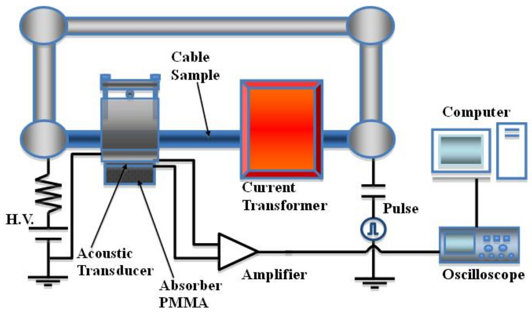


Figure 1: Illustration of a modified PEA system with current transformer for cable.

Cable Samples and Temperature Gradient

The cable samples used in our research were obtained from commercial 11 kV ac XLPE insulated power cable (inner radii = 5.8mm; outer radii = 9.2mm; XLPE insulation thickness = 3.4mm; cross-section of stranded aluminium conductor= 95mm^2). Degassing process was not applied on the cable samples. Therefore, cross-linking by-products are present in the insulation material.

Once in operation, the temperature gradient within the insulation material is obtained by the current transformer through induction heating, which heats up the cable and generates a radial temperature gradient across the insulation material as illustrated Figure 1.

A stabilised temperature gradient of 10^{o}C is obtained by having a ~55^{o}C temperature at its inner semiconductor and ~45^{o}C at its outer semiconductor and a 20^{o}C temperature gradient is obtained from having a ~89^{o}C temperature at its inner insulation and ~69^{o}C at its outer insulation. Both 10^{o}C and 20^{o}C temperature gradients are obtained through an ac current of 250A and 350A respectively across the insulation after 2 hours of induced current heating, where the outer semiconductor of the cable is cooled through natural convection cooling by the ambient temperature

Test Configuration

Three test conditions were setup for the experiments as follows:

1) No temperature gradient across the insulation at ambient temperature.
2) A 10^{o}C temperature gradient across the insulation.
3) A 20^{o}C temperature gradient across the insulation.

In both test conditions for 10^{o}C and 20^{o}C, the cable is first heated up through the current transformer prior to 2 hours to obtain the desired stabilised temperature gradient before starting the experiment and the current transformer remains on throughout the experiment measurements. The cable is then stressed at +80 kV for a total of 9 hours and space charge measurements were taken at different stressing times.

With the space charge distribution accumulated across the insulation after the 9 hours of positive voltage. The external positive voltage supply was switched off and the XLPE insulated power cable was short-circuited to release the surface static charge. Subsequently, negative voltage of -80 kV is then stressed on the cable and space charge measurements reading were once again taken at different stress times. The whole implementation of voltage polarity reversal procedure took less than one minute.

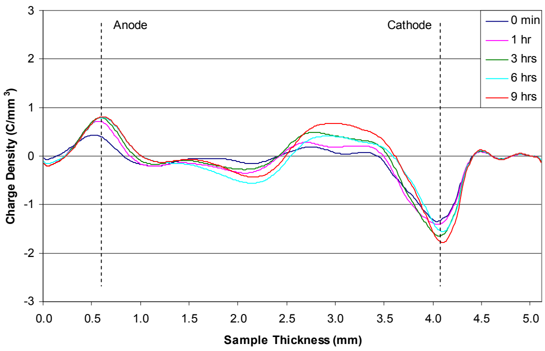
EXPERIMENTAL RESULTS AND DISCUSSION

The voltage on space charge profiles for no temperature gradient, 10^{o}C and 20^{o}C temperature gradients across the XLPE insulation material of the cable are presented in Figure 2 (a), (b) and (c) respectively.

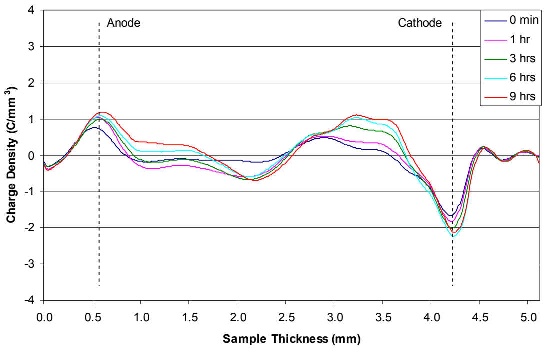
At the instant 0 min application of +80 kV to the central conductor of the cable, it can be seen from Figure 2 (a), (b) and (c) that heterocharge are already formed at the vicinities adjacent to the anode (inner electrode) and cathode (outer electrode). The amount of heterocharge accumulates at the instant 0 min tends to increase with the degrees of temperature gradient applied across the insulation material. Also with comparison between no temperature, 10^{o}C and 20^{o}C temperature gradients in Figure 2, the amount of heterocharge adjacent to the cathode tends to increase gradually. Furthermore by having a higher temperature gradient across the insulation, the heterocharge adjacent to the cathode apparently approaches a faster stable distribution time.

Therefore, it evidently shows that due to the cable did not undergo the degassing process, cross-linking by-products such as methane, cumylalcohol, acetophenone etc. are still present within the XLPE insulation [8]. These by-products may be present in the material for a long period of time and will undergo ionization process under a high electric field. Thus, under the influence of the electric field these ionized species will move towards the opposite electrodes to form heterocharge. Nevertheless, at high electric field accompanied with a higher temperature, the amount of charges tend to increase due to the higher injection rate and also having a higher mobility leading to the enhancement of the transportation of charges. Therefore, the observed heterocharge formation is due to the resultant effect of both scenarios.

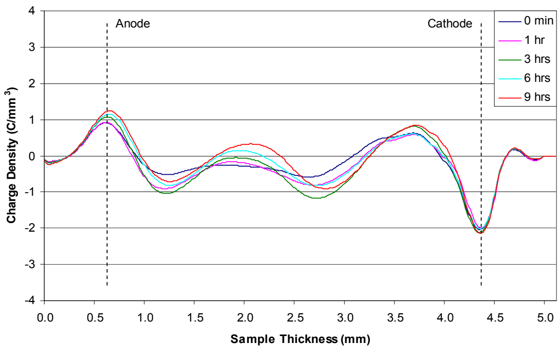
The overall space charge distributions in Figure 2 (a) and (b) are quite similar in shape to each other except for in Figure 2 (b) at 10^{o}C temperature gradient have a much higher accumulation of charges across its insulation. In addition, homocharge are observed accumulating and gradually increasing at the adjacent of the anode after 6 hours of poling. The purging of the initial 6 hours of negative charges might be due to the extraction by the anode and also the injection of positive charge where it cancels out or recombines with the accumulated negative charges. In view of the situation, the inner interface current seems to be triggered with higher activation energy than the currents in the bulk.



(a) No Temperature Gradient



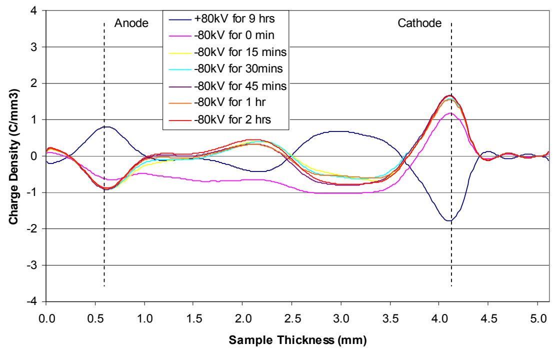
(b) 10^{o}C Temperature Gradient



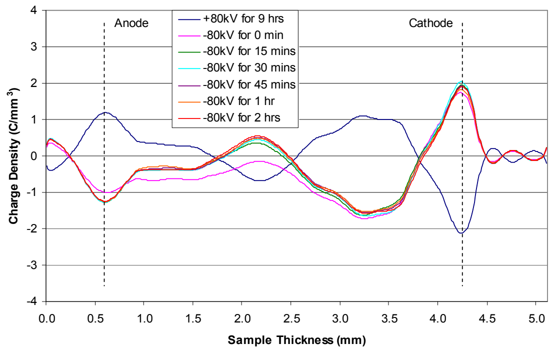
(c) 20^{o}C Temperature Gradient

Figure 2: Voltage on space charge profiles with ageing time under the application of +80 kV.

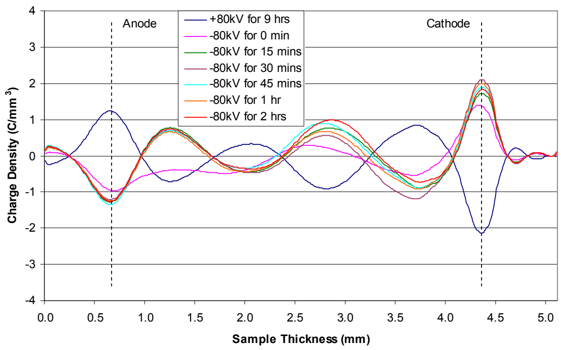
When 20^{o}C temperature gradient is applied across the insulation, it clearly shows the injection and transportation of charges increases with the temperature. As it has been reported, an average increase for positive and negative mobility is about 3 and 6 times larger respectively on doubling the temperature [10]. In Figure 2 (c) it illustrate that the amount of homocharge adjacent to the anode that was accumulated at 10^{o}C after 6 hours of poling has move further into the sample. Furthermore, heterocharge is again observed forming adjacent to the anode throughout the 9 hours of poling due to the removal of charge carriers by the anode is slower than the transit rate in which the negative charges are injected from the cathode.



(a) No Temperature Gradient



(b) 10^{o}C Temperature Gradient



(c) 20^{o}C Temperature Gradient

Figure 3: Voltage on space charge profiles with ageing time under the application of voltage reversal -80 kV.

In the voltage reversal experiment as illustrated in Figure 3 (a), (b) and (c), it shows that the space charge profiles that were previously accumulated at +80 kV for 9 hours are immediately overrun at 0 min by negative charges when the external voltage polarity was reversed. This immediate overrun of negative charges at 0 min tends to decrease with the increasing temperature gradient across the insulation due to the increase of mobility of both positive and negative charges enhanced by the temperature gradient. As having a higher mobility rate of positive charges, the initial negative charge tends to decrease in density due to the faster cancelling effect from the positive charge. In addition, we could see that immediately after voltage reversal, negative charge dominates across the insulation material first followed by the positive charge, where the later gradually take up its pace after the negative charge have done so. These whole events indicate that the activation energy of negative charges is indeed higher than positive charge and having a higher temperature gradient across the insulation increases the mobility of the both charges.

"Mirror image effect" is observed within 15 minutes of voltage reversal as shown in Figure 3 (a), (b) and (c), where the previous state of charge distribution under +80 kV for 9 hours is identical but of an opposite polarity. The duration of "mirror image effect" formation do varies with different cables as Fu et al [9] observed a stabilised "mirror image effect" at around 90 minutes after voltage reversal, whereas in our experiment a stabilised "mirror image effect" was observed within 15 minutes.

CONCLUSIONS

In this paper, we have replicate a power cable under service conditions, where temperature gradients across the insulation material and bi-direction power flow is considered. Measurements of space charge dynamics within the insulation of the power cable were taken under ambient and different temperature gradients followed by measurements after voltage reversal.

Through the existence of increase temperature gradient across the insulation, additional complexity is done on the space charge dynamics especially under 20^{o}C temperature gradient. Injection and transportation of charges increases with the increase temperature gradient across the insulation of the power cable. Activation energy of the negative charge is higher than positive charge.

"Mirror image effect" is observed and the duration for the formation of the mirror image to stabilise does vary with the different types of cables used.

Furthermore, the important issue of the electric field distribution across the insulation during voltage reversal under the above different service conditions will be investigated and discussed under future works.

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