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Corona ions from high-voltage power lines: Nature of emission and dispersion

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ABSTRACT

Positive and negative small ions, aerosol ion and number concentration and dc electric fields were monitored at an overhead high-voltage power line site. We show that the emission of corona ions was not spatially uniform along the lines and occurred from discrete components such as a particular set of spacers. Maximum ion concentrations and atmospheric dc electric fields were observed at a point 20 m downwind of the lines. It was estimated that less than 7% of the total number of aerosol particles was charged. The electrical parameters decreased steadily with further downwind distance but remained significantly higher than background.

1. Introduction

Atmospheric small ions mainly originate from the interaction of cosmic rays on air molecules and the presence of trace radioactive isotopes in the natural environment. These ions are usually found in the form of molecular clusters smaller than about 1 nm in size, bound together by charge [1]. Once produced, small ions quickly attach to aerosol particles in the size range, roughly 1 nm to 1 μm in diameter. These are classified as 'aerosol ions' [2]. While small ions have a higher mobility and migrate quicker towards the ground, aerosol ions can be transported to greater distances in the wind. Air ions are also produced by anthropogenic sources such as high voltage power lines, motor vehicle exhaust and air conditioning systems. The high electric fields existing close to overhead power lines can cause electrical breakdown of the surrounding air – commonly referred to as corona discharge. Most power lines are designed to operate with no corona to minimise loss of power during transmission. However, accumulation of dust and dirt and the presence of water drops from rain or dew may produce local intensification of the electric field on the surface of the conductors may give rise to corona discharge. Direct measurements of power losses from high voltage transmission lines are very scarce. Abdel-Salam and Abdel-Aziz [3] estimated that the corona power loss from a closely spaced, new and unwashed, 220 kV three phase line was about 0.04 mA m^{-1}. This corresponds to about 2.4×10^{14} ions s^{-1} m^{-1} of line. This value is expected to be higher for older lines. A single phase line of the same diameter and height above the ground showed a loss of almost one-third of the value for the three phase line [3]. While most of these ions recombine with the power line, a significant fraction may escape in the wind and be carried downwind from the lines, both in the form of small ions and aerosol ions [4]. The presence of elevated ion concentrations in the air downwind of power lines have been directly measured with ion monitors [5,6] and indirectly estimated by measuring the static dc electric fields at the ground [4,7,8]. Ion concentrations produced by ac high voltage lines are generally lower than from dc lines. For example, Carter and Johnson [5] measured air ion concentrations near a 500 kV dc test line and found small ion concentrations of up to 1.5×10^5 cm^{-3} and aerosol ion concentrations of a few tens of thousands cm^{-3}. Similarly, Suda and Sunaga [9] measured aerosol ion concentrations near a 750 kV dc test line and found concentrations as high as 10^4 ions cm^{-3} at a distance of 200 m downwind of the line. Grabarczyk and Berlinski [10] measured ion concentrations near high voltage ac lines using a Gerdien-type aerosol ion counter. They reported concentrations of the order of 10^3 cm^{-3} near two 110 and 220 kV lines and of the order of 10^4 cm^{-3} near a 400 kV line.

The vertical dc electric field at the ground gives an indication of the total net space charge within the column of air above the measurement point. The earth's natural electric field is positive (directed vertically downwards) under fair weather conditions and varies from about 100 V m^{-1} in clean environments to a few hundreds of V m^{-1} in polluted regions [11]. Its magnitude can be significantly affected by the presence of thunderclouds aloft as well as local space charge from sources such as overhead power lines. Fews et al. [4,7] used a field mill metre to measure changes in the earth's vertical electric field to estimate the ion concentrations near several overhead 132 and 400 kV transmission lines in the UK. They used a dispersion model to

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estimate the ion concentrations aloft and found values from 250 to 7000 elementary charges cm^{-3} with an average value of 3000 cm^{-3}. Both positive and negative space charge clouds were detected with an excess of positive charge during fair weather conditions.

In summary, very few studies have been conducted to directly measure ion concentrations near power lines and, as a result, our knowledge of how these ions are produced, how they attach to particles and how they are dispersed away from their source is extremely sparse. There are two other aspects of the corona ion emission process from a power line that merit investigation: do lines emit corona at a constant rate and is the emission uniformly distributed along a line or does it occur from discrete points or components of the line? The present study was aimed at answering these questions.

2. Methods

2.1. Description of the study area

This study was carried out near three parallel ac double circuit power lines running roughly east-west across an open parkland. The site was chosen because of an above average concentration of ions in its vicinity that enabled the nature of emission and dispersion of the corona ions to be easily determined over the background concentrations. We shall denote the three sets of power lines as 1, 2 and 3 from south to north. power lines 1 and 2, carried a transmission voltage, defined as between 220 and 330 kV while power line 3 carried a sub-transmission voltage, defined as between 110 and 132 kV. Line heights varied from about 25 m at the pylons to about 20 m at mid-span. A photograph of the site is shown in Fig. 1. The view is from the east looking west. The three sets of lines are 1, 2 and 3 from left to right (or south to north). The two larger pylons on the left support two sets of transmission voltage lines (1 and 2) while the smaller pylon on the right carries a single set of sub-transmission voltage lines (3). The ground in the immediate vicinity of the lines was level and clear of any buildings or trees. A day was selected when the sky was totally free of clouds and there was a steady wind of 5.2 ± 0.8 m s^{-1} blowing normal to the lines, directly from the south, i.e from left to right in the picture. Measurements were first made along a line parallel to and downwind of the lines. Measurements were also made at a point upwind of the lines, about 20 m to the south of power line 1, in a clearing away from tall trees and repeated at various points under the lines and extending to a distance of about 80 m from power line 3 in the downwind direction.

Fig. 1. The measurement site showing the three sets of double circuit lines.

2.2. Instrumentation

Small ion concentrations were measured with two Alphalab air ion counters that were factory-calibrated just prior to the measurement campaign. This instrument has a dynamic range of $10–10^6$ ions cm^{-3} with a minimum detectable charge concentration of 10 ions cm^{-3} and a response time of 2 s. The minimum characterisable mobility of the unit is 0.5 $cm^2\ V^{-1}\ s^{-1}$, which corresponds to a detectable maximum ion size of 1.6 nm. The instrument has the capability of monitoring negative and positive ions separately, but not simultaneously. Hence, two instruments were used to measure both positive and negative small ion concentrations separately at each measurement point. A TSI 3068 aerosol electrometer was used to measure the net aerosol ion concentration. This instrument draws ambient air through a particle filter and determines the total net charge present on aerosol particles in the size range 2 nm–5 μm. Nominal response time is about 1 s. Ultrafine particle number concentration was monitored with a TSI-3782 water-based condensation particle counter (CPC) that measures particles down to a size of 10 nm in number concentrations up to 5×10^4 cm^{-3}. The time response of the instrument is less than 3 s.

A JCI-140 electric field mill metre was used to measure the vertical dc electric field at a height of 1 m above ground level. The instrument has a time response of 50 ms and a resolution of 10 V m^{-1}. It was pre-calibrated in the laboratory using two large, flat, parallel plates connected to a variable voltage supply to simulate a known electric field. A correction factor of 1.45 was derived and applied to all field readings to correct for fringing effects. The ac magnetic field strength was monitored with a handheld monitor from Gigahertz Solutions, Germany. The instrument was set to the frequency range 5 Hz–100 kHz as recommended for the electric power grid and its natural harmonics. The maximum detectable magnetic field value was 2000 nT. At each location, the instrument was oriented to determine the maximum field strength which was generally in the north-south direction.

All data were logged at 1 s intervals on a laptop computer. Each reading was obtained as the average over several minutes which were considerably longer than the response times of the instruments. Meteorological parameters such as wind speed, wind direction, temperature and relative humidity were monitored continuously. The relative humidity affected the zero stability of the aerosol electrometer when it exceeded about 65%. However, during the entire measurement campaign, the ambient relative humidity did not exceed about 44% and, so, did not cause any problems.

2.3. Measurement techniques

Fig. 2 shows a plan view of the measurement site. A and B are the positions of the pylons supporting the three sets of power lines denoted 1, 2 and 3. A1, A2 and A3 are the three pylons observed in

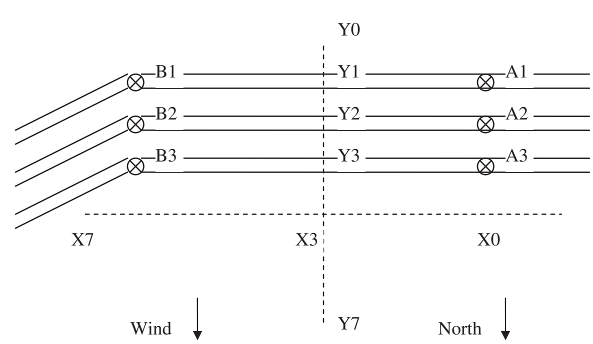

Fig. 2. Plan view of the measurement site.