Fixed site monitoring of potential gradient fluctuations near to AC high voltage power lines

J C Matthews
University of Bristol, UK
E-mail: j.c.matthews@bristol.ac.uk

Abstract. A fixed site monitoring station recorded the potential gradient disturbances near to two high voltage power lines during 2008. The full year’s results show that the electrical environment downwind of power lines is modified compared to that upwind. Potential gradient disturbance was greater on days when there was rainfall. Humidity was inversely correlated with mean potential gradient when the station was both downwind and upwind of both power lines. Wind speed is weakly correlated with the standard deviation of a 10 minute sample of potential gradient downwind of both power lines, but not upwind. The distributions of mean and standard deviation of potential gradient in 10 minute samples showed that the field was more negative overnight and on days where there was rain, but less variable at night and on dry days. Upwind of the power lines, the average 24 hour trace exhibits the natural background Carnegie curve, with peaks corresponding to increased global thunderstorm activity, while local effects mask this trace when the FSMS is downwind of the power lines. The results show that corona ions can cause potential gradient disturbances downwind of high voltage power lines, most particularly during rain and high humidity, and overnight.

1. Introduction
The Earth has a natural potential gradient (PG) between the ground and the ionosphere. High voltage power lines can produce corona ions when the field gradient near the cables is sufficient to ionise the air. If these ions escape the line, and there is a charge separation between positive and negative ions, then the space charge can be measured as fluctuations in PG using electric field mills [1].

It is useful to know the times and conditions when corona ion emission is most likely to occur. A fixed site monitoring station (FSMS) was constructed in a field in Littleton-Upon-Severn, South Gloucestershire, UK to investigate the fluctuations in PG downwind of a 275 and a 400 kV power line in different meteorological conditions [2].

2. The fixed site monitoring station
The FSMS contains a JCI 131 all weather electric field mill meter recording the vertical PG at 1 s intervals, and a Davis Instruments weather station recording the wind speed and direction, temperature, pressure, humidity and solar radiation at 10 minute intervals. Zero levels were checked approximately every 2 weeks by recording the response when the field mill aperture was placed into a grounded chamber. The field mill output was compared to the recorded PG from a factory calibrated JCI 140 field mill placed 10 m away approximately monthly [2]. After two years of measurements at 1 s intervals, an extensive database has been created of the PG and weather conditions at the FSMS.
The mean and standard deviation of the PG were calculated for every 10 minutes and put into a database with the weather conditions. Data was discarded where there was less than 600 seconds of PG data recorded and where the field meter generated an alert signal from its internal operational health monitoring. Data was separated by wind direction into three zones as shown in figure 1.

![Map showing the position of the FSMS (marked by an X) with respect to a 400 kV power line and a 275 kV power line and the M48 motorway. The FSMS is 175 m from the 400 kV line at its closest point and 750 m from the 275 kV line. The map is split into 3 zones dependent on wind direction. In zone 1, the FSMS is downwind of the 400 kV power line, zone 2, downwind of the 275 kV line and zone 3 upwind of both.](image)

3. Results

3.1. The effect of weather

3.1.1. Rainfall. Rainfall can affect the production of corona ions from HV power lines [3], therefore the PG on dry and rainy days is likely to be different downwind. Days in which there was at least 0.2 mm of rain were separated from days where there was less than 0.2 mm or no rain at all in 2008. There were 150 days with no rainfall, whilst the other 215 days had some rainfall.

The mean and standard deviation for each 10 minute sample were found for each of the three zones. Zone 3 had the smallest difference between rainy and dry days, due to the presence of charged clouds some difference would be expected in all zones. The increase of SD in zones 1 and 2 are expected as rainfall will create space charge. The histograms for zone 1 are shown in figure 2 and using Kolmogorov-Smirnov (KS) tests were shown to be significantly different to each other (at the $p < 0.01$ significance level).

3.1.2. Correlations between weather conditions. The Spearman rank correlation coefficient $\rho$, was found for the 10 minute mean and SD of PG and the measured weather conditions, all correlations presented here have a probability, $p$, less than 1% of being caused by chance. No strong correlations are present, but weak correlations are found which while not proof of a power line effect due to the large number of confounders, do give an indication of areas worthy of further investigation.

Temperature does not correlate with any of the PG metrics, other than a very weak correlation between PG SD and temperature in zone 3 ($\rho = -0.21$). Pressure is weakly inversely correlated with SD in zone 1 and (both $\rho = -0.24$), but not zone 3 ($\rho = -0.09$). Low pressure is associated with poor weather, such as increased winds and rainfall, and also storm clouds which have their own charge, so it is likely that these correlations are not due to the power lines. Humidity is inversely correlated with PG mean in all three zones. The correlation is strongest in zone 1 than zone 3 then weakest in zone 2 ($\rho = -0.40$, -0.31 and -0.27 respectively). Wind speed is weakly correlated with PG SD in zone 1 and ($\rho = 0.38$ and $0.36$) in zone 3 there is near to no correlation with SD. It is important to note that wind speeds can be higher in zone 1.

3.2. The effect of time of day

3.2.1. Distributions at day and night. Mean and SD data from the FSMS were separated into night and day, according to solar radiation data (daytime is when solar radiation > 0), and plotted as histograms (shown for zone 1 in figure 3). The difference between the mean PG at night and day is small in zone
yet for zones 1 and 2, the distribution is more negative overnight. For SD, the difference between the distributions in night and day in zone 3 is very small. The variability of PG is consistently greater downwind of a power line during the day than it is during the night, but the difference is small. In zone 2 there is greater difference than in zone 3, where 32.3% of measurements in the day and 38.7% of measurements in the night are found under 20 V m$^{-1}$. In zone 1 there is greater difference again where 32.3% of measurements in the day and 38.7% of measurements in the night are found under 20 V m$^{-1}$. All histograms were compared using the KS test and differences were significant to the $p < 0.01$ level.

Figure 2. Histograms showing the distributions of mean (a) and SD (b) of PG downwind of a 400 kV power line, separated by rainy or dry days.

3.2.2. Diurnal cycles and the Carnegie curve. Global thunderstorm activity peaks after midday and is at a minimum overnight, GMT. The average global background PG has been shown to correlate well with global thunderstorm activity, and this average curve is known as the Carnegie curve [4].

The mean PG for each hour was averaged throughout 2008 from all three zones. The resulting curves were compared to the Carnegie curve. Only the control data from zone 3 shows a strong correlation, with a Pearson correlation coefficient of $\rho = 0.83$. Zone 2 is weakly correlating ($\rho = 0.52$) while data from zone 1 does not correlate well ($\rho = 0.29$, $p = 0.18$). The average curves of zones 1 and 2 are weakly correlating to zone 3 ($\rho = 0.56$ and 0.50 respectively, $p \sim 0.01$) but the correlation between 1 and 2 is weak and insignificant ($\rho = 0.37$, $p = 0.07$).

Figure 3. Histograms showing the distributions of mean (a) and SD (b) of PG downwind of a 400 kV power line, separated by day and night.

4. Discussion and conclusions

4.1. Natural sources of PG fluctuation
There are several natural sources of space charge that need to be considered when interpreting the PG measurements downwind of HV power lines. Clouds can often carry charge and can cause changes of PG over several seconds or minutes of up to a few thousand V m$^{-1}$ in extreme cases. Without measurements at the opposite side of the power line, it is impossible to separate the contribution to PG from clouds and from corona ions (though times during the day when there is a lot of cloud cover can
be ascertained using solar radiation measurements). The assumption is made in this work that there is not a significantly different amount of PG disruption from charged clouds from south westerly winds, as the distribution of PG measured for all wind directions at the Reading University Atmospheric Observatory [5] do not show the extreme values of PG shown in the distributions.

The FSMS is positioned to the east of the mouth of the River Severn, and is north of the motorway. Both traffic and water can produce ions, but measurements of space charge from water and traffic show that PG modifications are greatly reduced after 2 km [6] making the effect at the FSMS small.

4.2. Weather conditions for the highest corona ion emission

These findings show that the highest levels of corona emission occur in damp atmospheres, whether it is raining or there is very high humidity, or when the wind speed is high. The PG readings at these points would tend to be more negative than average PG values.

Previous results from real DC and AC lines [7] have shown an increase in negative corona ion emission with increasing humidity. However, humidity is often higher overnight when the atmosphere is more stable, and space charge could be trapped in a layer near the ground, increasing the space charge density. The other confounder is that very high humidities are associated with disturbed weather, which can affect atmospheric PG.

As wind speed increases, lighter negative ions produced after corona avalanching are more likely to be ‘swept away’ by the wind, suppressing the creation of positive corona streamers [8]. This would result in more negative corona loss. Higher wind speeds downwind of the 400 kV line at the FSMS showed median values reducing with increasing wind speed [2], so as predicted, more negative corona ions are escaping the line. The turbulence in the atmosphere increases with increasing wind speed, so the result that higher wind speeds are correlated, albeit weakly, with increased standard deviation of 10 minute samples of PG downwind of both power lines at the FSMS is unsurprising. There is no correlation in zone 3, as there is less space charge in the mixing layer of the atmosphere, the more turbulent atmosphere will not affect PG readings.

4.3. Time of day for the highest corona ion emission

For measurements in zone 3, the results correlated very well with the natural Carnegie curve that is expected during fair weather conditions, measurements from zone 1 and zone 2 did not correlate with the Carnegie curve. The space charge produced from the power lines is high enough to mask the natural Carnegie curve. Overnight, the mean value of PG in zones 1 and 2 is negative for some hours. The most likely explanation for the increase in negative space charge overnight is the increase in humidity, which has been shown to be associated with negative fields.

Acknowledgements

This work was funded by Children with Leukaemia, registered charity number 298405.

References

[1] Fews A P, Wilding R J, Keitch P A, Holden N K and Henshaw D L 2001 Atmos. Res. 63(3-4) 271-89
[2] Matthews J C, Ward J P, Keitch P A and Henshaw D L 2010 Atmos. Environ. 44 5093 - 100
[3] Kirkham H 1980 J. Appl. Meteorol. 19 35-40
[4] Harrison R G 2005 Surv. Geophys. 25 441-84
[5] Bennett A J and Harrison R G 2008 J. Phys. Conf. Ser. 142 012046
[6] Muir M S 1977 J. Atmos. Terr. Phys. 39 1341-6
Issalesson S amd Lelwala R 1999 Atmos. Res. 51(3-4) 301-7
[7] Hendrickson R C 1986 Bioelectromagnetics 7(4) 369-79
Broom K N and Chalmers J A 1967 J. Atmos. Terr. Phys. 29 613-5
[8] Deno D W and Comber M G 1982 Corona phenomena on AC transmission lines Transmission Line Reference Book, 345 kV and Above (Palo Alto: EPRI) chapter 4, pp 122-48