

## Frequency Dependence of Electroluminescence Measurement in LDPE

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### ABSTRACT

A good insulator for high voltage cable has low dielectric loss, reasonable flexibility and thermo-mechanically stable. However, prolonged application of electrical stresses on the cable will degraded the cable; physically and morphologically. Electrical degradation in high voltage cable can be detected using electroluminescence (EL) method. Electroluminescence is a phenomenon that occurs when the atoms of a material are being excited due to the application of and external high electrical stresses. There are several external factors that affect the behaviour of electroluminescence emission such as, applied voltage, applied frequency, ageing of material and types of materials. . In this paper, the EL measurement is employed to determine the effect of applied frequency on virgin LDPE at fixed and varying applied voltage. It can be observed that EL emission increases as applied frequency increases with increasing voltage applied. However, interesting EL behaviour is observed when varying frequency is applied from 10 Hz to 100 Hz.

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## 1. INTRODUCTION

Electrical degradation of high voltage cable is one of the biggest challenges faces by electrical provider world wide. Defects during manufacturing such as poor adhesion, voids and inclusion in the cable are some of the possible factors of initiating degradation and ageing processes in polymeric insulating material. Prolonged degradation will eventually resulted in electrical breakdown assisted by the formation of electrical treeing and partial discharges in the bulk of the cable. Numerous investigations have been conducted by researchers to observe the behaviour and effect of electrical breakdown [1]-[2]. Electrical treeing and partial discharges are said to be closely related to the behaviour of mobile and trapped charges in polymeric material [3]-[4]. The energy dissipation of these charges when subjected to high external field can be measured using a non-destructive measurement know as electroluminescence (EL). EL imaging captures the light emission of visible photons released during the interaction between both charges; namely the

injection and recombination of charge carriers of opposite polarity into the bulk of the insulating material. Several studies concluded that EL measurement can be used as an indicator for electrical degradation in polymeric insulating material [5]-[6].

However, the characteristics of the EL emission can be affected by several factors such as applied voltage, applied frequency, ageing material and types of material used in a particular study. The characteristics of EL phenomenon in virgin and thermally aged low density polyethylene (LDPE) at varying applied voltage has been discussed elsewhere [7]. It was found that EL intensity increases with increasing applied voltage for both virgin and thermally aged LDPE. This is consistent with many other studies [8]-[9]. Ageing temperature also influence the EL emission with LDPE aged at lower temperature (310 K) has higher EL intensity than that of higher temperature (350 K) [7]. However, very limited studies were conducted on the effects of frequency of applied voltage on the behavior of EL emission. A study by [10] on LDPE subjected to applied frequency of 60Hz to 10kHz under divergent field configuration, found that the EL intensity decreases for increasing frequencies. For LDPE of 50  $\mu\text{m}$  thickness subjected to frequencies in the range of  $10^{-2}$  Hz to  $10^2$  Hz under uniform field configuration, there is a constant increase in EL counts per cycle for increasing frequency for applied voltage below 80 kV/mm as obtained by [11]. At higher voltage levels, there is a drastic decreased as frequency increases. A mathematical model has been developed relating the light emission data and the factors contributing to it through the aid of Dimensional Analysis method [12]. This section will present and discuss the influence of the frequency of applied voltage on the characteristics of EL emission for LDPE samples of 100  $\mu\text{m}$  thickness under uniform field configuration subjected to varying frequencies ranges from 10 Hz to 100 Hz. The effect of frequency will be observed at fixed and varying applied voltage.

## 2. RESEARCH METHOD

The EL measurement is collected from an additive-free virgin low density polyethylene (LDPE) of  $100 \pm 5 \mu\text{m}$ . To fit the sample holder, samples are cut into 60 mm x 60 mm squares. The sample is metallized with about 20 nm thick of semi-transparent gold layer on both sides of the sample using gold-sputtering process with sputter time of 2.5 minutes on each side. This produces a 35mm diameter of gold electrode that will provide reasonable electrode conduction for the uniform field configuration. A silicon rubber is applied around the edge of the gold electrodes in order to reduce the presence of discharges. For EL measurement, the uniform field configuration is shown in Figure 1 using a plane and grounded ring electrodes. Sample is sandwiched between these two electrodes and placed inside a vacuum chamber. The vacuum chamber is filled with 1 bar of dry Nitrogen to avoid corona discharges. The detection system utilizes a Peltier cooled electron multiplying charge coupled device (EMCCD) camera and is connected to high voltage amplifier and function generator. For EL experiment, phase-resolved measurements is applied which involve 100 sets of 1000, 2.168ms exposures. The measurement is synchronized with the applied field using the zero crossing point trigger. Two experiments are conducted to observe the frequency dependence of EL intensity. First experiment involves subjecting samples to varying applied voltage from 3 kVp to 6 kVp at fixed frequency of 20 Hz, 50 Hz and 80 Hz, AC sinewave. Voltage is kept constant for 4 minutes and then increased at 1 kV peak steps. Measurements are taken at each step. In second experiment, samples are subjected to varying applied frequency from 10 Hz to 100 Hz, AC sinewave at fixed voltage of 6 kVp, 7 kVp and 8 kVp. Frequency is kept constant for 4 minutes and then increased at 10 Hz steps. Measurements are taken at each step. All experiments are conducted at room temperature.

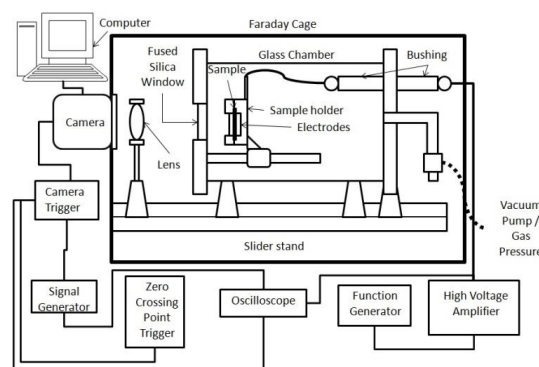


Figure 1. Experimental setup for EL measurement on LDPE samples

### 3. RESULTS AND ANALYSIS

In this section, the EL results obtained for both experiments are discussed.

#### 3.1. Varying applied voltage at fixed frequency

In this experiment, samples are subjected to varying applied voltage from 3 kVp to 6 kVp at fixed frequency of 20 Hz, 50 Hz and 80 Hz, AC sinewave. Figure 2 shows the intensity of EL peak for each frequency of 20 Hz, 50 Hz and 80 Hz at every voltage step emitted during the first and third quadrant of the applied voltage. The EL intensity is lesser for lower applied frequency at increasing applied voltage. This result is supported with the result in Figure 3. Figure 3 shows the average value of EL intensity for applied frequency of 20 Hz, 50 Hz and 80 Hz from 3 kVp to 6 kVp. Evidently there is a direct relationship between average EL intensity and applied frequency. As applied voltage increases, the average EL intensity increases with increasing applied frequency. At 80 Hz, the average EL intensity increases drastically from 3 kVp to 6 kVp. However at 20 Hz, the increment is very linear with only small increases while there is a steady increase at applied frequency of 50 Hz. This direct relationship of EL behavior is expected since EL is controlled by the number of recombination of injected and trapped charges of opposite polarity. At lower frequency, the voltage during the first and third quadrant of the cycle stays above the threshold level of EL emission for a longer time than the higher frequency. Therefore, less number of charges is injected at the polymer interface and thus less chances of charge recombination. For example, during the acquisition time of 4 minutes or 240 s, applied frequency of 50 Hz produces 12,000 AC cycles while applied frequency of 80 Hz produces 19,200 AC cycles. This means that the former has 0.625 times lesser AC cycles than the latter in 240 s of acquisition time. As explained by bipolar recombination model in [13], when sample is subjected to external electrical stress, charges are injected into the polymer at every first and third quadrant of the AC cycles. Therefore less charges is injected during applied frequency of 50 Hz than at 80 Hz since the AC cycles of the former appears 0.625 times lesser than the latter.

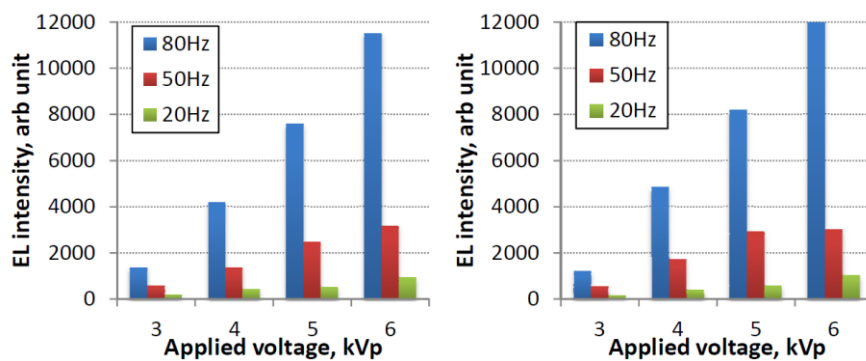


Figure 2. Peak of EL intensity at each voltage level for (a) first quadrant and (b) third quadrant for all samples

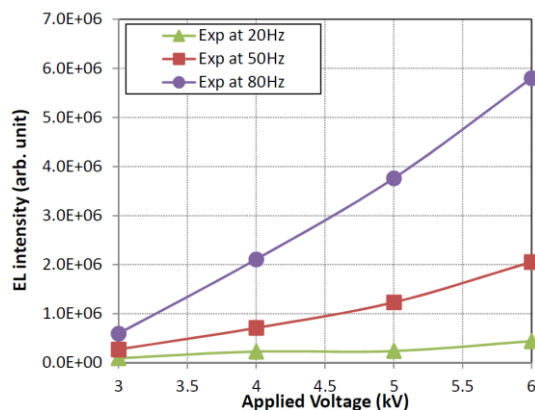


Figure 3. The average value of EL intensity for applied frequency of 20 Hz, 50 Hz and 80 Hz at all voltage steps

### 3.2. Varying frequency at fixed applied field

In this section, virgin samples are subjected to applied frequency of 10 Hz to 100 Hz at a constant applied voltage of 5 kVp, 6 kVp and 7kVp. Figure 4 shows the average EL intensity of LDPE samples at increasing applied frequency from 10 Hz to 100 Hz when subjected to applied field of 5 kVp, 6 kVp and 7 kVp. It can be observed that the EL intensity behaviour for all voltages is indistinctive. However, there are some visible patterns that occurred at 20 Hz, 60 Hz and 90 Hz. The EL intensity had a drastic increase at 20 Hz after a low intensity at 10 Hz followed by a dropped at 30 Hz for all voltage applied. This pattern is repeated at 60 Hz and 90 Hz where the EL intensity had an evident increased at both frequencies followed by a dropped at subsequent frequency of 70 Hz and 100 Hz respectively. EL intensity is the lowest at 100 Hz for all voltages. It is assumed that at the early stage of the experiment i.e. at 10 Hz, the injected charges would first fill the surface states. As the frequency is increased to 20 Hz, the number of charge injection increases thus higher number of the charge recombination is obtained. This is illustrated with the high EL intensity at 20 Hz. The dropped of EL intensity at 30 Hz is the result of high charge recombination rate that occurs during the preceded frequency. Figure 5 shows the shift of phase angles of sample at all applied frequency for first and third quadrant. Likewise, there is no significant pattern that can be observed from this experiment and hence no relationship can be deduced between phase angle and increasing applied frequency. The variations are scattered for both the first and third quadrant.

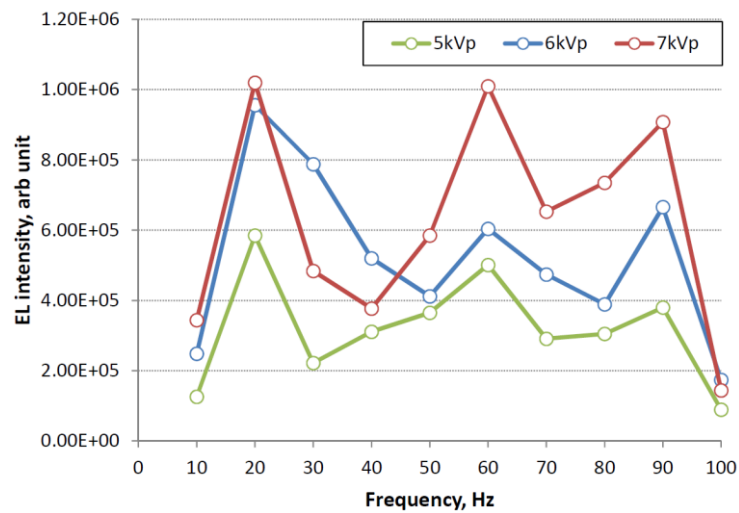
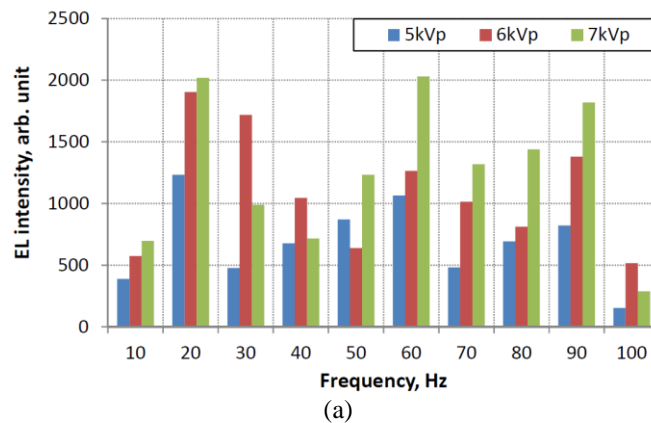


Figure 4. The average value of EL intensity for applied field of 5 kVp, 6 kVp and 7 kVp at all frequencies



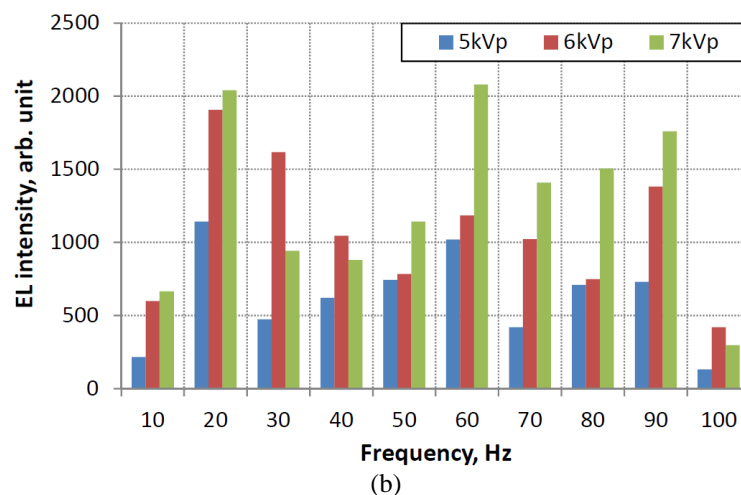


Figure 5. Peak of EL intensity for applied field of 5 kVp, 6 kVp and 7 kVp at all frequencies for (a) first and (b) third quadrant

#### 4. CONCLUSION

It can be observed that EL phenomenon behaves differently for both EL experiments. The value of EL intensity is also different for both EL experiments even though the same of frequency is used due to the nature of the accumulation and recombination of trapped and mobile charges in the material. For EL measurement in varying applied voltage at constant frequency, a direct relationship is obtained between EL intensity and applied frequency where higher applied frequency resulted in higher EL intensity. For EL measurement in varying frequency at constant applied voltage, there is no specific pattern or trend that can be concluded from the experimental data. However, it was observed that EL emission reached its peak at 20 Hz, 60 Hz and 90 Hz. In both experiments, the EL intensity is greatly influenced by the number of charge and recombination in the material.

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#### REFERENCES

- [1] Abd Allah M. A. A, *et al.*, "Effect of Coating of Earthed Enclosure and Multi-contaminating Particles on Breakdown Voltage inside Gas Insulated Bus Duct," *International Journal of Electrical and Computer Engineering (IJECE)*, vol/issue: 4(4), pp. 471-485, 2014.
- [2] Rouini A., *et al.*, "Prediction the AC Breakdown Voltage in Point/Plane Air Gaps with Barrier Using Design of Experiments," *International Journal of Electrical and Computer Engineering (IJECE)*, vol/issue: 12(12), pp. 8033-8041, 2014.
- [3] L. A. Dissado, *et al.*, "Discussion of Space-Charge Life Model Features in DC and AC Electrical Aging of Polymeric Materials," *IEEE 1997 Annual Report Conference on Electrical Insulation*, vol/issue: 1(6), pp. 36-40, 1997.
- [4] L. A. Dissado, *et al.*, "The Incorporation of Space Charge Degradation in the Life Model for Electrical Insulating Materials," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol/issue: 2(6), pp. 1147-58, 1997.
- [5] A. M. Ariffin, *et al.*, "Comparison of Electroluminescence Phenomenon in LDPE, PET and PEN under the Application of High Electrical Stress," *Annual Report Conference on Electrical Insulation and Dielectric Phenomena*, pp. 260-263, 2006.
- [6] G. Teyssedre, *et al.*, "Charge distribution and electroluminescence in cross-linked polyethylene under dc field," *Journal of Physics D: Applied Physics*, pp. 2830 – 2844, 2001.
- [7] N. A. Bani, *et al.*, "Characteristics of electroluminescence phenomenon in virgin and thermally aged LDPE," *AIP Conference Proceedings*, vol. 1674, pp. 020005, 2015.

- [8] A. Mohd Ariffin, *et al.*, "Determining the Occurrence of Electroluminescence in Polymeric Materials with Respect to the Applied Alternating Electrical Stress," *IEEE International Conference on Solid Dielectrics*, pp. 703-706, 2007.
- [9] D. Mills, *et al.*, "Comparison between the Electroluminescence and Space Charge of Ultraviolet and Thermally Aged Low Density Polyethylene," *Annual Report Conference on Electrical Insulation and Dielectric Phenomena (CEIDP)*, pp. 1-4, 2010.
- [10] N. Shimizu, *et al.*, "Space Charge Behavior and Luminescence Phenomena in Polymers at 77 Kelvin," *IEEE Transactions on Electrical Insulation*, vol/issue: 14(5), pp. 256-263, 1979.
- [11] L. Cissé, *et al.*, "Influence of Frequency, Electrode Material and Superimposed DC on AC Electroluminescence in Polymer Films," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol/issue: 9(1), pp. 124-129, 2010.
- [12] N. A. Bani, *et al.*, "Modelling the Effect of Applied Voltage and Frequency on Electroluminescence in Polymeric Material," *International Journal of Electrical and Computer Engineering*, vol/issue: 6(3), pp. 1375-1384, 2016.
- [13] J. M. Alison, *et al.*, "Dynamic Bipolar Charge Recombination Model for Electroluminescence in Polymer Based Insulation during Electrical Tree Initiation," *Journal of Physics D. (Applied Physics)*, vol/issue: 28(8), pp. 1693-1701, 1995.

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