further damage on the molecular chain of the cables.

In the following graph, Figure 3 demonstrates the electrical conductivity as a function of the annealing temperature. On the first graph displayed in figure 3, one can see the electrical conductivity of the inner portion of the insulation layer. The inner portion describes a change in electrical conductivity, the three cables start off by decreasing as the annealing temperature increases, the smallest conductivity for XLPE-15 AND XLPE-30 being at 100 degrees celsius. Meanwhile, for XLPE-0 the smallest conductivity is 95 degrees celsius. In the middle portion, XLPE-15 now has the smallest conductivity at 100 degrees celsius, while the other two cables have the smallest at 95 degrees celsius. Lastly, the outer portion demonstrates the electrical conductivity but changing rapidly until they reach the same optimum values at the same annealing temperature at 105 degrees celsius. While viewing these graphs, there is a similar pattern amongst the DSC results, the three cables demonstrate the electrical conductivity at 95 ◦C and 100 ◦C. Thus, the optimum annealing temperature for XLPE-15 and XLPE-30 is at 95 ◦C, while the optimum annealing temperature for XLPE-0 is at 100 ◦C.

Conclusion

Throughout this lab, the previous hypothesis, which stated that the optimum annealing temperature for rejuvenating retired power cables was less than 100℃, was proven correct. The two cables with service years of 15 and 30 had an optimum annealing temperature of 95 ◦C, while the cable with 0 service years had an optimum annealing temperature of 100 ◦C. In this lab, it was also determined that despite the heat process that these cables underwent, the molecular chain was not affected because the same crystals that had melted at the start of the heating process, reformed during the cooling stage. New York can save a significant amount of money if they attempt to rejuvenate retired power cables instead of spending billions of dollars paying for new ones.

References

Campbell, J. (2016, August 16). *Watchdog: What drives up New York's electricity rates?* https://www.democratandchronicle.com/story/news/local/2016/08/12/new-york-state-electricity-power-generation-nuclear-rate-payers-transmission/88617454/

Xie, Y., Zhao, Y., Bao, S., Wang, P., Huang, J., Liu, G., … Li, L. (2020, January 6). *Rejuvenation of Retired Power Cables by Heat Treatment: Experimental Simulation in Lab*. IEEE Xplore. https://ieeexplore.ieee.org/document/8950072

Audience Profile Sheet

Reader: **New York Companies responsible for maintaining power cables and replacing old cables.**
Kind of Reader: Primary___X___ Secondary______
Reader's Level of Education: **College Degree**
Reader's Professional Experience: **Must have previous experience working with power cables**
Reader's Job Responsibilities: **N/A**
Reader's Personal Characteristics: **N/A**
Reader's Cultural Background: **N/A**
Reader's Attitude Toward the Writer: **N/A**
Reader's Attitude Toward Information: **Very Interested**
Reader's Expectations: **To learn a new way to restore power cables**
Reader's Way of Reading the Document: **Study it**
Reader's Reading Skill: **Exceptional**
Reader's Physical Environment: **An office**

Reflection

The genre of this assignment is a lab report because it follows the necessary requirements of a lab report. This includes an abstract, an introduction, a materials list, a methods or procedure section, a results section, a discussion section, and graphs or tables to display the information that was found. The media I utilized was digital because it was both written on a digital platform and submitted on a digital platform.

My stance is neutral because I aim to inform my audience of a better solution for handling retired power cables. By studying my lab report, I hope that my audience will gain further knowledge on how to utilize heat treatment to rejuvenate retired power cables.

The exigence that influenced the creation of a lab report on whether heat treatment can be used to rejuvenate retired power cables arose from that idea that New York spends a consistent amount of money to replace old power cables, that means billions of dollars that can be used for other factors is being spent to keep the electricity functioning. If there was a way to rejuvenate old power cables instead of simply replacing them, then that money can be utilized more efficiently.

The purpose of my lab report is to inform my audience on how heat treatment can be used to rejuvenate retired power cables. The information presented includes how the lab was conducted and the results. By studying my lab report, I hope that my audience will be introduced to a new way of rejuvenating power cables instead of wasting money replacing the old ones.

My target audience were companies responsible for maintaining power cables. This includes companies who replace them and who are in charge of the older cables that can no longer be used. In this lab report, I attempted to provide a brief explanation as to what is being addressed in my lab report and what were the findings. Then, I introduced my topic so that my audience can understand the purpose of my lab, followed by the materials they'll need and how this lab was conducted. The graphs and tables displayed the findings and then they were further elaborated in the discussion portion. The language that was utilized was also for an audience that already has some sort of experience with power cables.

This assignment helped me meet a specific amount of course learning outcomes that will help develop my writing. This assignment meets course learning outcomes 3, and 8. It demonstrates my use of number 3, negotiate your own writing goals and audience expectations regarding conventions of genre, medium, and rhetorical situation, because in order to properly display all the information that was gathered from this lab, I had to take into consideration my audience and what kind of language to use for individuals who already work with cables. As well, I had to include certain factors that are necessary within a lab report. In addition, this assignment also meets number 8, strengthening your source use practices (including evaluating, integrating, quoting, paraphrasing, summarizing, synthesizing, analyzing, and citing sources), because I had to find a way to incorporate the information I found ona separate lab report without fully taking the information they provided. With the lab I found that I utilized in my lab report, I had to learn to properly cite specific information.