Breakdown Characteristic Analysis of Paper- Oil Insulation under AC and DC Voltage

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Abstract. This paper presents the study of breakdown characteristic of Kraft paper insulated with two different types of insulating fluid, which are Palm oil and Coconut oil. Palm oil and Coconut oil are chosen as the alternative fluid to the transformer oil because it has high potential and environmentally-friendly. The Segezha Kraft papers with various thicknesses (65.5 gsm, 75 gsm, 85gsm, 90 gsm) have been used in this research. High Voltage Direct Current (HVDC), High Voltage Alternating Current (HVAC) and carbon track and severity analysis is conducted to observe the sample of aging Kraft paper. These samples have been immersed using Palm oil and Coconut oil up to 90 days to observe the absorption rate. All samples started to reach saturation level at 70 days of immersion. HVDC and HVAC breakdown experiments have been done after the samples had reached the saturation level based on normal condition, immersed in Palm oil and immersed in Coconut oil. All samples immersed in liquid show different breakdown voltage reading compared to normal condition. The analysis of carbon track and severity on surface has been done using Analytical Scanning Electron Microscope (SEM) Analysis. The results of the experiment show that the sample of Kraft paper immersed in Palm oil was better than Coconut oil immersed sample. Therefore the sample condition was the main factor that determines the value of breakdown voltage test. Introduction

1. Introduction

In the power system, transformers perform an important role in providing electricity supply. Most of the transformers in power system network are oil filled type. The main function of the oil is to dissipate the heat generated by the winding and core, to insulate between components at different potentials which include being able to withstands system transient due to switching or lightning surges.

Kraft paper, made from chemical pulp produced by the Kraft process, has good insulating properties and much more economical, has lower thermal contraction and elastic elongation at low temperatures. Kraft pulp is darker than other wood pulps, but it can be bleached to make very white pulp. Fully bleached Kraft pulp is used to make high quality paper where strength, whiteness and resistance to yellowing are important [1]. Oil impregnated Kraft paper gradually aged due to thermal stress, moisture and acidity. Aging process of Kraft paper will affect the lifetime of power transformer

to operate safely. Electrical breakdown test is applied to determine the highest level of electrical voltage for Kraft papers to age [2].

Although the majority of the world's electric transmission is carried on AC systems, high-voltage direct current (HVDC) transmission by overhead lines, submarine cables, and back-to-back installations provides an attractive alternative for bulk power transfer. HVDC permits a higher power density on a given right-of-way as compared to AC. transmission and thus helps the electric utilities in meeting the environmental requirements imposed on the transmission of electric power. HVDC also provides an attractive technical and economic solution for interconnecting asynchronous AC. systems and for bulk power transfer requiring long cables [3].

2. Sample Preparation

Test sample for this project is already defined. Segezha Kraft paper with various thicknesses (65gsm, 75gsm, 85gsm, 90gsm) will be cut into circular sample with a diameter of 50mm and will be soaked completely into the oil for several periods until it reach its saturation point. The palm oil and coconut oil will be the sample that will be used in this test in attempting to prove it as the alternative of electrical insulating liquid in the high voltage application. When the sample had reach its saturation point, the samples will be tested using HVAC and HVDC voltage experiment to prove which samples give the best performance after being impregnated for several period. An Analytical Scanning Electron Microscope will be used to examine the sample thoroughly.

Kraft paper was the first insulation materials used in high voltage technology. The paper describes the behavior of paper oil insulation system, which is widely used in field and affected by all voltage mechanisms [4]. Moreover, paper is cheaper compared to plastic tapes. Meanwhile, Coconut oil, as non-toxic, is environment friendly alternative oil. Coconut oil is dominated by saturated fats (about 90%) and out of that, about 65% included medium and short chains such as Lauric acid, Myristic acid, Capric acids and Caprylic acid [5]. From previous researches, the breakdown strength of natural ester is much higher than mineral oil during the entire aging process. When impregnated for 30 days, the breakdown voltage of natural ester is only comparable with mineral oil aged at the same time. Kraft paper which impregnated in natural ester show higher strength of breakdown value rather than Kraft paper impregnated in mineral oil [6, 10]. Beside breakdown voltage, thermal aging properties also can give effect to the kraft paper [9].

There are several type of palm oil that are currently being considered as the insulating fluids in high voltage applications. For this experiment, RBDPO Olein has been chosen as a sample. To maintain great performance of insulation in the transformer, free moving water molecules in the oil must be specifically in low level. This free water content that exist will affect the entire performance of insulation, thus degrading the life time of a transformer. If the oil can absorb water and reduce amount of free water, it will help reducing changes of complete insulation breakdown when the oil is at high moisture condition [7].The study result shows that substances absorbed by kraft paper immersed in both insulation oils is dependent on paper thickness and chemical composition of the oils [8]. Researcher [11] found that capacitance varies according to the oil-paper insulation condition. This is because the complex relative permittivity of oil-paper is dependent on moisture content and temperature. The dielectric material requires an electric field at low frequencies to be completely polarized. Kraft paper has been used as insulation in transformer. Table 1 show the designation for each sample of Segezha Kraft paper based on their condition implemented. The various thicknesses (65.6gsm, 75gsm, 85gsm, 90gsm) of Segezha Kraft paper have been designated as A, B, C, and D.

Table 1. Designation for samples of Segezha Kraft paper

Designation	Thickness	Condition
A1	65.5gsm	Normal (without oil)
A2		Immersed in Palm Oil
A3		Immersed in Coconut Oil
B1	75gsm	Normal (without oil)
B2		Immersed in Palm Oil
B3		Immersed in Coconut Oil
C1	85gsm	Normal (without oil)
C2		Immersed in Palm Oil
C3		Immersed in Coconut Oil
D1	90gsm	Normal (without oil)
D2		Immersed in Palm Oil
D3		Immersed in Coconut Oil

3. Results and Analysis

3.1 Average Value of Breakdown Voltage

High Voltage Direct Current (HVDC) breakdown voltage and High Voltage Alternating Current (HVAC) breakdown voltage will be measured in this experiment. HVAC breakdown test can show performance for solid insulation breakdown [12]. Table 2 shows the average value of breakdown voltage of A1, B1, C1 and D1. Figure 1 shows the trend of the average value of various thicknesses (65gsm, 75gsm, 85gsm, 90gsm) of Kraft papers which are designated as A1, B1, C1 and D1. A1 shows the lowest average value in HVDC while B1 has highest HVDC test than A1, C1 and D1 with value at 18.65 kV. For HVAC test, B1 recorded the highest value among the A1, C1 and D1 at 17.84 kV.

Table 2. Comparison of the average value of breakdown voltage for A1, B1, C1 and D1

Breakdown Voltage	A1	B1	C1	D1
HVDC (kV)	18.29	17.62	18.65	17.25
HVAC (kV)	17.79	17.84	17.61	17.58

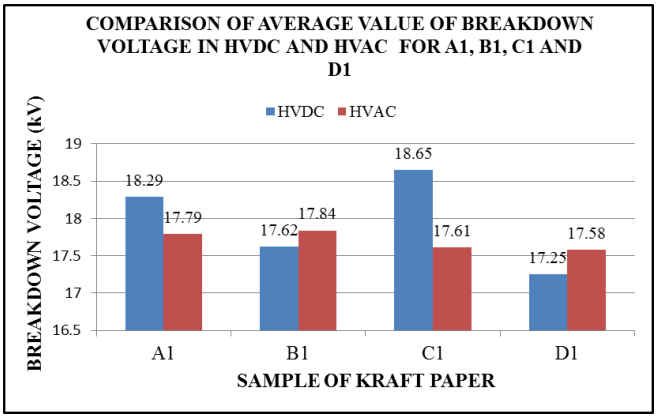

Figure 1. Comparison of the average value of breakdown voltage in HVDC and HVAC for A1, B1, C1 and D1

Table 3 shows comparison the average value of HVDC and HVAC for A2, B2, C2 and D2 after breakdown voltage test. Figure 2 shows the relationship of the breakdown voltage for A2, B2, C2 and D2 after the effect of breakdown voltage test. The graph shows the downward and linear trend of the average HVDC and HVAC value of A2, B2, C2 and D2. The patterns are quite similar between A2, B2, C2 and D2.

Table 3. Comparison of the average value of breakdown voltage for A2, B2, C2 and D2

Breakdown Voltage	A2	B2	C2	D2
HVDC (kV)	19.95	19.92	19.50	19.50
HVAC (kV)	18.66	18.53	17.96	17.89

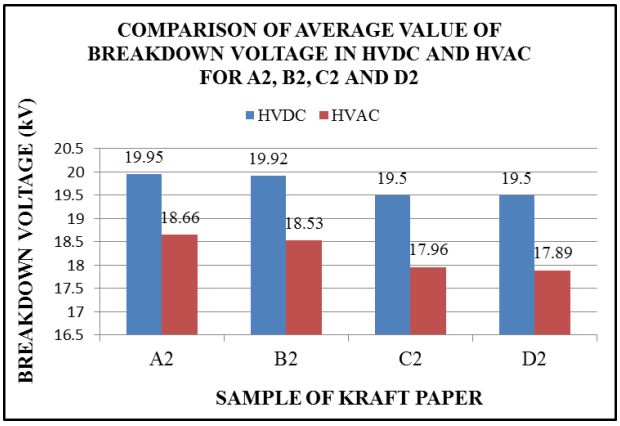

Figure 2. Comparison of average value of breakdown voltage in HVDC and HVAC for A2, B2, C2 and D2

Table 4 shows the comparison the average value HVDC and HVAC for A3, B3 C3 and D3 after breakdown voltage test. Figure 3 shows the relationship of the breakdown voltage after the effect of breakdown test. From the graph shows the both data increase linearly. HVDC readings for all samples increased. As well as for HVAC samples. This shows a correlation between the various thicknesses (65.5 gsm, 75 gsm, 85 gsm, 90 gsm) of Kraft paper with the insulating oil.

Table 4. Comparison of the average value of breakdown voltage for A3, B3, C3 and D3

Breakdown voltage	A3	B3	C3	D3
HVDC (kV)	18.51	18.84	20.65	20.17
HVAC (kV)	16.66	17.68	22.39	20.88

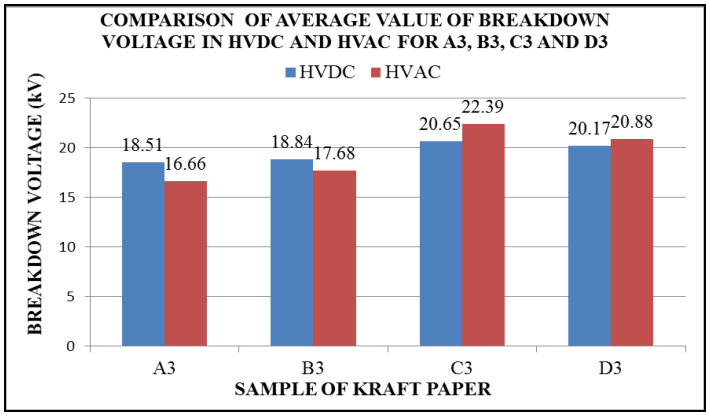

Figure 3. Comparison of the average value of breakdown voltage in HVDC and HVAC for A3, B3, C3 and D3

3.2 Analysis of Surface Degradation

Insulation degradation is produced exclusively as a result of the heat of sparks, and heat will carbonize tracking if applicable, or volatilizes when erosion occurs. Carbonization cause permanent extension of the electrode and usually takes the form of dendritic growth. With the aid of microscope, the carbon track is finally been traced in certain amount of area including the effect of erosion in which could not be detected by naked eye. Carbon track is a process that takes place on the surface of insulator due to the surface tracking phenomena. The possibility of carbon track to occur is when there is the presence of carbon in most polymers.

Figure 4 show the Kraft paper after it has undergone breakdown voltage for HVDC and HVAC test. Equipment used is an Analytical Scanning Electron Microscope (SEM) Analysis to analyse the Kraft papers thoroughly. Areas ranging from approximately 1cm to 5 microns in width can be imaged in a scanning mode using conventional SEM techniques Data are collected over a selected area of the surface of the sample, and a 2-dimensional image is generated that displays spatial variations in these properties.. Carbon track can be recognized by dark spot appeared on Kraft papers surface. While, severity effect can be detected by white line appeared on Kraft papers surface.

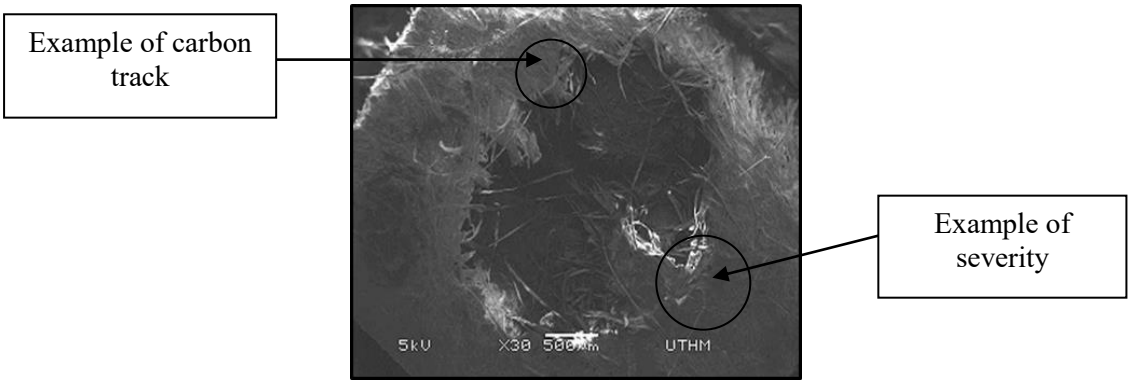

Figure 4. The example of sample that show the existence of carbon track and severity

Figure 5 shows the image of A1, B1, C1 and D1 the analysis of the severity of A2, B2, C2 and D2 after HVDC Test and HVAC test. After HVDC test occur on A2, B2, C2 and D2 the development of carbon track is slightly increased at A2, B2 and C2 where small severity is detected in a small surface area. However, D2 did not have any carbon tracks but has small severity on the surface. After HVAC test carbon track development is almost hard to find on A2, B2, C2 and D2 compared to the previous test samples.

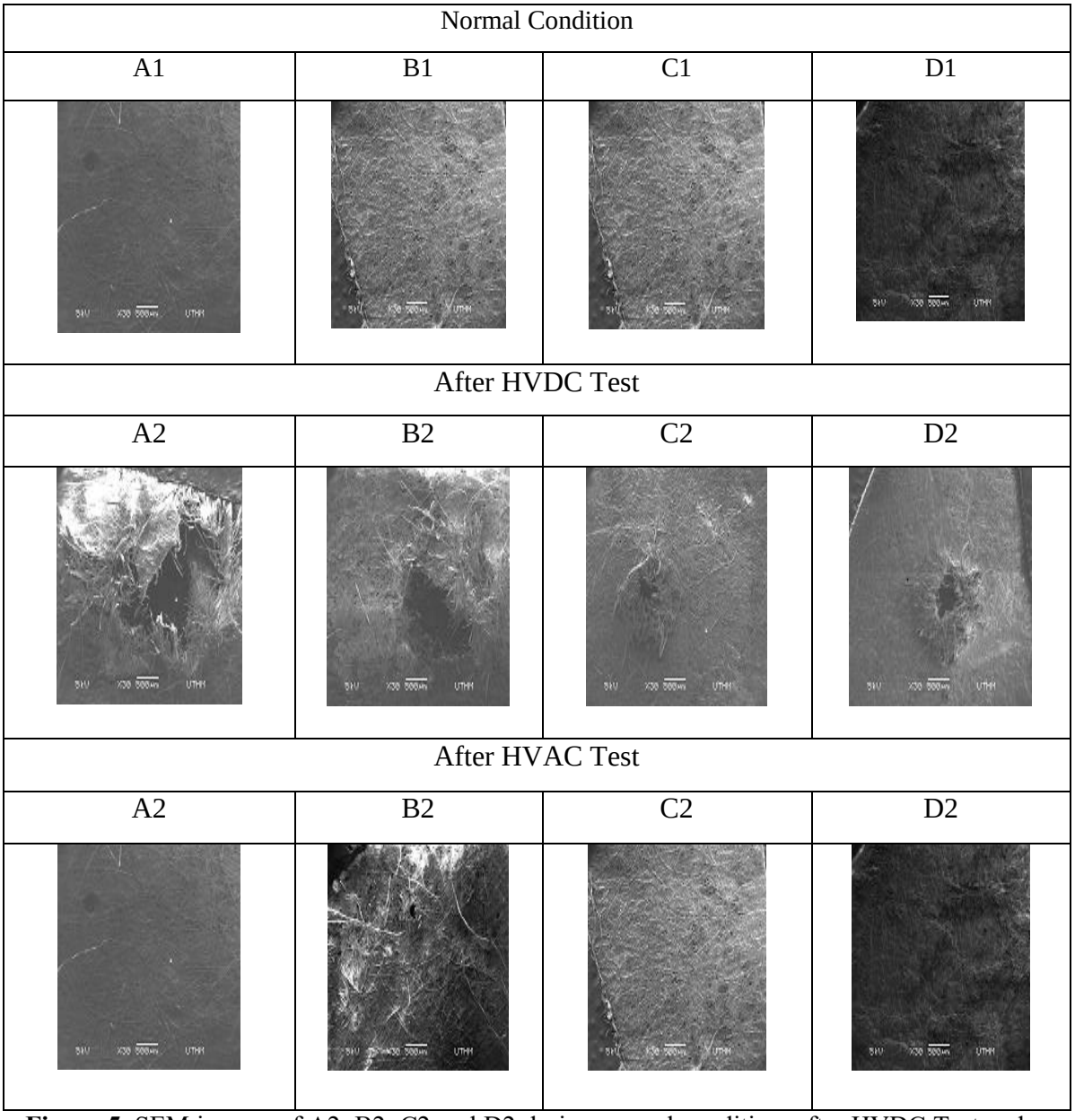

Figure 5. SEM images of A2, B2, C2 and D2 during normal condition, after HVDC Test and after HVAC Test

Figure 6 shows the image of A1, B1, C1 and D1 the analysis of the erosion of A3, B3, C3 and D3 after HVDC and HVAC test under the Analytical Scanning Electron Microscope (SEM) Analysis. Same goes to the physical surface on B1 and C1, final observation shows that there were very little carbon track identified. After HVDC test, carbon track developments were increase to A3, B3 and C3 especially C3 with deeper erosion compared with the A1, B1, and C1. However, after HVAC test A3, B3, C3 and D3 carbon track development on the surface of Kraft papers has been minimized. It showed that the major carbon track progression was obvious at HVDC test and more erosion on HVAC test.

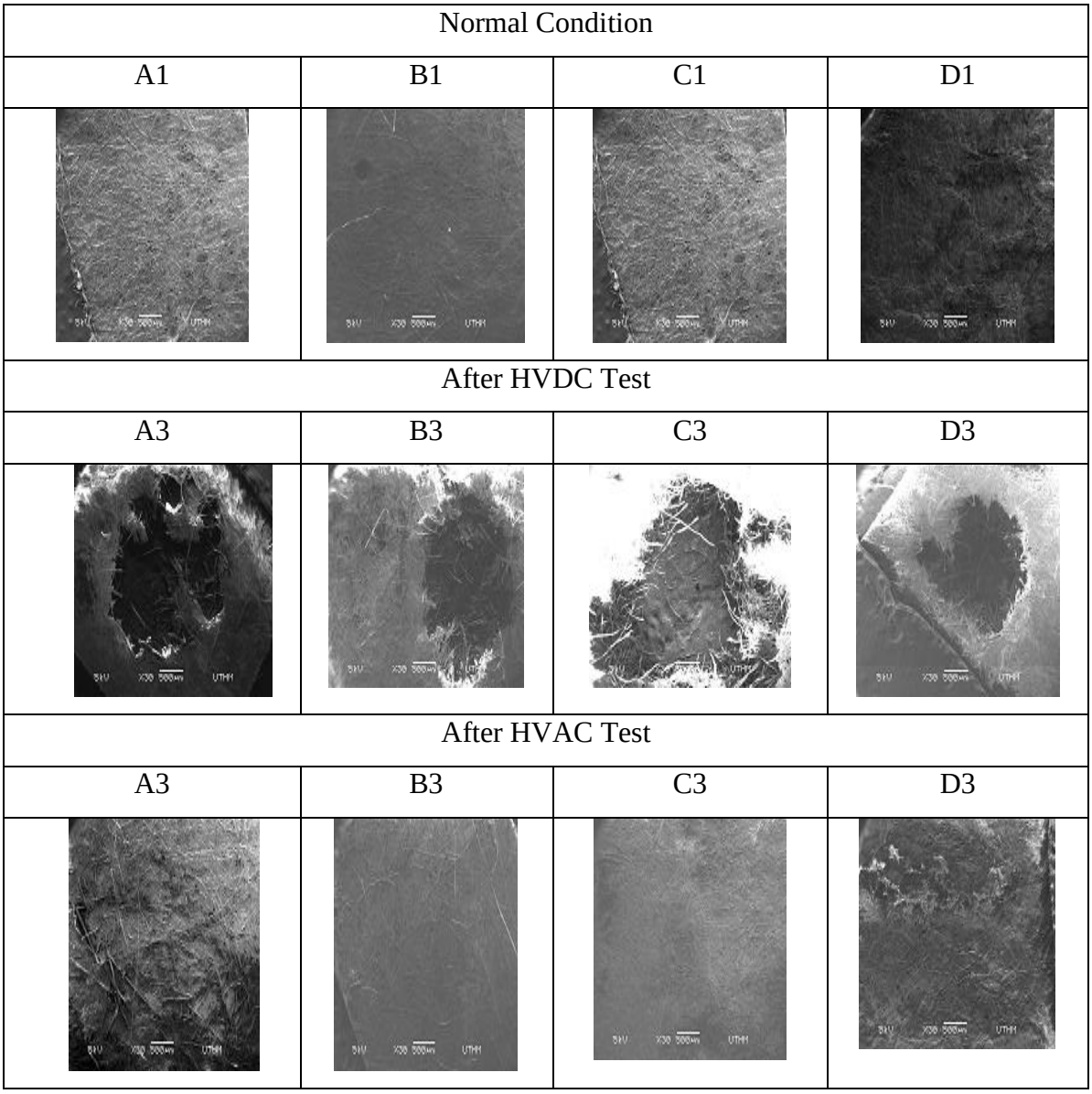

Figure 6. SEM images of A3, B3, C3 and D3 during normal condition, after HVDC Test and after HVAC Test.

4. Conclusion

Based on the result gained from breakdown test and analysis of severity, it showed that sample C has become the best sample among the Kraft paper in terms of level of damage when immersed in Palm oil and Coconut oil. In HVDC test and HVAC test, sample C has showed quite interesting performance rather than sample A, B and D. For severity and carbon tracking analysis, sample C and D has gained less carbon spot and less severity. Hence, proved that the samples of are stable in Palm oil. From this experiment, it is been concluded that the Kraft papers are able to perform together as an insulator for transformer based on breakdown characteristic of paper-oil insulation under AC and DC Voltage. Kraft insulation paper impregnated with mineral oil is used as an electrical insulation medium in power transformer and high voltage cables. By using HVAC and HVDC breakdown experiment it's prove that the insulation breakdown strength is meet the requirement of insulation standard.

5.0 Acknowledgments
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