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Environmental Impact Study:

Australian Rain ATLANT Technology

Report prepared for Australian Rain Pty Ltd
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Contents

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1. Scope

Australian Rain Pty Ltd ("the Client") has developed a "rainfall enhancement technology" named the "ATLANT system". It is designed to produce significant amounts of negative ions via a corona discharge. The ATLANT is currently undergoing scientific trials in various parts of Australia.

The aim of this study is to provide an objective assessment of the possible impact of the operation of the ATLANT system on local persons, flora, fauna, communications and air traffic.

The remainder of this report is divided as follows. In Section 2, a brief description is provided of the relevant physical features of the ATLANT system. Section 3 reviews the main principles of corona discharges and Section 4 quantifies the main features and parameters of the ATLANT system as an ion generation source. Section 5 compares the corona characteristics of ATLANT system with high voltage power transmission lines. Section 6 presents the results of extensive literature research and an analysis of the impact of the ATLANT in terms of humans, fauna, flora, communications and air traffic. Finally, Section 7 summarises the work and Section 8 provides the conclusions of the study.

2. ATLANT System Description

Figure 1 is a photo of an existing ATLANT system, as used by the client in recent field trials. According to the Client, the ATLANT concept spans four distinct physical phases that differ on a temporal and spatial scale. The first phase involves the generation of negative DC corona around the ATLANT ground-based device to produce a negative space charge in the surrounding air. The next phase involves the formation of light ion clusters or attachment of the negative ions to naturally occurring aerosols present in the atmosphere, creating so-called heavy ions. These light and heavy ions are then transported away from the technology by the mean wind and to higher levels in the atmosphere by turbulence and convective updrafts. Finally, within hours, the microphysical processes of cloud droplet growth and raindrop formation are enhanced and rainfall is generated.

According to the Client, a typical ATLANT system:

- Has a footprint of 12 x 5 metres with 4 pyramidal peaks at a height of about 5 metres above the ground.
- Uses about 7000 m of wire wound in a multiple, pyramidal-stack formation, as seen in Figure 1.
- The diameter of the wire is approximately 0.2 mm.
- The wire is raised to a negative potential with a high voltage DC source capable of supplying up to about -85 kV at a maximum current of 15 mA.
- Voltages of the order of ten's of kV have been shown to be sufficient to cause a corona discharge for this configuration and, eventually, a region of unipolar (negative) space charge around the ATLANT system.

Figure 1: ATLANT system installed at Paradise Dam, Queensland, 2008

The Client has also provided documentation claiming the following operational features:

- Negative ions underneath the electrodes form a current leakage towards the ground, representing a loss for the system.
- Negative ions above the ATLANT system experience a repulsive, upward force from nearby wires.
- The average electric field strength is about 2.5 kV/m near the installation situated on the ground, so the ions may move upwards at about 1 m/min.
- At altitudes much higher than the height of ATLANT's corona electrode, the electric field is assumed to fall away as $1/h^3$.
- Taking into account the corona electrode size of 16 m^2, they have estimated a cut-off altitude in the order of tens of metres.

3. Basic Principles of Corona Discharges

When an electrode (or conductor) is raised to a high potential in a gas such as air, a variety of discharge phenomena may be observed as the air molecules separate into electrons and positive ions, followed by the movement of these charged particles under the action of the electric field. The discharge phenomena include steady glow discharges, radio-frequency oscillations ("Trichel pulses"), arcing and spark breakdown.

For the correct combination of electrode geometry, applied potential and the nature of the gas, a corona discharge may be observed. Corona discharges only occur if the electric field is very non-uniform. The field near the electrode must be much stronger than in the space between the electrode and the opposite electrode. According to Raizer (1997), the characteristic size r of the electrode must be much smaller than the inter-electrode distance d, so that $d/r > 5.85$. Otherwise, a spark discharge will occur between the electrodes.

As noted by Budd (1991), a corona discharge comprises a thin region of glowing gas close to the most highly curved part of the electrode, the "corona sheath" or "ionisation zone", within which the electric field is sufficiently high to break down the air molecules and hence produce free electrons and charged ions of both polarities.

Outside the ionisation zone, in an electrically negative (electronegative) gas such as air, the current is transported by ions, because electrons become attached to oxygen molecules at the very beginning of the "drift process" (Bazelyan & Raizer 1998). In this drift region, ions with the same polarity as the electrode drift outwards to form a unipolar space charge region, with the corona discharge acting as a current source for this region.

If the applied voltage is below the threshold for corona onset, a non-self-sustaining current in the order of 10^{-14} A can be detected. This "background current" is due to ions produced by cosmic rays and natural radioactivity. There are about 1000 such ions per cubic centimetre in air at sea level. As the voltage is increased just beyond the corona threshold, a discharge current of about 1 μA will begin to flow.

Many experimental investigations have been carried out on the corona onset voltage for wires (or cylinders) and points (or spheres) as a function of (wire) radius, voltage polarity, gas temperature and gas pressure, e.g., see Peek (1929), Kip (1938), Loeb (1965), Grunberg (1973), Nasser & Heiszler (1974), Waters & Stark (1975), D'Alessandro & Berger (1999) and Moore *et al* (2000*a*,*b*).

Of particular note is the landmark investigation of Peek (1929), who developed an empirical equation for the electric field, E_c, at the surface of a wire for the onset of corona as a function of the wire radius, r, and relative air density, δ. The basic equation for cylinders is known as Peek's equation and is given by

$$E_c = 30\delta\left[1 + \frac{0.3}{(\delta r)^{1/2}}\right], \quad (1)$$

where E_c is in kV/cm and the wire radius r is in cm. Peek's reference temperature and pressure, for which Eqn. (1) is valid, was 25°C and 1.01 bar.

Hence, corona onset at a wire surface will occur when the energising potential reaches a value V_c that results in a surface field of E_c. For a long, single wire at a height h above a parallel ground plane, the electric field at the surface of the wire of radius r is given by (Raizer 1997, p. 345):

$$E_c = \frac{V_c}{r\ln\left(\frac{2h}{r}\right)} \quad (2)$$

Figure 1 shows the dependence of corona onset on wire radius (experimental results and analytical formulae).

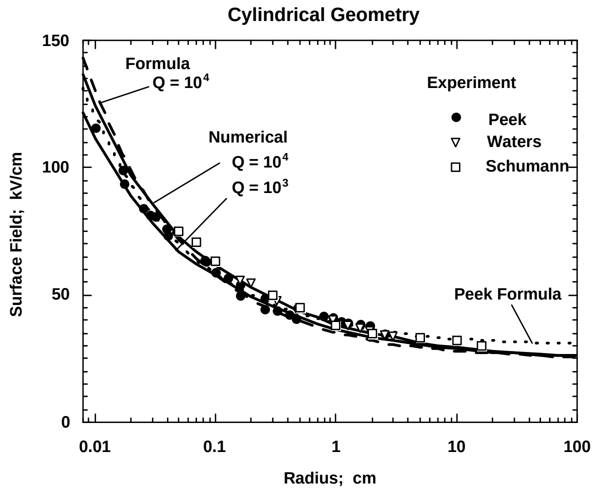

Figure 1: Experimental data points for corona onset from wires as a function of wire radius. Curves show theoretical predictions obtained numerically, predictions from Peek's formula (Eqn. 1), and predictions from the Peek-like formula (for Q = 10^4) obtained by Lowke & D'Alessandro (2003) from the general breakdown criterion in gases.

Although the phenomenon of corona discharge was discovered by Benjamin Franklin and his associates around the mid-1700's, no quantitative information was available for well over a century. Then, Warburg (1899) found a quadratic relation between the voltage he applied to sharpened electrodes in his laboratory and the currents that flowed into the air surrounding the electrode. Later studies by Whipple & Scrase (1936) and Large & Pierce (1956) confirmed the quadratic relationship for the corona current I_c as a function of the applied voltage. In general:

$$I_c = \alpha V \left(V - V_c\right) \tag{3}$$

where I_c is the corona current in μA, α is a constant and V, V_c correspond to the applied voltage producing the current I_c and the corona onset potential respectively. The constant α has some dependence on the polarity of the corona current.

This relationship must be modified in the presence of wind. By experimentation, Large & Pierce (1956) found that corona current is not dependent on wind speed for magnitudes less than about 2 m/s. For higher wind speeds, they found a quasi-linear dependence,

$$I_c = \alpha \left(V - V_c\right) \sqrt{\left(W^2 + \beta^2 V^2\right)} \tag{4}$$

where α, β and V_c are constants and W is the wind speed in m/s.

These findings were recently confirmed in an analysis carried out by D'Alessandro (2009) on corona discharge measurements under atmospheric thunderstorm conditions. Overall, as a rule of thumb, for a change from 0 to 10 m/s in the wind speed under the same conditions of potential or electric field, an increase of up to 50% may be seen in the magnitude of the corona discharge from an electrode.

Two important points summarise the most salient aspects of corona discharges once onset has occurred, namely:

- The magnitude of the corona current is proportional to V^2, and
- Corona current has a quasi-linear dependence on wind speed.

4. Summary of findings regarding the ATLANT System

In a previous study of the performance of the ATLANT system as an ion generator[1], the following conclusions were arrived at:

- For a wire energised with a given voltage, the field at its surface depends strongly on its radius and also has some dependence on its height above the ground. The closer the wire is to the ground, the greater the wire surface field.
- The corona onset field for wires of diameter 0.2 mm, as typically used in the ATLANT system, is approximately 12 MV/m.
- *Microscopic* electric field values were computed close to the wires in various parts of the ATLANT system. These values are of direct relevance to corona onset calculations for the ATLANT system. For a system base height of 4 m and an energising potential of 100 kV, the microscopic fields ranged from about 1 MV/m to almost 100 MV/m.
- The lower values of the microscopic field calculations were obtained for the central wires in the ATLANT pyramids, whilst the higher values were found to be near the lowest wire (particularly) and the highest wire on the pyramid. Furthermore, the fields were higher for the lower pyramids than the upper pyramids in the ATLANT system.
- *Macroscopic* field values were computed around various parts of the ATLANT system (at approx. 30 cm distance). For a system base height of 4 m and for an applied potential of 100 kV, the macroscopic fields ranged from 0.5 kV/m to 30 kV/m.
- The macroscopic field values are of direct relevance to ion movement and ion mobility calculations for the ATLANT system. Figure 2 shows the expected direction of movement of negative ions generated by the ATLANT under a DC voltage of (-)100 kV. Approximately one half of the ions may go directly to the ground close to the ATLANT, whilst the other half is available to be swept upwards by convective updrafts.

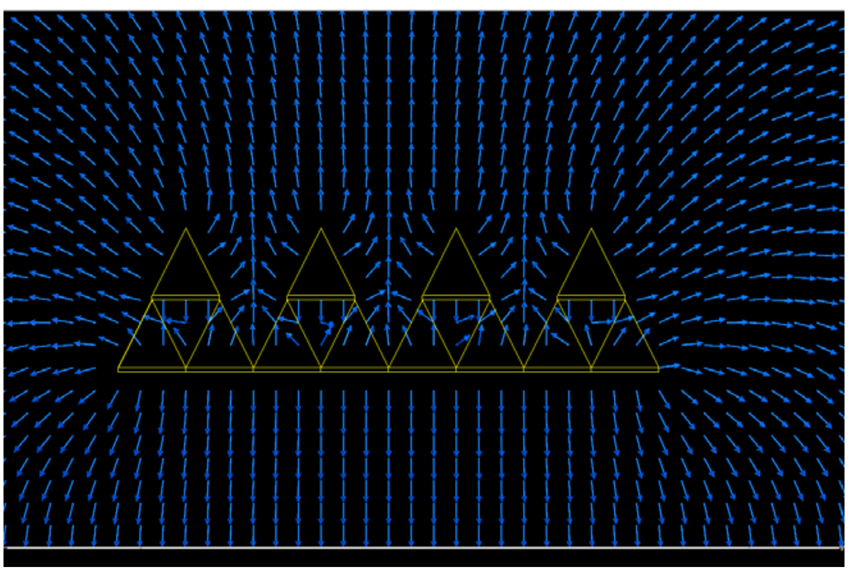

Figure 2: An "E-vector" plot from a 3D electrostatic model of the ATLANT system under operating conditions. The arrows show the direction in which negative ions would move (assuming no wind) after being generated via the wires undergoing corona discharge.

[1] *Report 1 – "Functional description of the existing ATLANT system", March 27, 2009.*

Some important additional statements and calculation results regarding the ATLANT include:

A. It is operated with a DC voltage, hence it is surrounded only by an electrostatic field. No low frequency electromagnetic radiation is produced.

B. The electrostatic field immediately surrounding the ATLANT is a maximum of a few ten's of kV/m. The electric field due to the ATLANT that would be present outside the fence perimeter is negligibly small, e.g., -10 V/m. By comparison, the Earth's fair weather field is typically in the range -100 to -300 V/m (McGorman & Rust 1998).

C. The ratio of wire diameter to the electrode gap (essentially the distance from the wire pyramids to the ground, say, 4 m) is very large, i.e., ~ 20,000. Hence, from Section 3, where it was stated that d/r > 5.85 to assure corona and not a spark discharge (Raizer 1997), it can be seen that the ATLANT will not, under normal operating conditions, produce any sparks. It operates very much in the corona space charge regime.

D. If it is assumed the ATLANT behaves like a long wire 4 m above the ground (this would be the scenario for *maximum* ion production, which will not occur due to shielding effects as noted in a previous quantitative study[1]) and energised at 100 kV, then from Eqn. (2), the wire surface field would be ~ 48 MV/m. This is about 4 times higher than the estimated corona onset field, which means that approximately 16 times the onset current would flow. Hence, each wire would produce a maximum of about 16 μA of corona current.

E. During the "quasi-static" phase of a thunderstorm (before the lightning bolt descends), ambient electric fields of 5 – 25 kV/m are common (Uman 1987). Under this ambient field, many sharp or pointed ground objects will produce a corona discharge of similar magnitudes (a few to ten's of μA). In other words, the ATLANT produces a similar level of corona current as natural point discharge processes during the "quiet phases" of a thunderstorm. Furthermore, in an ambient field of, say, 10 kV/m, an object 5 metres in height is at an "induced potential" of 50 kV, i.e., of the same order of magnitude as the ATLANT operating voltage. In other words, the corona discharge from the ATLANT system is not dissimilar to the common atmospheric phenomenon of a thunderstorm.

F. The HVDC generator driving the ATLANT system has a maximum loading of 15 mA. If the ATLANT is energised with the full potential of 85 kV and draws the maximum current of 15 mA, then the maximum power output is 1275 W. This corresponds to a corona power loss or dissipation of about 0.18 W per km of wire in the ATLANT system.

5. Comparison with HV Power Transmission Lines

It is worth comparing the above features of the ATLANT system with the operating conditions of high voltage power transmission lines (HVPTL's), which are also known to be a source of corona discharges. The topic of corona losses from HVPTL's is not a trivial one, so some conservative assumptions will be made in order to generate a simple comparison with the ATLANT system.

In Australia, HVPTL's generally operate at voltages of 110 kV to 500 kV. Most are HVAC lines, so a direct comparison with the DC-operated ATLANT system is not possible. However, some estimates can be made based on published differences between HVAC and HVDC lines. For the purpose of the calculations, it will be assumed the average operating voltage is 300 kV, the height above ground is about 30 m, and the conductor diameter is 6 mm.

Broadly speaking, it is possible to use Eqns. (1) and (2) to determine the corona onset voltage for a HVPTL, although Eqn. (3) or (4) along with the relevant constant α are needed to obtain the absolute corona current. For HVPTL's, it is necessary to define a "roughness" or "stranding" factor, m, which can have a significant effect on corona discharge and corona losses. For conductor surfaces that are stranded, have protrusions, water drops etc., the roughness factor $m < 1$ must be introduced into Eqn. (1), so that:

$$E_c = 30\, m\, \delta \left[1 + \frac{0.3}{(\delta r)^{1/2}} \right], \qquad (5)$$

On cylindrical transmission line conductors, the presence of water drops could result in values of m in the range 0.3 – 0.6, whilst a thick, uneven layer of soil may reduce m to 0.2 or lower (Maruvada 2000). More typically, a value of about 0.8 is used for rough conductors exposed to atmospheric severities or for local corona on stranded conductors.

Hence, for the conditions assumed above, at normal temperatures and pressures, it is found that $E_c \approx 46$ kV/cm and $V_c \approx 137$ kV for the "generic" transmission line. For the ATLANT system, the corresponding values are $E_c \approx 120$ kV/cm and $V_c \approx 13.5$ kV.

In terms of the absolute corona current for each system, the constant α, which will depend on the wire radius, must be determined. This is typically done via experimentation. However, D'Alessandro & Berger (1999) and Moore et al (2000*a*) have shown, experimentally and theoretically, that α is proportional to the square of the electric field enhancement factor, K_i, at the surface of the conductor. Numerical simulations, using the techniques described in D'Alessandro (2003), show that $K_i \propto (h/r)$. This enables the ratio of corona currents for the two systems to be computed. Hence, the ratio R for the HVPTL to the ATLANT is given by

$$R = \frac{\left(\frac{h_H}{r_H}\right) V_H \left(V_H - V_{Hc}\right)}{\left(\frac{h_A}{r_A}\right) V_A \left(V_A - V_{Ac}\right)} \qquad (6)$$

For an operating voltage of 300 kV for the HVPTL and a typical voltage of 65 kV for the ATLANT, R = 3.65. Hence, under the stated conditions, the ATLANT does not have more environmental impact (in terms of corona ions) than a typical power transmission line.

Finally, it is also instructive to compare the corona power loss of a HVPTL with the value computed for the ATLANT, viz. 0.18 W per km of wire (remembering that this length of wire is wound over a footprint of about 12 x 5 m). Such a calculation is not trivial but some simplified relations can provide rough approximations. Corona power loss in HVPTL's differs for AC lines, monopolar lines and bipolar lines. For AC lines,

$$P_c = \frac{3.73K}{\left(\frac{D}{r}\right)^2} f\, V^2 \times 10^{-5} \text{ kW/conductor/km} \qquad (7)$$

where f is the frequency, V is the line voltage, D is the phase conductor separation and K is a factor that depends on the ratio V/V_c (Khalifa 1990).

For the conditions described above, and taking D = 6 m and K = 80 for $V/V_c = 2.2$, the corona power loss is $P_c = 3.4$ W/conductor/km. However, the most appropriate comparison with the ATLANT is a unipolar DC line. Due to the space charge formed around the conductors, a unipolar DC line may have about half the loss per unit length of an AC line carrying the same amount of power (Khalifa 1990).

Therefore, the corona power loss of a unipolar DC line is estimated to be roughly 1.7 W/conductor/km under normal operating conditions. This is about 10 times the loss or dissipation computed for an ATLANT system. Again, the impact of the ATLANT is less.

6. Impact Studies

Building upon the analysis carried out earlier in this report, this section will present the most important findings of an impact study on humans, fauna and flora, communications and air traffic. The impact study results to be described are based entirely upon calculations and a literature survey, i.e., no experimental work has been carried out.

Before discussing the impacts related to ion generation, a brief comment should be made about the fact that the ATLANT operates at a high voltage, around 60 – 85 kV. As long as each ATLANT site is fenced off and all relevant standards are followed, e.g., appropriate power earthing, the ATLANT poses no threat to people outside the security fence. The same applies to on-site personnel as long as they maintain an appropriate air clearance distance from the energised wires. Similarly, the ATLANT poses no threat to birds that may land on the wires. Since all the wires are at the same potential and the nearest low-potential point is the ground at a distance of 3-4 m, birds are not harmed by the high voltage.

Even though the ATLANT is a new, unique technology, it uses the well-established principles of corona discharges to operate as a negative ion generation device. Hence, it is entirely reasonable that its impact is assessed by comparison with a known, documented and well-studied system, namely high voltage power transmission lines. Importantly, in Section 5, it was demonstrated that the degree and intensity of ionisation produced by a single ATLANT system is less than that of a typical HVPTL. So, depending upon the findings of the literature search, some deductions can be made about the impact of the ATLANT system.

Since it has been established that the ATLANT cannot produce low frequency electromagnetic radiation, this section will focus purely on the effects of DC corona discharges (an electrostatic field effect). These effects can be summarised as follows:

- Direct impact of charged particles / ions, e.g., inhalation of charged pollutants;
- Possible indirect effects via increased ozone levels; and
- Corona noise (electrical noise, not audible noise).

Note that a detailed study of the biological and medical issues associated with the inhalation of ions or how elevated ozone levels may affect humans is outside the scope of this study. However, published results will be considered.

Before presenting the impact studies, it is worthwhile analysing the importance or relevance of ozone production via corona discharges.

Ozone (O_3) is generated and used every day as a powerful cleaning product and has many other applications in various industries, e.g., residential and leisure (control of indoor odours, air pollution, cigarette smoke, mould, insects and vermin), hospitality, food processing and storage, workplaces, farming (dairying, aquaculture, hydroponics etc.), horticulture, water and waste water processing etc. Commercially-available ozone generators use corona discharges (more commonly) or ultraviolet radiation to produce the ozone. Larger versions of these generators for use indoors can produce as much as 7 kg of ozone per hour. Ozone is also produced by common equipment such as photocopiers and laser printers.

Not a great deal of quantitative information is available in the literature with regard to the amount of ozone produced in an atmospheric corona discharge of a given current magnitude. According to Yehia et al (2000), after allowance for ozone destruction, a linear relationship exists between the ozone generation rate and the corona discharge power. Hence, it is worthwhile comparing the discharge power of the ATLANT with that of an off-the-shelf ozone generator. The maximum discharge power of the ATLANT is $P_A = V.I = 85000 \times 0.015$ or 1275 W. The ATLANT is not operated at this limit (in fact, the HVDC generator would cut out). A more typical power rating would be 1 mA at 70 kV, or 70 W. An online search for the power rating of commercially available ozone generators shows that domestic units are typically rated at 10-20 W and commercial units are rated at 4 – 40 kW.

Therefore, the ATLANT's power rating and hence ozone generation rate is equivalent to a few small domestic units. Domestic units are widely available, well-accepted and used for air purification inside homes. Knowing this and the fact that the ATLANT is operated outdoors, its ozone generation rate can be considered totally harmless to humans. Furthermore, since ozone is a powerful oxidizing agent, it is unstable at high concentrations, where it decays to ordinary diatomic oxygen. The decay time of ozone in air is only about 30-60 minutes (Baba et al 2002).

Based on the above information, the effect of corona-based ozone generation on humans will not be considered further.

(a) Humans

Natural ions already exist in the air we breathe, e.g., produced by natural radioactivity, cosmic rays, waterfalls and wind action. The effect of corona ions on humans has been the subject of much debate over many decades. Commercial "air purification" units are available which claim beneficial effects through the generation and release of negative ions into the air. The beneficial effects of elevated negative air ion levels on humans that have been reported include an enhanced feeling of relaxation and reduced tiredness, stress levels, irritability, depression and tenseness (Buckalew & Rizzuto 1984). Conversely, it has been claimed that an excess of positive ions can have the opposite effect.

Man-made devices in use every day rely on ion production via corona discharge processes, e.g., electrostatic precipitators, photocopying machines and laser printers. To date, there has been no conclusive study that showed these everyday devices cause any problems to human health.

On the other hand, a large amount of research, particularly in the UK, has been carried out on a possible connection between ions carried away from coronating HVPTL's and an increased incidence of childhood leukaemia downwind of the HVTPL. Some of the key papers published in the international peer-reviewed literature on this topic include Fews et al (1999), NRPB (2004), Draper et al (2005), Sidaway (2008) and references therein.

The case-control study by Draper et al (2005) investigated the association between distance of birth address from HV power lines and incidence of childhood leukaemia. It was found that there was a statistically significant 1.23-fold increase of risk for children born within 600 m from HV lines. An increase in risk beyond 200 m is beyond the range of the direct 50 Hz magnetic or electric fields. After Fews et al (1999) proposed a mechanism whereby HV power lines could increase human exposure to airborne carcinogens by increasing their charge state and Knox (2005) found an increase in the risk of childhood cancers, including leukaemia, near sites of air-borne pollutants, Draper et al (2005) suggested an alternative mechanism to low-frequency electromagnetic fields for adverse health effects, viz. airborne corona ions produced by high-voltage power lines and their interaction with existing airborne pollutants.

On the contrary, a study by Swanson & Jeffers (1999) examined eight mechanisms (based on sound theoretical and experimental studies) involving HVPTL's and airborne particles. They could find no evidence for an association between HVPTL's and human health, stating that the effects are (i) very small, (ii) swamped by air currents and gravity, and (iii) are negligible because people spend such a limited time under these conditions.

The Netherlands Health Council, in their review of health effects of electromagnetic fields in 2001, also discussed the "corona ion hypothesis". The Dutch Council considered it "extremely unlikely that through this pathway the risk of cancer or other diseases might increase". The National Radiological Protection Board (NRPB 2004), now called the Health Protection Agency (HPA), carried out an extensive review of the topic and concluded:

"The potential impact of corona ions on health will depend on the extent to which they increase the dose of relevant pollutants to target tissues in the body .... it seems unlikely that corona ions would have more than a small effect on the long-term health risks associated with particulate air pollutants, even in the individuals who are most affected. In public health terms, the proportionate impact will be even lower because only a small fraction of the general population live or work close to sources of corona ions."

The research by Draper et al (2005) has been received in some quarters as not being complete and has been criticised for being published before any mechanisms were established. Hepworth (2005) states that "...the findings are inconsistent with another UK study, in which neither proximity nor estimates of dose to extremely low frequency magnetic fields from power lines showed any relation with childhood leukaemia". Furthermore, Jeffers (2007) recently published a technical note claiming "modelling and analyses do not support the hypothesis that charging by power-line corona increases lung deposition of airborne particles".

In Australia, the Energy Networks Association (ENA 2007) has also reviewed all of the publications and evidence presented. They have concluded:

"The 'corona ion' hypothesis by Prof. Denis Henshaw from Bristol University in the UK is based on recent work proposing a theoretical mechanism for the effect of electric fields emitting corona ions, against an extensive background of past research into magnetic field effects on health. Henshaw's theoretical mechanisms are not supported by epidemiological studies on real populations, and the NRPB do not think this type of study is worthwhile since risk magnitudes would be far too small to be demonstrable in even the largest epidemiological studies. Scientific studies since the 2004 NRPB review have been unable to produce evidence to confirm the health effects of the Henshaw 'corona ion' theory".

(b) Fauna and Flora

Studies of the effect of ions on biological systems have been carried out for several decades. In general, the studies reveal a positive effect. For example, Kreuger & Reed (1976) exposed mice to influenza virus and observed the rate of death for animals living in normal and ion-treated environments. Increased death rates were observed for ion depleted and positive ion enhanced environments. The death rate decreased for high unipolar concentrations of negative ions. Similar results were found in experiments with exposure to a fungal pathogen and a second bacterial type. The life span of mice in an ion depleted atmosphere was reported to be shortened.

During the 1960's and 1970's, some authors described behavioral changes of laboratory animals under the effect of air ions. However, subsequent investigations could not confirm such observations. Even a 100-fold increase in the concentration of positive and negative ions did not show any effect on the spontaneous motor activity of laboratory mice (Kroling 1985).

Negative ions have been reported to inhibit bacterial growth and spore germination. Kreuger & Reed (1976) also reported that a lack of atmospheric ions affected plant growth. Growth, measured by elongation and fresh and dry weights was reduced. Leaves were soft and lacked normal turgor.

More recently, Sidaway (2008) has researched all of the available literature in an attempt to map future research into the impacts of electricity utilization and air ionisation. He quotes a recent study concerned with the electromagnetic influences on corn and wheat crop yield near a 380-kV transmission line. The study disregarded possible air ionization responses whereas, in fact, in 1926 a system specifically designed to produce high levels of ionization by corona discharge from low-radius-of-curvature overhead wires was used. A 28% increase in grain yield of corn was obtained.

Sidaway (2008) also summarises laboratory, glasshouse and semi-commercial studies of corona discharge air ionization influences on plant growth, including flowering, carried out during the 1970's and 1980's. Unpublished observations were recorded by the UK Electro-Culture Committee, including a 118% increase in grain yield of barley after electrical treatment for one month, reductions in cereal leaf senescence and in cereal root dry weight, increased plant height but reduced development of lateral shoots, earlier flowering and ripening, and a stronger influence on reproductive growth than on vegetative growth were all reported.

Finally, there is very little information in the literature regarding the effect of corona-generated ozone on fauna and flora. Goheen et al (2004) investigated whether ozone production by corona near laboratory animals could reach levels of concern. Male rats were exposed to a corona discharge and the concentration of ozone produced was measured. The resulting concentration of ozone ranged from ambient levels to 250 ppb when animals were located 1 cm from the 10 kV source. However, such a small scale experimental set-up so close to the ozone source is not a realistic comparison with the scale, location or conditions under which the ATLANT is operated. In any case, as shown at the beginning of this section, the ozone generation rate of the ATLANT can be considered harmless as it is comparable to domestic ozone generators.

(c) Communications

"Corona noise" may potentially cause "radio frequency interference" (RFI), which includes interference with radio, television and other wireless reception. In general, it is not a problem – it is confined to lower frequencies and does not propagate very far from the source because it is a low-current or low-power phenomenon. The main source of corona radio noise is from *positive corona streamers* because their amplitudes are much higher than those of the "Trichel pulses" that comprise negative corona (Khalifa 1990, Ryan 2001). Since corona pulses are random in amplitude, duration and repetition rate, the noise spectrum is quite broad but the noise level decreases rapidly at higher frequencies and is quite small by the time the FM broadcast band is reached (> 80 MHz).

The most significant factor with respect to corona discharges and RFI is not the level of the corona noise, but how it compares with the strength of the broadcast signal. Very few problems have arisen with existing HVPTL's during wet weather (which is when power lines coronate the most). This is because most communications have adequate signal-to-noise ratios that ensure such interference is usually not a problem.

With reference to measurements of corona noise beneath bipolar HVDC lines, Khalifa (1990) states that "the highest level was recorded under the positive conductor while the noise contributed by the negative conductor was rather insignificant". Since the ATLANT is operated with a negative DC voltage, this information indicates that the ATLANT is unlikely to produce corona noise interference at a problematic level.

The other aspect about corona noise is that it is strongly attenuated within a short distance from the source. For power lines undergoing corona discharges, the "affected environment" is along the entire length of the transmission line but for a *narrow width* (Al-Bahrani & Malik 1990). An obvious question is – what is the width or distance required for substantial reduction in the noise? Olsen et al (1992) and Nayak & Thomas (2002) show that at a distance of 40 m from a HVPTL, the corona noise level decreases by a factor of about 1000.

(d) Air Traffic

The same logic used in Section 6(c) above can be applied here for air traffic. Air traffic control (ATC) communication frequencies are found between 118 and 136 MHz, where corona noise is more or less negligible. Hence, the ATLANT should cause no interference with ATC communications.

If the ATLANT is beneath the flight path of aircraft, another issue might be the effect of the aircraft flying through the ion plume or the charged droplets that are formed as the basis of the weather-modification principles of the ATLANT. The fact is that operational aircraft are charged from "normal" rain drops and ice crystals (this is called "precipitation charging"). Aircraft are designed to dissipate this charge in a safe manner via "static dischargers" on the wings and tail.

Finally, the fact that aircraft can take a lightning strike while flying, a process that involves huge amounts of charge transfer in comparison to the effect above, is an indication that the negative ions generated by the ATLANT system and carried into the atmosphere will not be a problem.

7. Summary

This report has considered the impact of the normal operation of Australian Rain's ATLANT technology, which is a negative corona ion generator designed to enhance rainfall in a given region. The report has reviewed the main physical and operating features of the ATLANT and the principles of corona discharges. The main features and parameters of the ATLANT system as an ion generation source were also quantified and then compared with the corona characteristics of high voltage power transmission lines (HVPTL's). The results of an impact analysis on humans, fauna, flora, communications and air traffic were then presented, based on extensive literature research and calculations.

Some of the key results from the calculations on the ATLANT system include:

- The ATLANT is operated with a DC voltage and so it is surrounded only by an electrostatic field. No low frequency electromagnetic radiation is produced. In its normal operating mode, it only produces negative DC corona, there is no sparking or arcing.
- The electrostatic field due to the ATLANT that would be present outside the fence perimeter is negligible (smaller than the Earth's fair weather electric field).
- It is estimated that each wire in the ATLANT produces a maximum of about 16 μA of corona current, a level that is not dissimilar to the point discharge currents that would be measured from pointed ground objects during the static phase of a thunderstorm.
- The maximum power dissipation of the ATLANT is 1275 W. This corresponds to a corona power loss or dissipation of about 0.18 W per km of wire in the ATLANT system. However, in its normal operating mode, the power level would be around 70 W and so the corona power loss is about 10 mW per km of wire.

Some of the key results from comparison calculations carried out for HVPTL's include:

- Under certain conditions, it was shown that ATLANT produces no more corona current than a HVPTL.
- The corona power loss of a unipolar DC HVPTL line was estimated to be roughly 1.7 W/conductor/km under normal operating conditions. This is about 10 times the loss or dissipation computed for an ATLANT system.

The environmental impact of the ATLANT was then reviewed in terms of three possible effects, namely:

- Direct impact of charged particles / ions, e.g., inhalation of charged pollutants via the "corona ion hypothesis" for HVPTL's;
- Possible indirect effects via increased ozone levels; and
- Corona noise (electrical noise, RFI).

A major review of the literature showed that the "corona ion hypothesis" is a theoretically-proposed mechanism for the effect of electric fields emitting corona ions against an extensive background of past research into magnetic field effects of HVPTL's on health. The mechanism is not supported by epidemiological studies on real populations and various government bodies consider the risk magnitudes to be indemonstrable in even the largest epidemiological studies. Furthermore, scientific studies since 2004 have been unable to produce evidence to confirm any health effects on humans of the proposed corona ion mechanism.

Since it has been demonstrated that the ATLANT has *less* impact than a HVPTL and the latter are considered to have no health effects even though they pass through heavily populated areas, the proximity of humans and local fauna to the ATLANT system is not considered to be a health issue. With regard to local flora, an analysis of the effects of corona discharges revealed that negative ions do not have a detrimental effect (in fact, they may be beneficial), so local flora should be unaffected by the operation of the ATLANT system.

It was shown that the ATLANT's power rating and hence ozone production rate is equivalent to a few domestic ozone generation units. Since the domestic units are widely available, well-accepted, used for air purification inside homes, and the ATLANT is operated outdoors, its ozone generation rate was considered to be harmless to humans and other living organisms.

Finally, “corona noise” interference with communications and air traffic control was studied. It was shown that the negative DC corona produced by the ATLANT system produces very little electrical noise and interference with communications is negligible at distances of a few ten’s of metres from the source. Also, it was found that corona noise at the higher frequencies reserved for air traffic control is even lower than in the lower-frequency range.

8. Conclusions

Based on the calculations, extensive literature research and current state of knowledge in this field as presented in this report, it can be concluded that the normal outdoor operation of the ATLANT system will have a negligible impact on:

- People located in the surrounding areas outside the perimeter security fence,
- Local fauna and flora,
- Communication systems, and
- Air traffic.

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