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INVESTIGATION OF CORONA SOURCES IN HIGH VOLTAGE POWER LINES

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ABSTRACT

This paper describes the results of experiments made in the vicinity of EHV overhead lines to investigate sources of clouds of charged particles using simultaneously-recording arrays of electric field meters to measure direct electric fields produced under ion clouds. E-field measurements, made at one metre above ground level, are correlated with wind speed and direction, and with measurements from ionisation counters and audible corona effects to identify possible positions of sources of corona on adjacent power lines. Measurements made in dry conditions on EHV lines in flat remote locations with no adjacent buildings or large vegetation indicate the presence of discrete ion sources associated with high stress points on some types of line hardware such as connectors and conductor spacers. Faulty line components such as insulators and line fittings are also found to be a possible source of ion clouds.

1. INTRODUCTION

The production of charged particles by high voltage power lines has been of interest to researchers for some time. Direct electric fields produced by ions blown from HV AC lines have been measured by several authors, notably [1], [2] and [3] and it has been shown that direct electric potential gradients of up to about ten times the earth's natural electric field (of about 100 +Vm^{-1} at ground level) are measured on the downwind side of lines. It has been suggested that the electric field indicates the existence of clouds of charge blown from lines. Measurements have indicated that excess charge in corona clouds may have negative or positive polarity and excess charges in the clouds has been estimated as being as high as 4.5×10^9 m^{-3}[1].

It is known that designers of overhead power lines generally use well-known formulae to estimate the corona inception voltage gradient and they try to design high voltage conductors to operate well below the inception voltage. Often this is done by the use of several conductors in each phase to increase the geometric mean radius of the phase conductors, thereby reducing the voltage gradient at the conductors. "Corona rings" are also often applied to fittings at the HV end of insulators to reduce the voltage stress in this region.

The question therefore arises, as to which parts of overhead lines cause the very significant amounts of charge emanating from HV lines that have been observed by previous researchers. In this paper voltage gradient measurements and ion and aerosol charge density have been made on a number of EHV lines with the particular objective of identifying corona-ing items.

2. LINE MEASUREMENTS

Equipment

Electric field gradients (E-fields), ion density and aerosol charge concentration were measured with JCI-131 field-mill meters[4], an AlphaLab Ion Counter, and a TSI Aerosol Electrometer respectively. Wind speed and velocity, and temperature and humidity were measured with a commercial data logger that was limited to a maximum recording speed of 1 data record every 2 seconds. All data was recorded on a laptop computer to which remote field mill meters were connected by wireless communication links.

Preparatory Measurements

Preliminary measurements were made at a site in a suburban area where there were three, parallel double-circuit EHV overhead lines. While it was possible to measure increased E-fields downwind of the line, the proximity of trees, buildings and other obstacles made it impossible to determine the exact location of sources of corona causing the E-fields. Subsequent measurements were therefore made in a remote rural region that was mainly flat with very few buildings or other features.

Wood Pole Line

A photograph of this line is shown in Figure 1. The single-circuit line is of a wish bone construction with hardwood cross-arms and seven glass, cap and pin insulators supporting each phase conductor. The ion density at about 1 m above ground level was checked in the vicinity of the line with a portable ion counter at a time when wind blew consistently at 90^o to the axis of the line with a variation of not more than about $\pm$ 5^o. Conditions during tests were dry: temperature was 23 ^oC, RH was 41% and there were some clouds as can be seen in Figure 1.

Measured ion densities are shown in Table 1. It was found that at all parts of each span except close to the wood poles the ion counts were low and close to the value recorded in Table 1 for the mid-span point (M): these values are very low and close to the background level upwind of the line. Adjacent to the poles there was a consistent increase in the ion count as shown in Table 1.

Fig. 1: 110 kV overhead line in typical, flat, isolated area with no adjacent structures.

Table 1. Ion densities along a 110 kV line.
Measurement points. P – wood pole. M – mid-span

Item No.	Ion Count (cm^3)		Item No.	Ion Count (cm^3)	
	P	M		P	M
1	1000	-	4	700	-
1-2	-	600	4-5	-	650
2	880	-	5	1100	-
2-3	-	600	5-6	-	400
3	800	-	6	900	-
3-4	-	650	-	-	-

E- field measurements made close to Pole 1 are shown in Fig. 2. The upwind E value (3) is low: down wind values (1)(2) are 50 to about 200 Vm^{-1} higher indicating that charge has been blown from the line

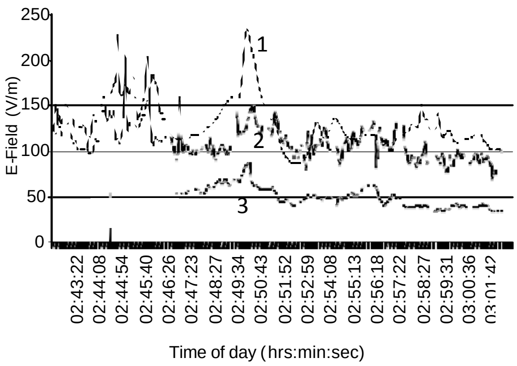


Fig. 2: E-field Measurements Adjacent to Pole 1of wood pole line.(ref. Table 1).
Downwind: 1 – meter 30 m from line: 2- -meter 60 m from line.
Upwind : 3 – meter 30 m from line. All in line at 90^{0} to Pole 1 .

The disturbances evident in the upwind E-field 1 value are attributed to the presence of clouds that can be seen in Fig. 1. The wind speed was in the range 1 to 6 knots during the measurements. As a result on several measurements at this site it was found that E-field 2 which was closest to the line was consistently higher than E-field 2 except when wind blew from 20^{o}. There was no identifiable variation in the E-fields with wind speed.

EHV Double-Circuit Steel Tower Line

In this line the main structures were cylindrical steel towers on each side of which three conductors were each supported by two composite (polymeric) insulators. A plan of the area of the line around the measurement site is shown in Fig. 3.

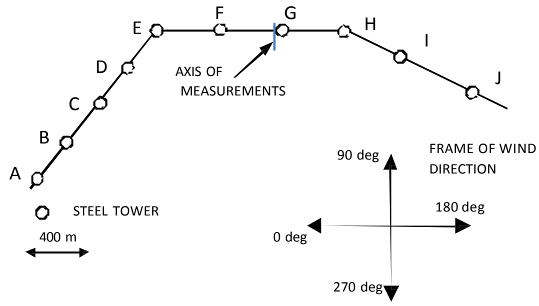


Fig. 3: Plan of the EHV line near the measurement site.

All days on which measurements were made were dry and cloudless with temperatures in the range 20-25^{o}C. Measurements were made close to tower G as shown in in Fig. 3. Field meter 1 was 50m above (in Fig 3) the line and meters 2, 3, and 4 were 50, 100 and 150 m respectively below the line. For E-field measurements shown in Fig. 4 meter 1 was upwind of the line and meters 2, 3 and 4 were down wind. This convention for numbering the E-meters and the associated measurements will be adopted from this point in this paper.

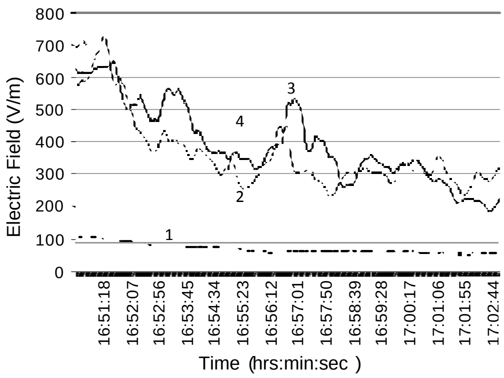


Fig. 4: E-fields recorded near to the EHV kV line. Numbers identify E-meter producing result.

The weather station which recorded the wind was 50 m from the line close to E-meter No. 2. E-field is shown as a function of wind direction in Fig. 5 for all measurements from one day. In this case it was found that the maximum average E-field occurred when wind blew from between 40^{o} and 60^{o}.

There were several peaks in the measured E-fields as a function of wind direction: these data are summarised in Table 2.

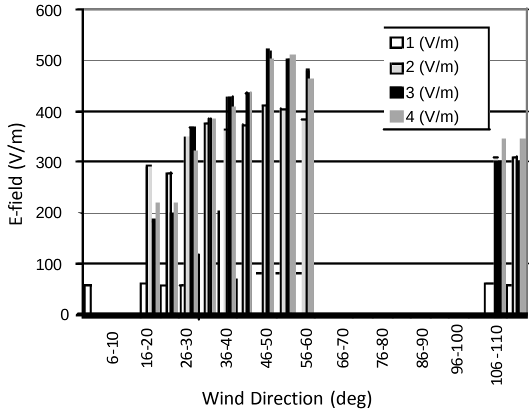


Fig. 5: Average E-field as a function of direction from which the wind blew: wind did not blow from directions with no results during the measurement period.

Table 2. Highest E-field measurements as a function of wind direction.

Wind Direction (deg)	11-20	30-35	56-60	81-85	111-125	331-335
Highest local E (V/m)	800	900	1000	660	600	700

Generally the upwind reading showed constant and stable readings close to the ambient electric field of the earth in the area. The three downwind E-fields fluctuated widely. Generally 2 appeared to be leading 3, but had a lower value. E-field 2 was usually lower than 3 or 4 except when wind came from 15-25^o.

An interesting example of a change in E-field with an abrupt change in wind direction is shown in Fig. 6. It can be seen that at about 13:00 hrs the wind direction suddenly changes from 50^o to 250-350^o. This appears to initiate a change in meter 1 from 150 V to almost 900 V in about 200 s. It can also be seen that the E-field of meters 3 and 4 appear to start changing 500 s before the wind direction is recoded at meter 2.

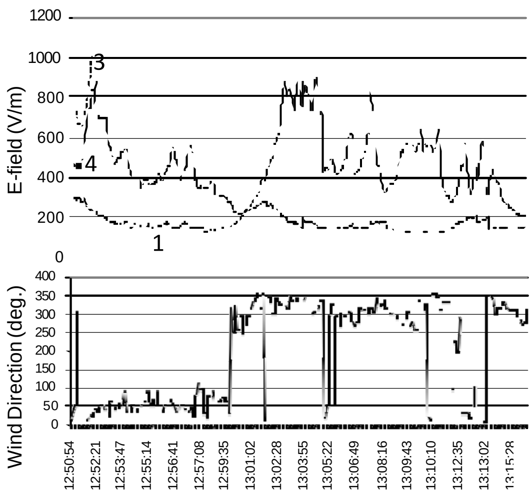


Fig. 6: E-fields due to abrupt change in wind direction.

Temporal displacement of some features in the shapes of the E-field waveforms could be discerned, indicating charge movement due to the wind. For example, in Fig. 4 the double peak in 2 at about 16:56:42 seems to occur in 3 about 20 seconds later, implying a charge drift velocity of about 2.5 ms-1 (about 5 knots) normal to the overhead line.

As this method of deducing drift of charge was not reliable, we plotted all digital data points recorded on one E-meter with corresponding data points measured at the same time instant from another meter. We found no correlation between measurements from E-meters 2 and 3 made at the same time. However, if we shifted the time scale of 2 forward in time by a time equal to the transit time of the normal (to the line axis) component of the wind between 2 and 3 we obtained strong correlation between elements of waveform 3 and the shifted waveform 2, confirming charge movement with the wind.

Fig. 7 shows an example of how, for many conditions, the down-wind measured E-field increased with wind speed. Interestingly this apparent relationship did not hold for all conditions investigated, particularly at low wind speeds.

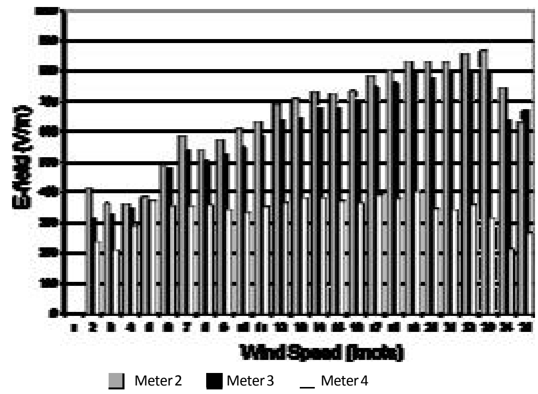
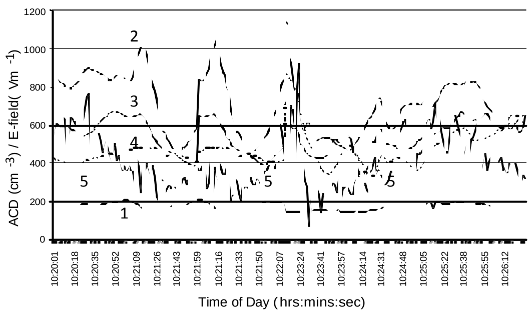


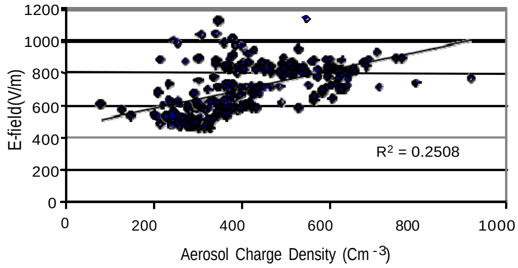
Fig. 7: E-field as function of wind speed

The aerosol charge density (ACD) in the air 0.5m above ground was also recorded [5] immediately under tower G and at the meter 2 position. An example of E-field waveforms and ACD recorded simultaneously is shown in Fig. 8(a).

Figure 8(b) shows a plot of several data measured at the meter 2 as a function of associated ion densities. Linear regression indicates a positive correlation for these results. The correlations were strongly affected by wind conditions. Stronger correlation (up to 0.61) was also a observed at a later time but earlier measurements indicated a very weak correlation.



(a) Temporal variation of E-fields and ACD



(b) Correlation between E-field and ACD

Fig. 8: Measurements of E-field and ADC at meter 2 position: ADC is trace 5 in (a).

3. POSSIBLE SOURCES OF CHARGE CLOUDS

Wood Pole Line

The wood pole line indicated a level of excess ion concentration at ground level that was close to ambient at points between the poles. Only close to the poles were there increased concentrations of ions. Close to the poles, increased E-fields were detected that were most likely due to the production of ions at the poles. The magnitudes of the E-fields were rather low.

Several possible sources of corona were observed on the high voltage equipment mounted on the wood poles. Firstly it was observed that the glass disc (cap and pin) insulators had several cracks at the edge of the insulators, and rusted pins. The high voltage end of an insulator string is shown in Figure 9. The bolts that can be seen protruding from the bottom of the high-voltage conductor fitting in this figure, and the fitting itself, will most likely produce higher electric field gradients than the conductor. All these features could lead to corona from the line even if the conductors had a diameter that would not produce corona under dry conditions.

EHV Line

The E measurements appeared to be affected by multiple sources. Referring to Table 2 and Fig.3, it can be seen that wind directions of 110-125^o might indicate corona from tower G.

The peaks at 30-35^o, 56-60^o and 81-85^o might indicate corona from conductors and fittings or towers E and F. Peaks at 11-15^o could indicate corona sources on the lines close to or fittings on tower E. Even the peak at 331-335^o could indicate corona from tower E, as it is likely that corona plumes will gradually broaden with distance from source in away similar to dispersal of smoke from a stack [6].

Fig. 9: Cap and pin insulators and a line fitting on the wood pole line. Arrow indicates glass disc insulators.

Discussion

We investigated by walking under the line. Corona-like noises could be heard from several sources. The spacers (there were several spaced at equal distances in each span) separating the sub-conductors in the same phase were particularly noisy. On some of the towers conductors were connected by connectors which appeared to have rather sharp edges. We heard a particularly strong corona-noise from tower E but were unable to ascertain its source. During measurements we noticed that when the wind blew from roughly 0^o ± 20^o there were high E-fields which appeared to indicate a very strong corona source somewhere between towers D, E and F. This was not unusual as other researchers [1] have reported measurements of artefacts of corona several km from the possible source.

4. CONCLUSIONS

E-fields, excess ions and ADC were measured close to wood pole and EHV steel tower overhead power lines. Results seemed to indicate corona from high voltage line fittings and degraded insulators rather than from the high voltage conductors.

5. ACKNOWLEDGEMENT

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