FIRE AND HVDC LINES

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Abstract: The South African power utility, Eskom, is investigating the use of High Voltage Direct Current technology in evacuating power from the northern area of the country to mid and southern regions. The proposed scheme is to operate at either ± 600 kV or ± 800 kV voltage levels. Bush fires are common in the existing and proposed transmission line routes and the electrical effect that this may have on the HVDC scheme needs to be understood. Two aspects are considered as part of this paper. Firstly, the possibility of the line itself to cause ignition of ground vegetation was investigated. Results from this work show that the electric field gradients and induced current magnitude that would be required to cause ignition of vegetation is not experienced at the ground level except during transient and temporary overvoltages, mechanical failure of the tower, hardware and or insulator. In the second aspect, experiments were conducted to investigate the effect of the deposition of plant related hydrocarbon pollution from fires on corona inception and radiated radio interference voltage. It is shown that fires under the line definitely increase the radio interference levels and reduce the corona inception voltage.

1 INTRODUCTION

As part of Eskom's expansion program, new generation capacity is to be added near the large coal reserves in the northern regions of South Africa. In order to evacuate the power to the central and southern areas, a number of transmission scenarios have been proposed and are currently being evaluated. Within these scenarios, High Voltage Direct Current (HVDC) is one of the technology options for bulk power transfer over the large distances required, between 600 and 1200 km.

As part of the technology assessment, the influence of the line on the surrounding environment as well as the expected performance of the line needs to be evaluated. The proposed HVDC transmission lines are to operate at either ± 600 kV or ± 800 kV voltage levels. Major portions of proposed line routes cover terrain consisting mostly of bush type vegetation. Bush fires are a common occurrence in Southern Africa. At present, South Africa has one ± 533 kV HVDC line which is known to flashover as a result of fires under the line [1].

The first part of this paper investigated the possibility of the HVDC line initiating a fire. Transmission lines are susceptible to fire related line faults. Although servitude clearing programs are intended to pre-emptively remove fuel sources of fire, in a controlled environment, there may be concerns that the HVDC line itself may start a fire which in turn may lead to a line fault or other loss. The second aspect is the influence of the air borne pollutants from bush fires on corona inception and radio interference (RI) generation from the transmission lines. The output of this work is intended to complement existing information used in Eskom's vegetation management policies and environmental management plans.

2 AN INVESTIGATION INTO THE POSSIBILITY OF THE LINE TO IGNITE VEGETATION

An issue particular to HVDC lines is the impact of corona on the ionisation of air and the mobilisation of ions and charged aerosols to the area below (and in the local vicinity of) the line (i.e. the ground plane). This research has been conducted in order to determine the extent of the possibility of a line to ignite vegetation - possibly due to an enhancement of the electric field by the presence of space charge in the vicinity of the transmission line. Other effects such as lightning induced flash overs and sparking were not considered in this study.

2.1 Hypothesis

It is proposed that the following mechanism may result in an ignition of vegetation:

- A HVDC transmission line may generate excessive corona due to damaged hardware, conductor and insulator fittings,
- The corona may lead to the development of space charge in the vicinity of the line,
- The space charge may cause an enhancement of the electric field close to the ground,

- A higher electric field close to the ground plane may cause further corona on the tips of plants (or induce a current in it),
- The constant flow of current through a plant may cause it to heat-up and ignite.

When the direct current (DC) line conductor is energised, it becomes charged due to the capacitance between the conductor and the ground. The magnitude of the charge is dependent on the charge per length distributed throughout the line. The resulting electric field at all points in space is due to the charge on the conductor's surface (surface gradient), the presence of corona sources and the induced charge on the ground plane [2].

Any corona sources will result in the generation of negative and positive ions. Ions having the same polarity as the line (polarity) are repelled, drift away and are neutralised on contact with the ground plane. Corona on a positive polarity line results in a constant stream of positive ions moving away from the conductor. A negative polarity line results in a constant stream of positive ions moving towards the conductor. The steady flow of ions affects the electric field in the vicinity of the line and causes an ionic current to flow with respect to the ground plane.

Electrically, the organic matter of a tree represents a resistance to ground. The induced ionic current flowing through a tree will develop a potential difference across it. The energy dissipated in the tree (i^2R heating), over a period of time may cause the tree to heat up to a point where it burns.

Alternatively, the presence of space charge may alter the intensity of the electric field closer to the ground. The higher electric field may cause corona on the tips of the plants. The sustained corona activity over a period of time may cause the vegetation to dry out and ignite.

This ionic current and modified electric field may thus have an effect on vegetation growing within the servitude, however, no studies on this phenomenon have been published for HVDC transmission lines.

2.2 Test Program

In order to determine the extent of the problem a test program was proposed. The test program took into consideration:

- Fast growing species of plants that may grow in the existing and proposed HVDC servitudes,
- The practical voltage gradients that may be experienced under the line,
- The height of trees under lines,
- The amount of energy required to start a grass/bush fire.

2.3 Test Setup

Figure 1 is a schematic representation of the test setup. A portable ±250 kV HVDC test generator was used to energise a copper conductor. A plant was installed on a base plate holder (insulated from ground) and inserted below the conductor. The plant was grounded via an ammeter.

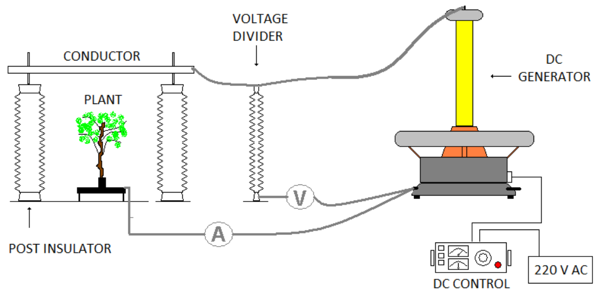

Figure 1: Schematic representation of the test setup.

The plant height was kept constant and the conductor was raised in order to alter the distance between the top of the plant and the conductor. This represented different ratios between the height of the plant above ground and the distance between the plant and the conductor and thus different electric field enhancements.

2.4 Test Methodology

The following variables were considered:

- The size of the gap between the top of the plant and conductor: 30, 42, 56, 63 and 74 cm,
- The ratio of the height of tree to the gap size (2 gap sizes were compared i.e. 30 cm and 42 cm),
- Resistivity of the plant.

The following comparisons were done:

- For the shortest gap, the magnitude of current that flows in each tree with respect to different voltages applied on conductor,
- Magnitude of the current required to start combustion, and
- As the gap increases, the decrease in the magnitude of induced current.

Both positive and negative polarity were tested to determine the worst case scenario.

2.5 Selection of plant species

The plants selected, shown in Figure 2, were Bamboo (Poaceae), Black Karee (Rhus lancea), Blue Gum (Eucalyptus), Reeds (Phragmites australis), and Wattle (Acacia). The research also considered the possibility of setting alight a bush of 1 m tall dry grass.

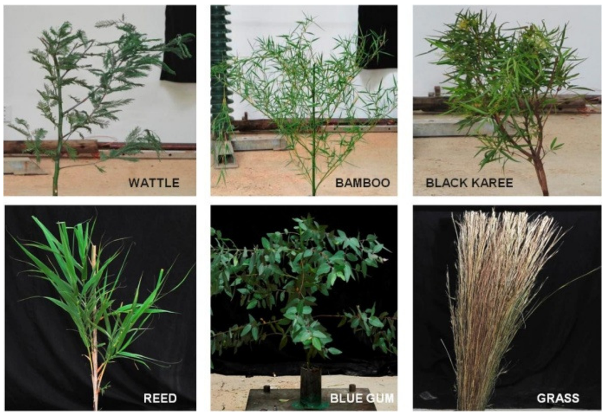

Figure 2: Plant species investigated.

3 RESULTS

3.1 Magnitude of current induced in plants

Figure 3 shows a plot of the induced current for the different voltages levels that were tested. The largest current measured was in the shortest gap between the conductor and the plant (i.e. 30 cm), representing the worst case condition tested. The largest current was measured through the Bamboo plant. The current induced in the plants were in the order of microamperes.

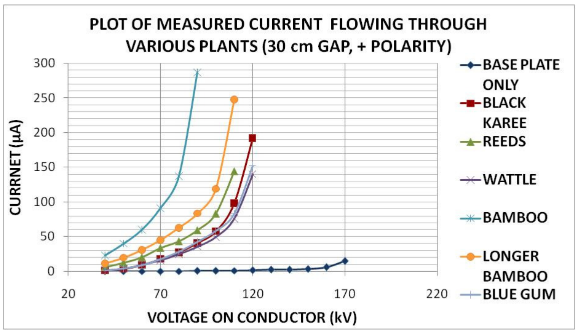

Figure 3: Plot of the induced current for the different voltages and plant species.

The same technique was used to determine the induced current in a bush of dry grass. Figure 4 lists the spread over several measurements.

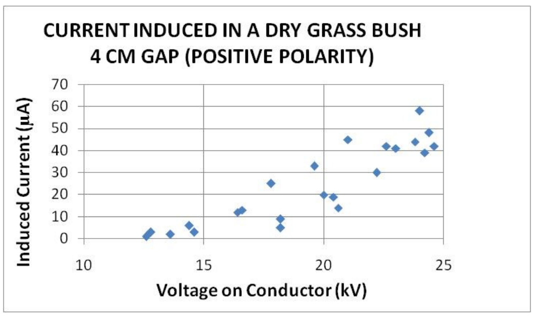

Figure 4: Induced current in a bush of dry grass.

3.2 Effect of the length of the plant on magnitude of induced current

It was assumed that the resistance of the plants would increase as the length increased. In order to investigate the impact of this on the experiment, both long and short plants were tested. Due to practical considerations 4 m and 1 m Bamboo plants were only considered. Result are shown in Figure 5.

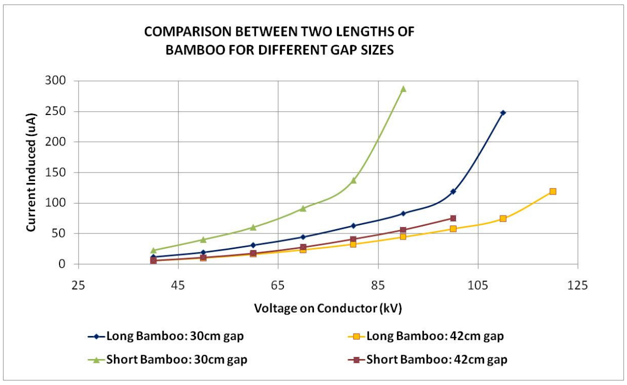

Figure 5: Induced current in 4 m and 1 m bamboo stalks.

For the same gap size, the short bamboo plant resulted in a higher induced current. The effect is more pronounced for the short gap lengths. As the gap was increased, the length of the tree does not have an impact on the magnitude of the induced current.

3.3 Effect of the line polarity on the magnitude of induced current

The physical phenomena are different for the generation of corona and space charge under positive and negative polarity [2,3]. This is due to the electron mobility and the development of positive and negative streamer activity. The effect that this would have on the induction of current in plants was tested. Figure 6 illustrates the influence polarity has on the induced current measured.

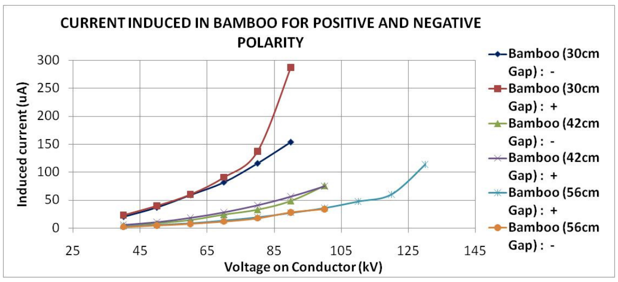

Figure 6: Influence of polarity on the magnitude of induced current.

It can be seen that the magnitude of current is dominated by the gap size. The smaller the gap, the larger is the induced current. The 30 cm gap closely resembled a point to plane configuration - a largely non-uniform electric field. It is observed that as the voltage on the conductor increased, the positive polarity case resulted in a higher induced current. This can be attributed to the electron mobility and the criteria for streamer generation being met [2,3]. It is expected that the same trend will hold true for the other cases as well. Measurement in other cases was limited as flashover of the gap occurred.

Positive polarity resulted in the highest current being induced and therefore represented a worst case scenario. As such it was decided that further tests will be conducted under positive polarity only.

3.4 Energy required for combustion of Bamboo and Grass

The energy required to cause combustion of the plant was investigated. The previous test setup resulted in microamperes of induced current. This magnitude of current was insufficient to cause ignition.

The test setup was modified in order to drive a higher current through the plant such that combustion occurred. The bamboo was tied together in order to take into account the collective resistance of the branches. A cable connected the bunched plant to the energised conductor. A constant current was supplied so as to measure the energy being supplied. The temperature of the plant stalk was measured periodically at its top, middle and bottom sections. Through experimentation it was identified that 20 mA (RMS) of current over a period of 40 minutes was sufficient to cause burning of the bamboo. Figure 7 illustrates the temperature rise with a constant 20 mA flowing.

Severe charring and tracking across the Bamboo stalk was observed. Small glowing flames and dense smoke were visible during the tests.

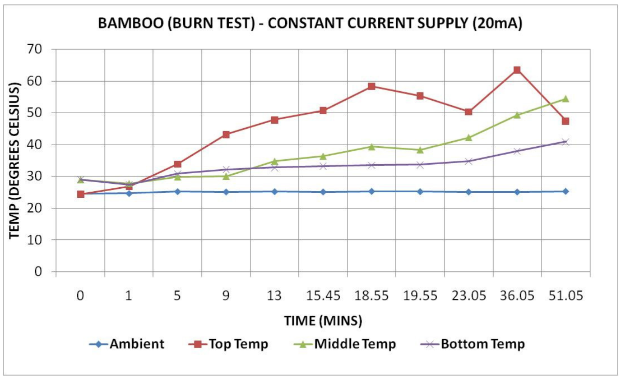

Figure 7: Temperature rise of bamboo plant with a constant AC current of 20mA.

The largest temperature difference was noted at the top of the plant, where the electrical connection was made. It may be noted that the current caused a period of "drying-out" of the plant. This increased resistance could have caused a lower current to flow, thereby resulting in a slight decrease in the temperature, after about 18 minutes.

A similar setup was used for the grass bush test. Through experimentation, it was observed that 10 mA over a 45 minute period was sufficient to ignite the grass. Figure 8 illustrates the temperature rise of the grass bush with a constant current of 20 mA.

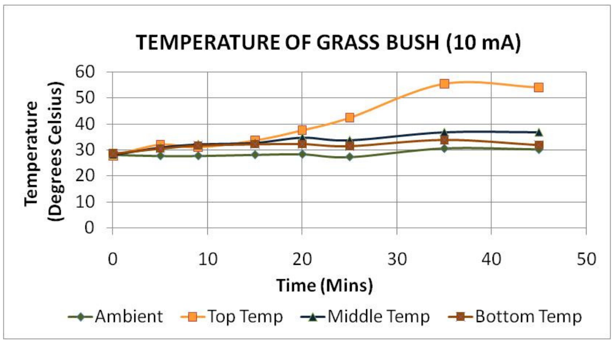

Figure 8: Temperature rise of grass bush with a constant AC current of 10mA.

The grass bush did not burn as aggressively as the Bamboo. Dense smoke was observed and charring was only visible at point of contact with the electrical connection. In an attempt to obtain a flame, repeated flashovers between the conductor and the bush were initiated. This resulted in a fire. The fire persisted whilst the conductor was energised and arcing between the flame tip and the conductor was observed.

4 DISCUSSION

4.1 Limitations of the test supply

The test supply presented limitations in terms of only being able to supply 250 kV DC. This limited the effective maximum size of the gap that could be tested. Further, the DC current was limited to 10 mA. In practice, the fault current of the transmission line is in the order of kilo-amps. The development of streamers and the effective mechanism of coupling of ionic current into vegetation may differ to the test source used. As a consequence, the gap size for the dry grass had to be reduced as the low magnitude of current could not be measured at the higher gap sizes.

4.2 The effect of the resistance of the plant

The voltage-current (V-I) characteristic of different lengths of Bamboo plants are shown in Figure 9. The trend is linear, indicating that the resistance of the plant is constant. When subjected to the electric field during the test, there is a change to the V-I curve as shown in Figure 10. There is a distinct knee-point where the V-I trend diverges.

The resistance before the knee point (R1) is 1.7 MΩ and the resistance after (R2) is 0.1 MΩ.

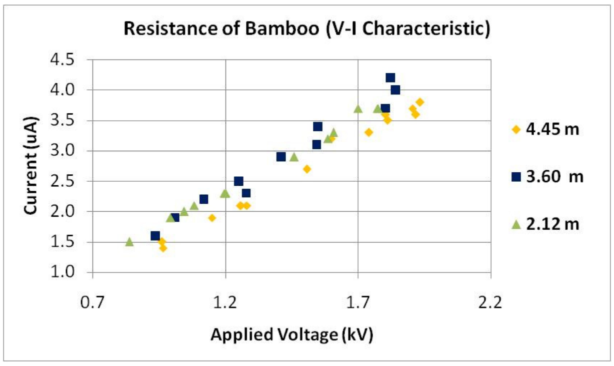

Figure 9: V-I characteristic of different lengths of Bamboo plants.

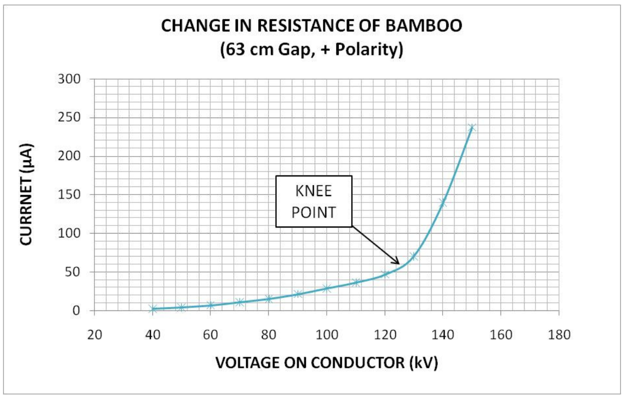

Figure 10: V-I curve of bamboo.

After the knee point (with high gradients/space potential), the resistivity of the plant does not have a large effect on the induced current, therefore, it is proposed that other mechanisms dominate the flow of current through the plant. This could relate to the capacitive coupling of the reactance of the AC ripple of the test power supply or additional corona current flowing from the tips of the plant, however, further work will be required in order to validate this result.

5 INFLUENCE OF BUSH FIRES ON THE CORONA INCEPTION AND CONDUCTED RADIO INTERFERENCE GENERATION OF HVDC TRANSMISSION LINES

5.1 Test setup and methodology

It is known that the pollution accumulation of a HVDC transmission line is different to an AC line. Further, the positive polarity catch is different to the negative case [4]. In order to investigate the different effects on the Radio Interference Voltage (RIV) of the DC line, a new, clean single Tern conductor was suspended 1.8 m above a ground plane. RIV measurements at 0.5 MHz were obtained for both polarities in accordance with [5], at different HVDC voltages this height resulted in a similar electric field gradient as expected under the Cahora Bassa Transmission line.

A sugar cane fire was ignited under the energised conductor. The objective of the test was to consider the effect of pollution on the RIV and not on the risk of flash-over, so the conductor was then lifted to 4 m above the earth plane to prevent direct fire damage and possible flash-over. This was done as the conductor was energised to (at first positive and then negative) 150 kV, in separate tests. The voltage would have caused a flashover to ground and this could have damaged the test supply.

After the fire, the conductor was then lowered to 1.8 m above the earth plane and the RIV measurements were repeated for each polarity. The polarity at which the burn took place with, was measured first. Figure 11 illustrates the test setup.

Figure 11: Sugar cane fire under an energised conductor.

5.2 Fire with Conductor Positively and then Negatively Energised

The conductor was positively energised during the first burn and a set of RIV measurements were taken. A second fire was made with the conductor negatively energised and the measurements were repeated. The results are depicted in Figure 12.

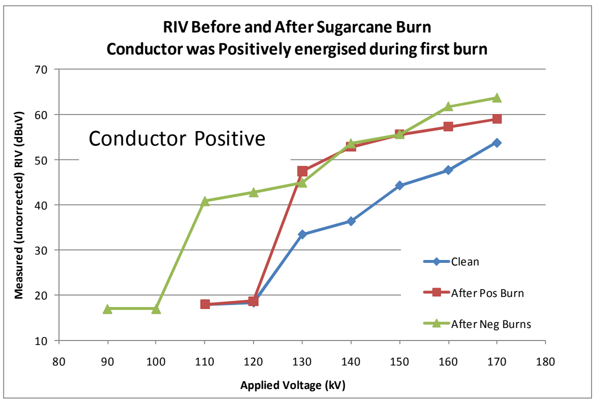

Figure 12: RIV before and after sugar cage fires.

The RIV levels increased by about 10dB in the 130 kV to 180 kV range. The second burn with the conductor negatively energised did not make a difference in this voltage range. However the corona inception dropped from 130 kV to 110 kV. No negative RIV was measurable before or after the burn.

5.3 Fire with Conductor Negatively Energised

A new conductor was installed. The conductor was negatively energised during the burn and a set of RIV measurements were taken. A second fire was made with the conductor still negatively energised and the measurements were repeated. The results are depicted in Figure 13 and Figure 14, respectively. The RIV level of the positive corona are much higher than that of the negative. After 2 burns, the negative RIV levels increased by 4-5 dB (in the 140 kV -180kV range), whereas the positive levels increased by about 20 dB.

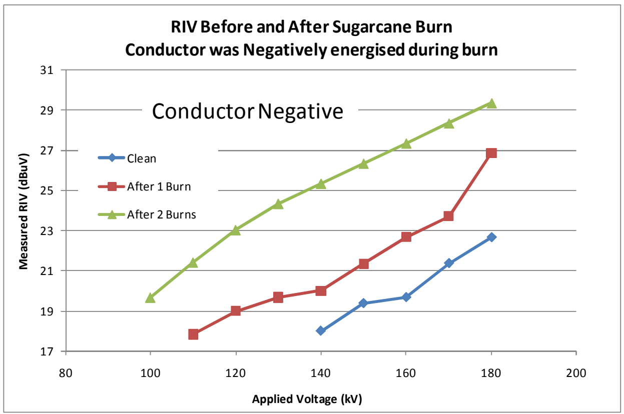

Figure 13: Negative RIV before and after 2 sugarcane fires (conductor negatively energised during burn).

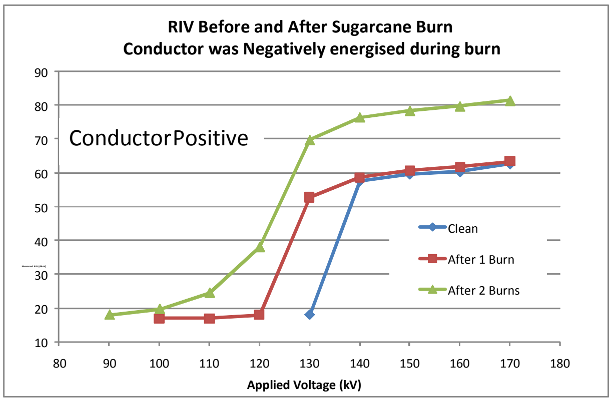

Figure 14: Positive RIV before and after 2 sugarcane fires (conductor negatively energised during burn).

From Figure 14 it can be noted that the corona inception voltage after the positive burn, dropped from 140 kV to 130 kV. After the negative burn, the corona inception dropped to 120 kV.

6 CONCLUSIONS

Eskom's transmission lines are designed for electric field exposure at the servitude boundary to levels less than 10 kV/m. It is seen that milliamp levels of current are required to cause sufficient heating of vegetation and ignition.

These limited tests shows that, practically, the electric field gradients and induced current flow required to cause ignition is not experienced at the ground level. Tall trees generally result in line fault events where there is flashover due to encroachment of the electrical ground clearance. Line inspections are quick to identify and mitigate such situations.

Although dry grass requires a lower magnitude of current, the gradient required to induce it is higher than the other plants tested. Practically, the conductor bundle will need to be very close to the ground (tower or insulator failure) to cause ignition.

From the fire work undertaken it is clear that fires under conductors definitely increase the RIV levels and reduce the corona inception voltage. Further work is being undertaken to evaluate the length of time required for the conductor to return to their original corona inception and RI level.

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