Investigation of Impulse Voltage on the Thermally-Aged Empty Fruit Bunches (EFB) Fiber Paper Immersed in Transformer Oil

Fatin Nazirah Hanapi
Department of Electrical and Electronic Engineering
Faculty of Engineering
National Defence University of Malaysia
Sg. Besi, Kuala Lumpur, Malaysia
fatinnazirah8183@gmail.com

Ja'afar Adnan
Department of Electrical and Electronic Engineering
Faculty of Engineering
National Defence University of Malaysia
Sg. Besi, Kuala Lumpur, Malaysia
jaafar@upnm.edu.my

Nur Sabrina Suhaimi
Department of Electrical and Electronic Engineering
Faculty of Engineering
National Defence University of Malaysia
Sg. Besi, Kuala Lumpur, Malaysia
0000-0003-1790-0278

Mohd Taufiq Ishak
Department of Electrical and Electronic Engineering
Faculty of Engineering
National Defence University of Malaysia
Sg. Besi, Kuala Lumpur, Malaysia
mtaufiq@upnm.edu.my

Nurul 'Izzati Hashim
Department of Electrical and Electronic Engineering
Faculty of Engineering
University of Malaysia, Sarawak
Kota Samarahan, Sarawak
hnizzati@unimas.my

***Abstract*— Empty Fruit Bunch (EFB) from palm oil residue is one of the materials with development potential. The tensile strength and lightning impulse tests of Kraft paper are compared in this paper to those of unrefined and refined EFB fibre insulation papers aged at 90°C and 140°C, respectively. The performance of the insulation paper should be prioritised by impregnating it with transformer oil (mineral oil) and ageing it for 30 days at 90°C and 140°C. To undergo the impulse breakdown testing, a multistage impulse generator is used with the increment of 1 kV charging voltage for the first test and 2 kV charge voltage for the second test. Lianapac Measure (v15.5.1e) and CCK-2712 controller (100) software are used to observe the result of the impulse breakdown. In comparison to Kraft insulating paper, refined EFB paper has a higher tensile strength than unrefined EFB and Kraft paper. However, as the temperature of ageing increased, the trend of EFB decreased gradually. When it comes to lightning impulse tests, refined EFB paper performs better than Kraft paper. This demonstrates the potential for refined EFB paper to replace Kraft paper in transformer insulation systems.**

Keywords—empty fruit bunches, insulator, kraft paper, lightning impulse, tensile strength, transformer

I. INTRODUCTION (*HEADING 1*)

Impulse breakdown is the overvoltage that comes from the lightning spark and switching that will cause the power system to fail to operate. One of the most important pieces of equipment in power systems is transformers which may be exposed to the impulse voltage when operating. Therefore, to determine the lifetime of the power transformer and to withstand high voltage, the performance of insulation under standard lightning and switching impulses needs to be considered but in practice, the transformer failure is due to its system components' potency being stressed with the overvoltage of non-standard impulses. Thus, it is important to test the insulating materials with non-standard impulses [1]. The type of insulating materials can be liquid, gas or solid. An example of liquid insulation is the mineral oil which in this project, hyrax oil has been used. Meanwhile, the example of gas insulation is Sulphur hexafluoride (SF6) and some of the paper insulation is the press paper and pressboard, which are generally made from softwood pulp and have been widely used in power transformers for several decades [2]. However, the source for softwood becomes lacking because of the rapid use of softwood as it cannot withstand for a long time.

Therefore, a new material that can full fill the most important requirement to withstand operational stresses without breakdown for the whole period of operation is being investigated. In power transformers, the widest insulation material is oil-paper insulation because of its excellent electrical and mechanical performance. The oil (mineral oil or esters) acts as dielectric and coolant, while cellulose materials (paper or pressboard) for insulating and supporting. The oil-paper insulation is continuously exposed to thermal, electrical, mechanical and chemical pressures during the power transformer operation. This will cause the performance of the insulation material is reducing in the mean of time.

For cellulose paper, it consists of cellulose, hemicellulose, and some residual lignin that has not been completely removed during the pulping process. Cellulose is a natural polymer that is composed of linear, polymeric chains of cyclic, β-Dglucopyranosyl units. The degree of polymerization refers to the number of such units per chain (DP). Under various ageing stresses, cellulose paper ageing is essentially one depolymerization process. When inter-unit linkages in cellulosic chains are broken, the DP value and some paper properties such as mechanical strength and electrical performance suffer. The insulation condition has a significant impact on the lifetime of these power components. There is a known correlation between DP and tensile strength, with a reduction in tensile strength to 50% of its original value corresponding to a reduction in DP value down to 25%, implying a complete loss of mechanical strength [3].

Kenaf fibre and Empty Fruit Bunch (EFB) from the residue of palm oil fibre are easily available in large amounts as they can be produced from a naturally renewable source. The Kenaf or scientifically known as hibiscus cannabinus fibre is easily be found as it can grow very fast with a height of 1.5–4.5 m tall with a woody base and requires less water to grow because it has a growing cycle of 150 – 180 days or can be harvested after 4-5 months of planting [4], [5]. The plant has two types of fibres: long fibres extracted from the bast and short fibres extracted from the core.

Kenaf is well known as a cellulosic source with both economic and ecological benefits. It is a hardy plant with a fibrous stalk that is resistant to insect damage and can grow in a variety of climatic conditions while requiring minimal fertilisers, water, and pesticides [5]. Meanwhile, according to data from the Malaysian Ministry of Plantation Industries and Commodities, oil palm cultivation was the most dominant commodity crop in 2015, accounting for nearly half of total Malaysian farmland (MPIC, 2015). In 2016, the oil palm cultivation area recorded was 5,737,985 hectares, with Peninsular Malaysia and East Malaysia cultivating 2,679,502 and 3,058,483 hectares, respectively (MPOB, 2016). The large cultivation area has boost-up the production of oil palm products. However, it also increased concurrently the by-product produced as much as 15.8 million tons [6].

II. METHODOLOGY

There are two basic parameters; tensile strength and impulse breakdown strength of insulating paper that are emphasized in this study.

A. Paper Manufacturing Process

Figure 1 illustrates the overall process of work in this study. First of all, the insulating paper will undergo a pulping process to reduce the wood into fibres where the fibres have to be separated at the middle lamella (mostly lignin) without damaging the fibres [7]. Next, the papermaking will undergo a refining and beating process wherein papermaking technique, beating is the most important step that can change the fibre morphology, sheet formation ability of fibre suspension and properties of the wet-laid mat and the value of the beating process must not exceed 8000b due to suspensions beaten at revolutions above 8000b were uniform with a few broken glass fibres. After that, the paper will be tested for its tensile strength. The suitable value requires for tensile strength for testing need to be set according to IEC 60641-3-2 [8] which must be equal to or larger than 75 MPa. If the value of tensile strength is below or less than 75 MPa, chemical paper additives such as starch will be used to improve the strength and stiffness of the paper. After that, the paper will undergo the sample preparation process and impulse breakdown testing.

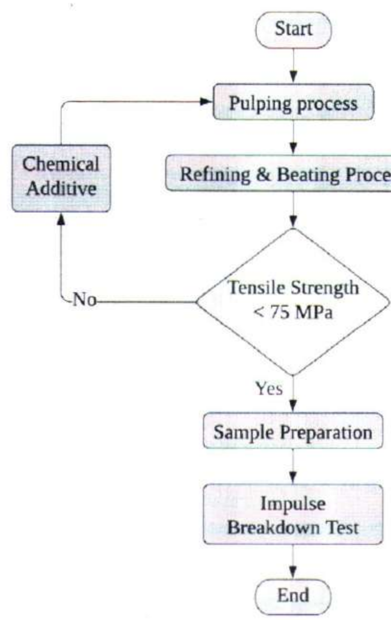

Fig. 1. The overall flowchart of methodology research

B. Sample Preparation

This study used Kraft paper, unrefined and refined EFB paper with a thickness of 0.06 mm. To test the insulation paper for impulse breakdown testing, two separate samples need to be prepared. First, for fresh paper (not undergoing the ageing process), and then for the paper that has been aged at temperatures of 90ºC and 140ºC respectively. With the ratio of 1:20, the 1 g of paper is equivalent to 20 g of the transformer oil (hyrax oil) where 4 mm thickness is used and need to be measured by using a calliper in order to find the ratio of paper and oil. Then, the paper is weighed and the result shows that 4 mm of paper is equivalent to 24 g and 600 ml of oil. Therefore, the preparation was started with 600 ml of transformer oil being filtered by using FB70155 Vacuum Pump in order to remove the foreign particle such as dust in the oil [9]. The process is repeated 3 times. Next, the oil is dried inside the oven at 85°C for at least 48 hours with an open cap to remove the moisture in the oil [10]. To prevent the bottle cap from melting inside the oven, therefore it needs to be opened. After 48 hours, the bottle has been taken out from the oven, close with the cap and left at room temperature in order to remove the vapour.

Next, 24 g of insulation paper for every ratio is rolled and tied with thread before being dried in the oven at 85°C for at least 5 hours to evaporate the moisture inside the sample. This is particularly compulsory for insulating materials with special care that should be taken to remove all moisture inside to prevent this moisture from freezing when the specimen is impregnated in the hyrax oil. Frozen elements are likely to affect electrical conductivity [11]. Before the ageing process starts, the insulating paper is untied and impregnated in the transformer oil for a week to ensure that the paper is fully immersed in the oil. Then, sealed the bottle with Aluminium foil and tied it with copper wire. This is to replace and ensure that the cap is not melting when at a high temperature. Finally, for ageing purposes, the bottle containing the transformer oil-impregnated samples are placed in an oven at 90°C and 140°C for 30 days. The samples were removed from the oven after 30 days and were ready for testing. Repeat the step for the fresh paper sample that is not being aged. For this sample, the insulating paper was impregnated in the transformer oil and then left at the ambient temperature for 24 hours. There is no ratio for the insulating paper to soak in the transformer oil.

C. Impulse Breakdown Voltage Testing

After 30 days of ageing, the bottle contains insulating papers that are impregnated into the transformer oil being taken out from the oven. Then, the bottles need to be left at ambient temperature for about 30 minutes. The test cell must be dried at the ambient temperature for 24 hours before conducting the testing [12]. Then, the insulating papers were taken out by using forceps and placed in between two cylindrical metal electrodes. The gap between two cylindrical metal electrodes needs to be adjusted until it suits the thickness of the paper . The impulse voltage cable needs to be connected at the top of the electrode while the ground cable is at the bottom of the electrode. The multistage impulse generator that has 8 steps where one step has the maximum charging voltage of 100 kV been used to generate the impulse voltage. For the first testing, start with the charging voltage of 10 V with the constant increment of 1 kV until breakdown happens. Then proceed to half the breakdown voltage with a constant increment of 2 kV until breakdown occurs. The wavefront and wave tail are fixed which is 1.2/50 μs [13]. Then, observe the breakdown voltage and waveform for every testing by using Lianapac Measure (V15.5.1e) and CCK-2712 controller (100). In order to conduct a new test on another sample, for the precaution step make sure that the multistage impulse generator is fully discharged and press the emergency button. Then, make the grounding to the electrode that is attached to the test cell. Finally, change the new sample of insulating paper between two cylindrical metal electrodes.

III. Results and Discussion

A. Tensile Strength

Tensile strength is a material's ability to withstand a pulling (tensile) force and refers to the breaking strength of a material when a force capable of breaking many strands of the material simultaneously is applied at a constant rate of extension/load. Tensile strength is calculated using the average of 10 samples. This is in accordance with EN 60243-1:2013, a European Standard [30]. According to Figure 2, the average tensile strength of Kraft insulating paper without the ageing process is 36.84 MPa, followed by EFB paper at 49.12 MPa and Refined EFB at 51.01 MPa. Referring to IEC 60641-3-2 standard, the tensile strength of Kraft paper shall be greater than or equal to 35 MPa [31]. As a result, both unrefined and refined EFB insulating paper meets the requirements for usage as a power transformer insulation. After a thorough 90°C and 140°C ageing process, seems that refined EFB achieves the highest tensile strength with 5.06% and 4.35% increments compared to the Kraft paper. The decrease in tensile strength of paper shows a paper degradation in insulation. It can be observed that Kraft paper after ageing at 90°C increase to 42.87 MPa and begin to decrease to 36.52 MPa after ageing at 140°C temperature. In contrast, the tensile strength of unrefined and refined EFB paper decreased as temperature increased.

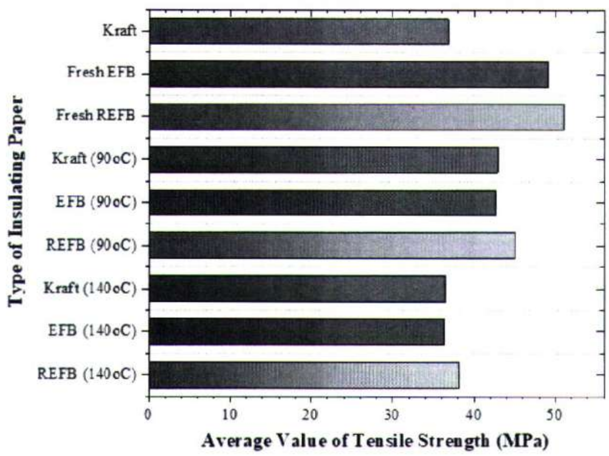

Fig. 2. Average of tensile strength values of Kraft paper, unrefined and refined EFB paper before and after the ageing process.

B. Impulse Breakdown Voltage

Lightning is a high voltage impulse that occurs in extremely short bursts of high magnitude. A lightning impulse test aims to generate impulse voltages that simulate lightning strikes. Because more than 90% of natural lightning has a negative polarity, this work focuses on measuring negative lightning impulse voltage at negative polarity. Figure 3 shows the average results of Kraft paper, unrefined and refined EFB paper before and after ageing. It can be observed that refined EFB paper immersed in mineral oil obtains the highest breakdown before and after the ageing process, followed by unrefined EFB and Kraft paper. Before the ageing process, refined EFB obtain a 71.38% improvement compared to the Kraft paper. While after the ageing process at 90°C and 140°C, refined EFB obtain 66.60% and 36.09% increment in breakdown strength compared to the Kraft paper. However, if focusing on the trend of each paper before and after the ageing process, the Kraft paper after ageing for 90°C tend to slightly decrease from 16.06 kV/mm to 15.75 kV/mm, and then increased to 18.45 kV/mm. While unrefined and refined EFB paper is decreased substantially after the ageing process.

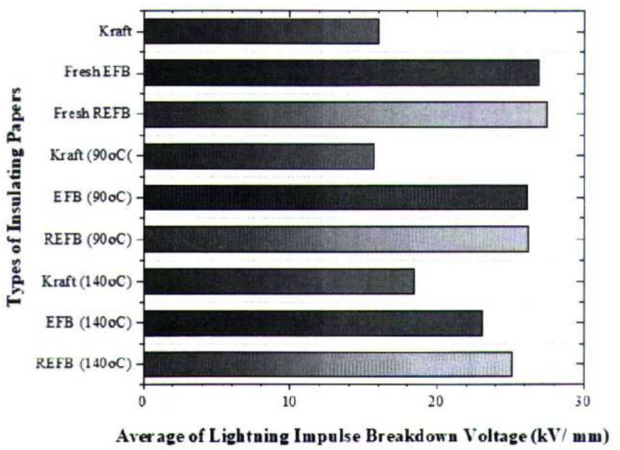

Fig. 3. Impulse breakdown voltage results of Kraft paper, unrefined and refined EFB paper before and after the ageing process.

IV. CONCLUSION

The tensile strength of refined EFB was found to be the highest, followed by unrefined EFB and Kraft paper before and after ageing. However, for Kraft paper immersed in mineral oil, a slight increase trend is observed after ageing at 90°C and a decreasing trend is observed after ageing at 140°C. While both unrefined and refined EFB immersed in mineral oil show a similar trend in which tensile strength decreases over time after being aged to 90°C and 140°C temperatures. The decrease in tensile strength indicates that the paper in the insulation system of the transformer has degraded. In the lightning impulse test, refined EFB paper immersed in mineral oil has the highest breakdown value both before and after ageing, followed by unrefined EFB paper and Kraft paper. This suggests that refined EFB has the potential to replace Kraft paper as an insulator in transformers. However, other electrical, mechanical, and physicochemical properties are required to support this research.

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