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Effects of Electrical Insulation Breakdown Voltage And Partial Discharge

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Abstract. During the last few decades, development of new materials using composite materials has been of much interest. The Cross-linked Polyethylene (XLPE) which is insulated power cables has been widely used. This paper describes the theoretical analysis, fundamental experiments and application experiments for the XLPE cable insulation. The composite that has been tested is a commercial XLPE and Polypropylene with 30% fiber glass. The results of breakdown strength and partial discharge (PD) behavior described the insulating performance of the composite.

Keywords*—Insulation breakdown, Cross-linked Polyethylene (XLPE), partial discharge, high voltage.*

1. Introduction

For the last decade, natural rubber has been replaced by synthetic rubbers and plastics as cable insulation. The Cross-linked Polyethylene or commonly known as XLPE is a form of cross-linked polyethylene. XLPE is a thermo set material, which does not deform at higher operating temperature. It is used from 400 V up to transmission voltage [1]. According to previous researches, long term exposure of the insulator surfaces to environmental and operational stress causes several changes on the composition, surface morphology, and reduce water repellency. The excellent resistance to thermal deformation and excellent property of XLPE cable enables it to carry high electric current under normal (90ºC), emergency(130ºC) and short circuit (250ºC) conditions.

However, even though XLPE has great electrical properties, a breakdown in power cable still cannot be avoided due to certain cases [2]. When XLPE is exposed to an extended period of stress, the breakdown strength of XLPE cable will decrease from its original value. Thus, it leads to cable breakdown and it will act as a conductor [3]. By adding an addictive or filler to the XLPE material can increase the breakdown strength and other electrical properties of the cable itself [4]. Thus, in this paper, the XLPE breakdown voltage and partial discharge behavior and how to prolong the breakdown voltage of XLPE are investigated by adding XLPE and Polypropylene with 30% fiberglass filler. Polypropylene with 30% fiberglass is chosen to be a filler due to several advantages: cheaper in market value, more environmentally friendly and has more sustainable construction [5]. Besides, it exhibits high mechanical and electrical performances but low notched strength and resisting stress cracking. Fiberglass is a reinforcement agent that is mostly used in polypropylene based composites, as it has good balance between properties and cost. The mixture between polypropylene and fiberglass has resulted significantly improved tensile and flexural strengths over regular glass reinforced with polypropylene. It also improves dimensional stability, rigidity and the strength. Polypropylene with 30% chemically-coupled glass reinforcement increases the tensile strength over the non-reinforced polypropylene of 80% while a 50% improvement over conventional glass-reinforced grade. Thus, these two types of materials have been mixed industrially with 30% of fiberglass to ensure the material is stronger in terms of electrical properties.

The significance of this study is to investigate the best insulation with its high insulating performance. The objectives of this study are to study the insulating performance, to collect and analyze data of partial discharge and breakdown voltage, and to compare the partial discharge and breakdown voltage behavior between pure XLPE and modified XLPE (with Polypropylene 30% fiberglass filler). The experiment was conducted based on the breakdown voltage according to IEC 60156, IEC 60502, and IEC 60840 standards. Observation, collection, and evaluation of the results of the dielectric properties of pure XLPE and XLPE with added Polypropylene with 30% fiber glass are also included.

2. Methodology

Testing and experimental work is carried out at Nano Laboratory, Polymers Laboratory and High Voltage Laboratory, Faculty of Electrical Engineering and Faculty of Applied Sciences, Universiti Teknologi MARA Shah Alam. A sample of 160-gram XLPE and several samples of polypropylene with 30% fiberglass filler are measured precisely according to their percentages which are 3%, 5%, 7% and 9% as shown in Table 1.

TABLE 1 : List of Sample

Sample	Description
S1	100% XLPE
S2	100% XLPE + 3% Polypropylene 30% Fiber Glass
S3	100% XLPE + 5% Polypropylene 30% Fiber Glass
S4	100% XLPE + 7% Polypropylene 30% Fiber Glass
S5	100% XLPE + 9% Polypropylene 30% Fiber Glass

Fig. 1 shows the flow chart of sampling process which includes collecting information, sampling preparation, extrusion process, heating cooling and compressing process, testing and finally, collecting and analyzing data. Samples are cut with a diameter of 5 cm and 2 mm thickness. This shape is referred to the standard test (CIGRE METHOD II) as shown in Fig. 2.

The experiment was conducted using the High Voltage AC (HVAC) as shown in Fig. 3 and 4. Fig. 3 shows the circuit diagram with earthed point and Fig. 4 shows the testing circuit. Setting value of this experiment is stated in Table 2. Applied voltage is set from 5 kV and up to 100 kV, and each sample is tested until they are fully damaged. For safety purpose, the final voltage is set lower than the limit voltage. The duration of the step is 20 seconds.

TABLE 2: Parameter setting MDSWIN

Limit Voltage (kV)	100.00
Final Voltage (kV)	80.00
Starting Voltage (kV)	5.00
Step Voltage (kV)	1.00
Rate of Voltage rise (kV/s)	3.00
Tolerance of step volt (%)	2.00
No of cycle	20
Duration of Step (s)	00:00:20
Break Duration (s)	00:00:05

3. Result and Discussion

Table 3 shows the results of voltage breakdown across the 5 samples of insulation material that has been tested. In addition, Fig. 5 shows the graph of voltage breakdown against number of test according to the percentage of filler. The graph in Fig. 5 shows the relationship between percentage of filler and the value of breakdown voltage. The breakdown voltage increases as the percentage of filler increases. The results show that XLPE with added polypropylene with 30% fiberglass performs better in insulation behavior compared to the pure XLPE.

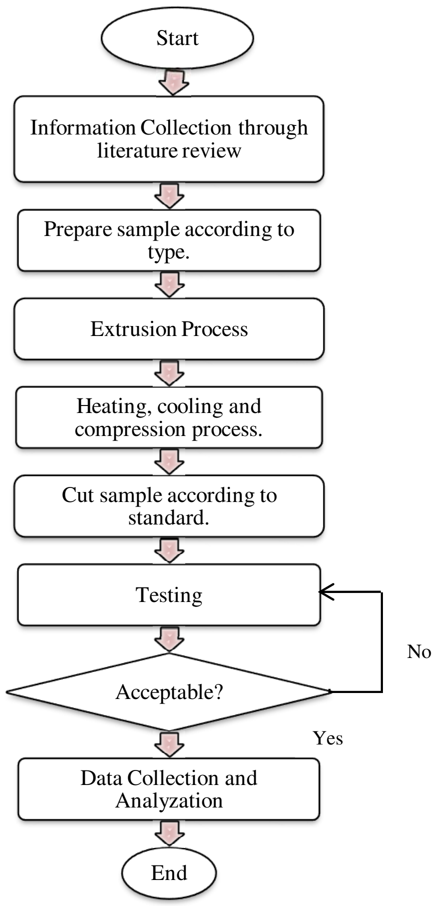


Fig.1 Flow chart of sampling process

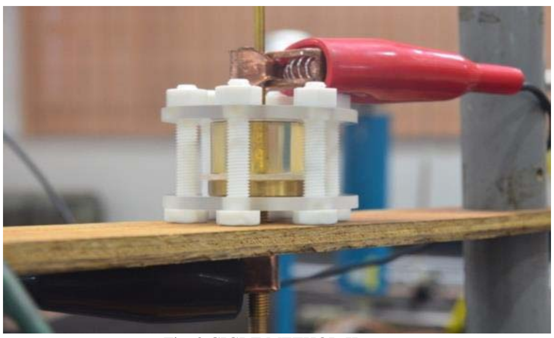


Fig. 2 CIGRE METHOD II test

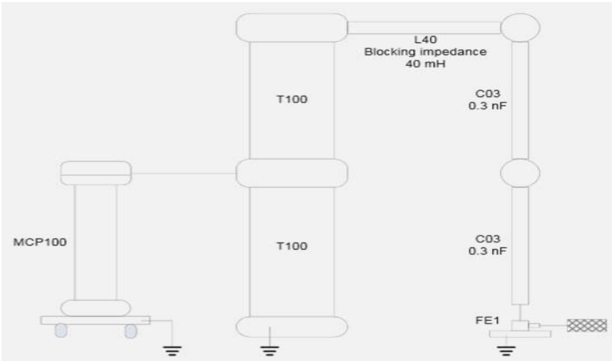


Fig.3 Testing circuit with earthed points

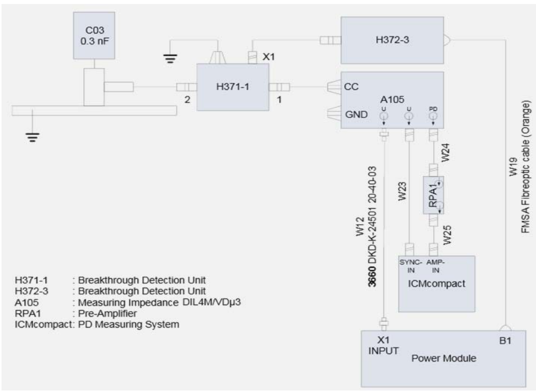


Fig.4 Measuring circuit

TABLE 3: Breakdown voltage for each sample

SAMPLE		S1	S2	S3	S4	S5
BREAKDOWN VOLTAGE(kV)	T1	23.68	26.32	28.43	29.96	24.20
	T2	21.54	26.15	23.40	22.20	24.20
	T3	18.33	23.09	19.83	17.65	24.3 0
	T4	16.98	17.66	13.63	7.39	24.20
	T5	16.21	14.82	8.40	4.39	23.30
PARTIAL DISCHARGE		0 - 100	0 - 300	0 - 400	0- 450	0 - 500

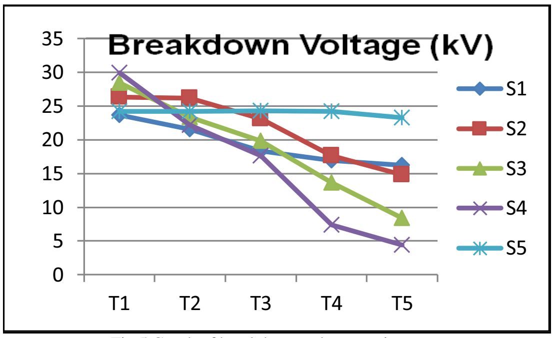


Fig.5 Graph of breakdown voltage against test.

Before the breakdown occurs, the corona sound starts to appear at higher voltage and spark occurs during breakdown. At this moment, the spark (partial discharge) acts as a bridge between two conducting electrodes in insulation system [7, 8]. This sparking can be seen in Fig. 6. The electrode strikes straight to the sample and focus on one point. Tests are repeated for several times on the same part to test on the insulation behavior of the insulation. Once the breakdown occurred, the material may or may not behave as an insulation because the breach has been altering the structure molecule.

Fig. 6 Sparking during breakdown

The insulators are fully broken down at the last stage of testing. During this stage, the sample has the lowest tracking resistance and when voltage is applied, it starts to conduct electric current. It is then leads the insulation to generate heat and causing the surface to become dry.

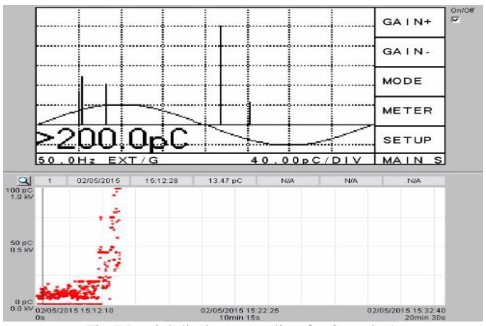


Fig.7 Partial discharge reading for Sample 1

Fig. 7 shows the development of tree length, fractal dimensions, and partial discharge characteristics of a representative branch tree and time for Sample 1. There are 3 regions of tree growth. The tree regions which are A, B and C are clearly defined by the development of the curve in figure above. In region A, the initial tree extends rapidly with a branch structure in the first several seconds. The average rating of growth during this time is 10 pC. The partial discharge activity in region A is intensive with discharge magnitude up to 20 pC. In region B, the branches are growing and a new part of void is formed, thus extending the region. Then, after several minutes with no growth or discharge activity, a little pine branch is formed at the tip of the main channel with the shortest distance from the electrode. The fractal of the tree increases as the time increases in this region. The B-C transition occurs when the pine branch exceeds the original leading branches. In region C, the pine branch grows rapidly away from the electrode. The average growth rate in region C is 75 pC and increases gradually as the trees are away from electrode. The fractal dimension also continues to increase with the tree growth up to 100 pC, thus leading to the breakdown.

(a) (b)

Fig. 8 Surface of Sample 1

Fig. 8(a) and 8(b) show the real surface degradation of Sample 1 which consists of hollow channels resulting from the decomposition of material after performing several series of breakdown test. First figure shows the upper-surface condition and second figure shows the back-surface condition. By comparing Sample 1 and Sample 4, Sample 4 has higher voltage breakdown of 29.96 kV and higher value of partial discharge. It shows that Sample 4 has longer life time.

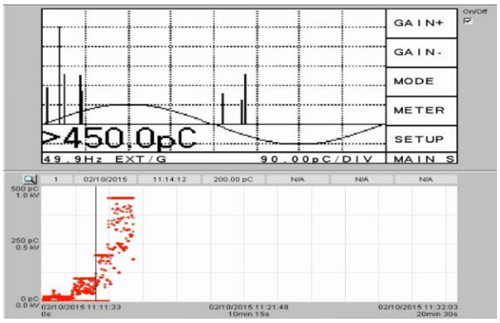


Fig. 9 Partial discharge reading for Sample 4

The tree propagation rate in region A is 120 pC, 450 pC in region B and up to 500 pC in region C as shown in Fig. 9. Fig. 10(a) and 10(b) shows the real surface damage due to the electric stress on Sample 4 after performing several series of breakdown test.

(a) (b)

Fig. 10 Surface of Sample 4

When breakdown occurs in voids, the degradation phenomena will happen, forming positive ions and electrons and they will have sufficient energy. When positive ions and electrons reach the void surface, they break the chemical bond. In each discharge, heat is dissipated in the cavities and carbonize the voids and this will cause erosion of insulator. An active discharge product formed during breakdown causes the chemical degradation All of these effecting results in a gradual erosion of the material and consequent reduction in the thickness of insulation lead to breakdown. Compared to the 100% XLPE, the rate of tree growth for Sample 4 is slower that leads to the increasing time of insulation breakdown. As a result, it shows that the breakdown strength, time and partial discharge increases with the increase in percentage of filler.

Next is Sample 5. Sample 5 is a little bit different. The breakdown voltage of this sample performs at constant value as shown on the graph in Fig. 11 below and has higher number of cycle of test compared to other samples. The sample is not fully broken down and the insulation behavior of this mixture cannot be identified. This problem is related to several reasons.

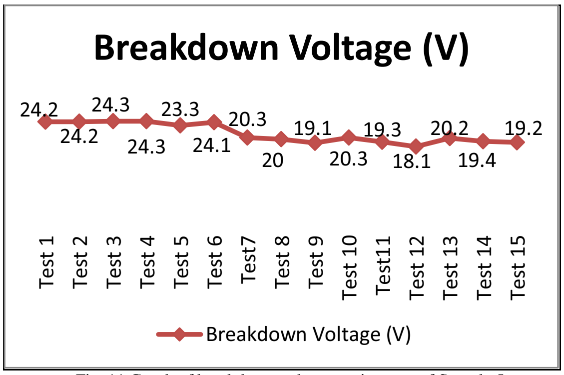
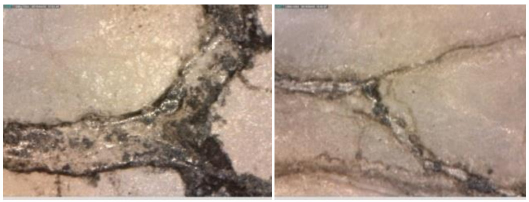


Fig. 11 Graph of breakdown voltage against test of Sample 5

Firstly, there are too many voids and unwanted particles in the insulation that may lead to tracking and treeing phenomena. Partial discharge of Sample 5 is unstable as the initiation and growth of tree is a random process and very complex. Parameters like material morphology, electric field, voltage and temperature play key roles in determining tree growth. This treeing growth is the key failure of the experiment on Sample 5. Water tree growth is marked on the surface of the sample. This can be seen in Fig. 12(a) and 12(b). Voids and unwanted particles in insulation cable can be minimized by a proper process of extrusion and compressing. The insulation needs to be dried in an oven for a night after the extrusion process. Then it must be compressed with hot pressing machine for the next day to make sure that there is no moisture in the insulation that causes void, bubble, etc.



(a) (b)

Fig. 12: Surface of Sample 5

This will prolong the sparking process that causes carbonization at the region of sparking and it will act as permanent conducting channels. The electric field stress of the conducting region increases as the process acts effectively. More and more conducting channels are produced on Sample 5. Thus, the carbonized tracks bridge the gap between the electrodes and finally leads to flash over or system failure. The flash over voltage is defined as the voltage at which current flashes from electrode to electrode or ground with the formation of a sustained arc. This is shown in Fig. 13 where the voltage disperses to the other part of the insulation that has the higher potential of partial discharge phenomenon to occur.

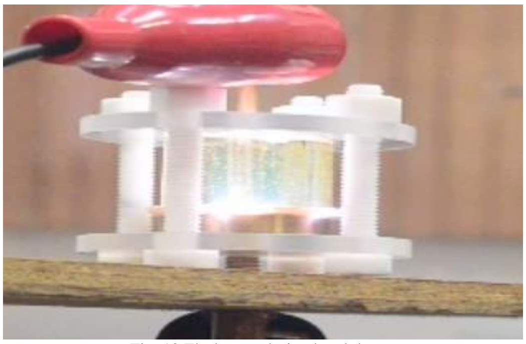


Fig. 13 Flash over during breakdown

Breakdown results on the chemical decomposition and erosion of the insulation material. It is noticeable surface carbonization but these degradations do not affect its flashover properties. However, the insulation properties of Sample 5 failed to be observed as the flash over voltage phenomena occurred.

Next, the silicon rubber that fills the gap between the specimen jigs are not the suitable type or thickness. This silicon rubber can be torn off or can be burned. Therefore, choosing the right silicon rubber is very important procedure. Lastly, the tree grew in the sample because of the presence of moisture. This moisture degrades the performance of the sample. For future study, samples need to be placed or stored at appropriate places.

4. Conclusion

The experiments have revealed that by adding polypropylene with 30% fiber glass with XLPE has improved the breakdown characteristic and performance of insulation compared to pure XLPE breakdown performance. At higher voltages, the partial discharge is high and leads to the formation of tree growth. The trees has produced conducting branches then shows the cross-over from a branch to branch and thus, resulting in increasing fractal dimension, degradation and breakdown phenomena. The most suitable insulation for power cable is XLPE with added 9% polypropylene 30% fiber glass as it can be concluded that the higher percentage of filler increases the insulation performance even though the test for Sample 5 is not a success compared to other samples.

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References

[1] M. Z. H. Makmud, Y. Z. Arief, Aulia, and M. U. Wahit, "Ageing and degradation mechanism of linear low density polyethylene-natural rubber composites due to partial discharge," in *Power and Energy (PECon), 2012 IEEE International Conference on*, 2012, pp. 985-989.
[2] Xiangrong Chen, Yang Xu, Xiaolong Cao, S. J. Dodd and L. A. Dissado "Effect of Tree Channel Conductivity on Electrical Tree Shape and Breakdown in XLPE Cable Insulation Samples" *IEEE Transactions on Dielectrics and Electrical Insulation Vol. 18, No. 3; June 2011*
[3] R. Kawashima, Y. Murakami, H. Shiota, T. Tsurimoto, and M. Nagao, "Influence of filler added into one side of insulation layers on electrical treeing characteristics," in *Electrical Insulation and Dielectric Phenomena (CEIDP), 2013 IEEE Conference on*, 2013, pp. 518-521.
[4] M. Abou-Dakka, A. Bulinski, and S. S. Bamji, "Effect of additives on the performance of cross-linked polyethylene subjected to long term single and periodically reversed polarity DC voltage," *Dielectrics and Electrical Insulation, IEEE Transactions on,* vol. 20, pp. 654-663, 2013.
[5] Shozo Sekioka, "Discussion of CIGRE Current-Dependent Grounding Resistance Model", in 2013 *International Symposium on Lightning Protection (XII SIPDA), Belo Horizonte, Brazil, October 7-11, 2013.*
[6] S. Mohamed Ghouse1, S. Venkatesh2, R.Rajesh3, and S. Natarajan4 "Effects of SiO2 and TiO2 Nano Fillers in Enhancing the Insulation Breakdown Strength of Epoxy Nano Composite Dielectric under Divergent Electric Fields" *International Journal on electrical Engineering and Informatics - Volume 5, Number 4, December 2013*
[7] Ling Zhang1, Yuanxiang Zhou1, Xiaoyang Cui, Yanchao Sha1, TrungHieu Le1, "Effect of Nanoparticle Surface Modification on Breakdown and Space Charge Behavior" *IEEE Transactions on Dielectrics and Electrical Insulation Vol. 21, No. 4; August 2014.*
[8] B. X. Du, Z. L. Ma, Y. Gaoand T. Han "Effect of Ambient Temperature on Electrical Treeing Characteristics in Silicone Rubber" *IEEE Transactions on Dielectrics and Electrical Insulation Vol. 18, No. 2; April 2011*