# DESIGNING 400KV AND 765KV LINES OVER CANE FIELDS

R. Vajeth, S. Narain and R. Moodley
ESKOM Line Engineering Services, 1 Eglin Road Sunninghill, South Africa
Email: riaz.vajeth@eskom.co.za

**Abstract**: The burning of sugarcane before processing underneath 400kV and 765kV power lines increases the possibility of fire induced flashovers. The practice of removing the cane after compensation to farmers is not practical to certain farmers and millers, as these areas may be crucial to the sustainability of the local sugar cane industry. This increases the need to find solutions that will benefit both Eskom and the canegrowers. This paper includes studies on cane farming, cane burning, line servitudes, withstand and flashover gradients, flame heights, fire induced faults and clearances. Eskom recorded a maximum cane fire flame height of 32 meters. This can become a problem as the highest attachment height of the towers in the 400kV and 765kV range is 33 to 35 meters. To clear the fire the resulting towers will have to be in the 50 to 60 meter range. It was also necessary to look at the probability of phase to phase flashovers and compare them to phase to ground flashovers. The cost for taller and sometimes wider towers will be high. Hence it was necessary to balance performance with cost. Laboratory testing and simulations were done to determine the withstand voltage gradient so that an optimum midspan clearance can be determined. The three alternative solutions compared in this project are; green harvesting, removing the cane and compensating the landowner, and taller structures for increased midspan clearance. In South-Africa green harvesting is not a viable solution at this time, as it requires costly procedures and modifications to the farmers harvesting process. Removing the cane underneath the power lines may at times cost the cane industry more than what it would cost Eskom to build taller towers. Taller towers, although costly, will reduce the probability of line faults, and may be the only option for Eskom when option 1 and 2 are not viable.

## 1 INTRODUCTION

Eskom Transmission, Land and Rights Department, requested Eskom Line Engineering to find a technical solution that will allow sugar cane farmers to burn under the new 765kV and 400kV lines, planned in certain areas of Kwa-Zulu Natal. Cane fires burning under power lines are known to cause line faults. The strategy to be investigated was therefore to find a solution that prevents line faults during a cane burn.

## 2 BACKGROUND

The issue of sugar cane fire faults on transmission lines occurs in various parts of the world. Utilities in these some of these countries reported the following:

Australia – Green harvesting implemented in most areas and increased heights of conductor midspan in areas where green harvesting was not possible.

Costa Rica – Prohibit the growing of sugar cane within the servitude and compensate the farmers.

Brazil – Implemented increased midspan clearance to ground until a law prohibiting burning of cane up to 15m away from transmission lines was passed.

South Africa – Implemented a cane fire management strategy so that farmers inform Eskom before burning, so that the affected line can be switched out. In some cases cane was removed from the servitude after compensating the farmers.

To track the fires occurring in South Africa a system known as Advance Fire Information System (AFIS) is used. This is coupled with notifications from the farmers whenever possible.

A study was performed to check the cane height, in other countries cane heights up to 6m is experienced and in South Africa the heights are around 4m to 6m depending on the type of cane.

## 3 STRATEGIES

- Green harvesting
- Cane Free Servitudes
- Technical Solution

### 3.1 Green Harvesting

Most farmers within the sugar cane belt in Southern Africa still use the conventional way of burning and then harvesting. For South African sugar cane farmers the method of green harvesting has not met widespread acceptance, and is in its early stages of application as costs and other logistical issues have not been sorted out.

Figure 1: Green Harvested Cane Field near Transmission Line

On the Southern African sugarcane belt most the fields are on hilly terrain and making mechanical green harvesting inefficient and costly. These harvesters also damage the crops and replanting of the crop is done sooner than normal burning and manual green harvesting. But for ESKOM to achieve less faults and disruption on their powerlines, green harvesting is an attractive option. The trash can be used to generate electricity or even used for manure and other by products of the bagasse from sugarcane. The move toward green harvesting is occurring all over the world, yet in South Africa it is posing a problem. Locals are causing run-away fires for employment opportunities. This has led to green harvesting being taken out as one of the deciding options at this stage.

### 3.2 Cane Free Servitudes

Cane free servitudes are becoming more difficult to obtain due to the increased amount of transmission lines running down to the KZN area. The amount of cane farms which a Transmission lines passes over has increased and therefore depending on the size of the farmer's land it decides whether the farmer will take the option for cane free servitude. The issue being that farmer's with smaller plots lose significantly when they have cane free servitudes as the amount of land the transmission lines clear is a large percentage of their entire property. In total a significant percentage of cane will have to be removed to allow for all future Eskom transmission lines, this threatening the stability of the South African sugar cane industry.

The cost of acquiring cane free servitudes varies greatly depending on the farmer and miller and the location. Additional costs of maintaining a clean servitude must also be considered if the farmers aren't going to use the servitude for fire breaks or other purposes.

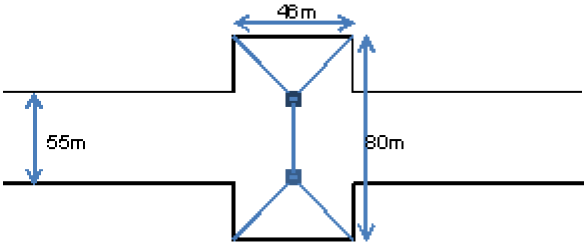


Figure 2: 400kV Servitude for Crossrope Tower

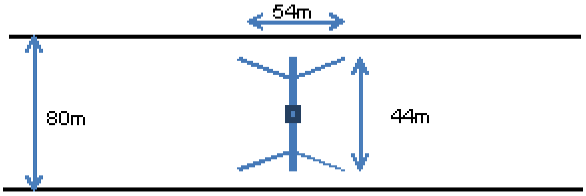


Figure 3: 765kV Servitude for Guyed-V Tower

Eskom strategy will be to obtain an independent valuation of the cane free servitude, and offer this to the landowner on a case by case basis.

### 3.3 Technical Solution of Taller Towers

Problems associated with sugar-cane fires beneath and in the close proximity of high voltage power lines have been experienced in many countries and have been described in many documents both locally and internationally. Phase to ground and phase to phase flashovers have been experienced by electricity utilities around the world under conditions of sugar cane fires.

In order to determine the insulation requirements of overhead lines crossing sugar cane fields, both the dielectric strength of air gaps spanned by flames as well as the distribution of flame heights have to be established.

#### *1.1.1. THEORETICAL FLASHOVER MECHANISM OF SUGAR CANE FIRES*

The detail analysis of the mechanism of flashover is beyond the scope of this paper. The main parameters governing the process of discharge are flame intensity and conductivity.

**Conductivity of flames**

Previous research shows that in diffusion flames, the maximum conductivity occurs in the lower part of the flame and not in the luminous part. The conductivity of the agriculture flames depends on many parameters, such as the chemical composition of the soil and vegetation, fertilizer used, and pollution. The conductivity of salted flames (salts of sodium, potassium) is much greater than for the unsalted flames. The distribution of the conductivity in the flame is given in Figure 4.

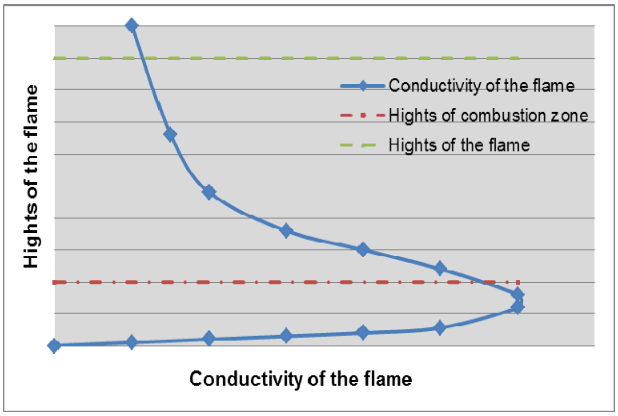


Figure 4: Conductivity Versus Heights of the Flame[1]

From Figure 4 it is apparent that the conductivity of sugar cane fires is largest in the close vicinity of the top of vegetation. This is in agreement with the test conducted by Eskom in 1993 at the CSIR H.V. Laboratory.

### *1.1.2. TEST PERFORMED AT NETFA HV LABORATORY*[2]

In order to determine the practical value of the breakdown strength of air insulation of HV lines under fire conditions as well as to confirm the accuracy of the results of tests performed by Eskom in 1995, a series of laboratory tests was carried out by Eskom at NETFA.

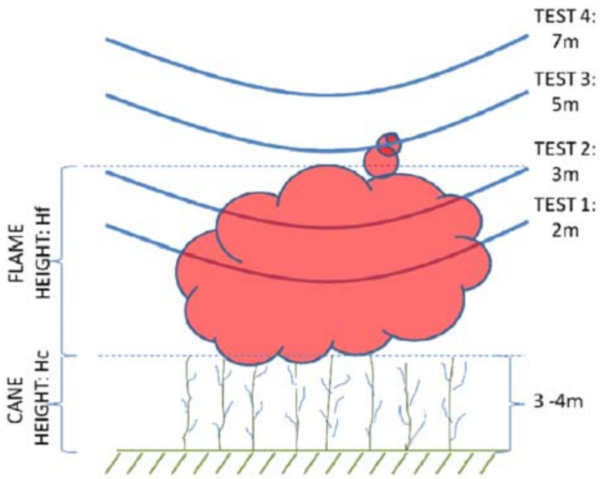


Figure 5: Graphical Representation of Test Programme

An experimental test span was erected at the High Voltage Laboratory, and the sugar cane was piled vertically underneath the line and burned, as shown in Figure 6. The heights of cane are of the order of ±2.5m (Size of cane "field" = 6x6m).

Figure 6: Test object set up at NETFA

The original aim of the test was to determine the dielectric strength of conductor-cane and conductor-conductor air gaps when:

- The gap is totally spanned by flame.
- The gap is partially spanned by flame.

Due to extreme weather conditions (wind, rain) and the restrictions placed on the utilisation of the 550 kV transformers by NETFA, the dielectric strength of air gaps partially spanned by flames could not be conducted. Hence, only totally spanned gaps were examined. The 70 kV, 70kVA, low impedance transformer was used for this purpose.

The results obtained are as follows:

Table 1: Conductor – Tip of Cane Gap

| Test No | Voltage (kV) | Gap Size (m) | Flashover Gradient (kV/m) | Result |
|---|---|---|---|---|
| 1 | 200 | 8 | 25 | Flashover |
| 2 | 35 | 2 | 17.5 | Flashover |
| 3 | 30 | 2 | 15 | Flashover |
| 4 | 25 | 2 | 12.5 | Withstand |
| 5 | 25 | 2 | 12.5 | Withstand |
| 6 | 45 | 3 | 15 | Flashover |
| 7 | 37.5 | 3 | 12.5 | Withstand |
| 8 | 60 | 4 | 15 | Spark over |
| 9 | 50 | 4 | 12.5 | Spark over |
| 10 | 44 | 4 | 11 | Flashover |
| 11 | 36 | 4 | 9..0 | Withstand |

Table 2: Conductor – Conductor Gap

| Voltage (kV) | Gap Size (m) | Flashover Gradient (kV/m) | Result |
|---|---|---|---|
| 20 | 0.9 | 22.2 | Flashover |
| 17.5 | 0.9 | 19.4 | Flashover |
| 13.5 | 0.9 | 15 | Withstand |

### *1.1.3. NETFA TEST FINDINGS*

From the series of tests performed at NETFA HV laboratory the conclusions obtained are as follows:

The withstand strength of the conductor – cane gap spanned by flame depends strongly on the moisture contents of the vegetation and was found to be as follows:

Cane delivered to laboratory (high moisture):12.5kV/m

Extremely dry cane (low moisture): 9kV/m

Due to the condition of the cane during tests at NETFA, these measured gradients were very low. It is anticipated that the gradients under field burn conditions will be in the range of 12.5 – 17.5kV/m for large gaps. These suggested gradients can only be justified by future tests. However, these gradients will be considered for line design in the next section, pending such future results.

The moisture content of the burning cane is the most important parameter governing the fire intensity, height of the flame and the transfer of high conductivity to the upper part of the flame. This has a significant impact on the withstand voltage of air gaps as measured at NETFA. It will be important to monitor this parameter during actual field burns. This will point to the practical withstand gradient to consider for the positioning of the phase conductors in cane fields.

The anticipated withstand voltages for partially bridged gaps are determined as follows:

$$V_W = E_F \times s + E_G \times (d - s)$$

Where:

$V_W$ = withstand voltage of conductor – conductor gap
$E_F$ = withstand gradient in flame (15kV/m)
$E_G$ = withstand gradient in gap not bridged by flame
d = conductor – conductor gap length
s = length of gap spanned by flame

$E_G$ is derived from the withstand gradient of gap without flame (150kV/m), but at an elevated temperature (2000C) due to the presence of a flame below the gap as follows:

$$E_G\,(kV/m) = 150 \times k_{fp} \times k_A$$

Where:

$k_{fp}$ = factor for reduction due to presence of floating particles [6]
$k_A$ = factor for reduction due to altitude

Assuming a 30% reduction due to floating particles and a 10% reduction for high altitude, the values for $k_{fp}$ and $k_A$ are 0.7 and 0.9 respectively.

The above equations have been used to calculate the withstand voltages for a conductor – conductor gap partially spanned by flame to varying degrees. The results are graphically illustrated below.

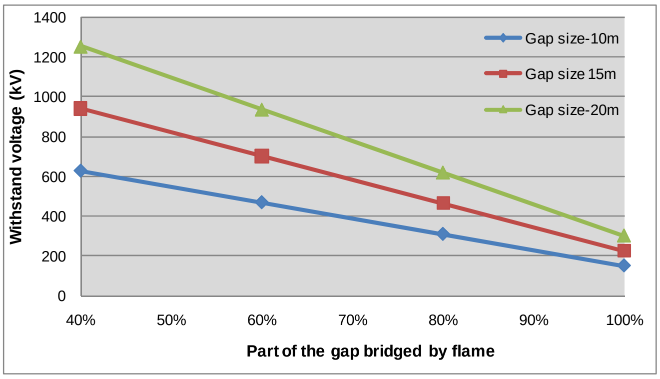


Figure 7:Withstand Voltage of Air Gaps Partially Bridged by Flame

The basis for the calculations in this document was based on a limited number of tests. More tests will be required to confirm the effects of the sugar cane moisture content and wind on the anticipated withstand gradients for both conductor-to-cane and phase-to-phase gaps.

The clearance required for 400kV and 765kV are as follows:

- 400kV clearance needed is 4m + 420kV/sqrt(3) / 12.5 kV/m = 24m
- 765kV clearance needed is 4m + 800kV/sqrt(3) / 12.5 kV/m = 41m

Since flame heights in South Africa have been measured up to heights of 32m, the 400kV height of 24m could still have phase to phase faults. The 41m is above the anticipated flame height.

Therfore a mid-span height of 36m is recommended for both the voltages pending further research. This is considered conservative, and will be applied to critical 400kV and 765kV lines, were even one line fault can cause widespread disruptions of power supplies.

#### *1.1.4. Towers*

To achieve midspan clearances of 36m for both 400kV and 765kV, new towers need to be developed which are shown in Figure 8.

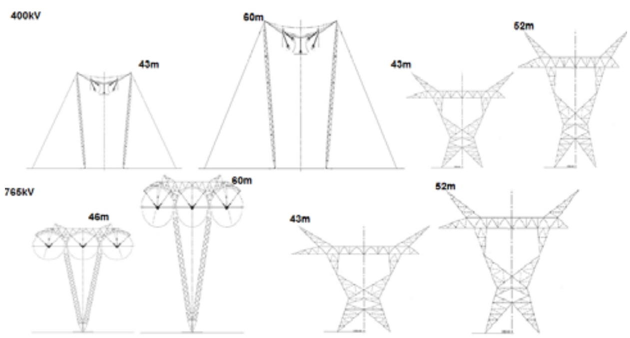


Figure 8: Standard Suspension and Strain Towers Compared to New Taller Structures

## 4 ECONOMIC ANALYSIS

### 4.1 Cost Comparison

The costs impacts were calculated using PLS-CADD on 2 proposed routes for the Athene – Theta (Mbewu) line, the sample profiles were developed using DEM data which had data points 20m apart, interpolated points were used between the DEM points. For each route 2 solutions were looked at, a self-supporting (SS) and a guyed (crossrope for 400kV and guyed-V for 765kV). For the profiling the 518 and 529 series were used for the 400kV and the 701 and 703 series for the 765kV. Various assumptions were made due to the conceptual nature of the study. The conductor type and bundle used was TERN with a 3x bundle for 400kV and 6x bundle for 765kV. A templating temperature of 60°C was used, and the effect of canfe fire temperature on line sag will be confirmed and a correction to the templating temperature then made. Each route was optimized although due to the short distance of the sample routes the optimization was minimized.

Table 3: Additional Cost Comparison for 36m Clearance

| Case | Average Additional Cost per km | Highest Additional Cost per km |
|---|---|---|
| **400kV** | | |
| Self Supporting | R1 601 000 | R1 873 000 |
| Guyed | R965 000 | R1 075 000 |
| **765kV** | | |
| Self Supporting | R2 126 000 | R2 740 000 |
| Guyed | R1 493 000 | R1 896 000 |

## 5 PERFORMANCE PREDICTION

In Eskom there are 132kV lines running over cane fields. One such line is the Avon-Mandini line, which experiences 34 faults per 100km per year due to cane fire faults. About 89 cane fires passed under the Avon-Mandini line in the same year. This can provide one with an indication of the worst case fault rate of a typical power line passing over a cane field.

Extrapolation to 400kV, considering the increased voltage gradient, will indicate up to 54 faults per 100km, with the typical midspan clearance of 8.2m. Extrapolation to 765kV will indicate up to 56 faults per 100km, with typical midspan clearance of 15m.

Hence to improve performance the midspan clearance will have to be increased. Prediction models tested by Eskom show a marked improvement in performance as the mid-span clearance is increased. These models are the corona inception gradient model and the equivalent electrical circuit model [3]. These models are in the process of being verified with actual tests and results will be published in the future. Any other international utilities doing similar work on cane fires, can lead to a pooled knowledge base on this rather complex phenomena of air gap breakdown from fires.

## 6 DISCUSSION

The power network in Kwazulu Natal is in urgent need of reinforcement. Therefore an urgent technical solution was needed to allow cane farmers to continue their activities and to allow Eskom to build the new power lines.

The strategy going forward will be to look at each farmers land on a case by case basis, due to the varying terrain and cost conditions. The cost of building a power line with enough mid span clearance will be compared with the cost of compensation to the landowner. The landowner and Eskom can then negotiate a win-win solution.

Further research work is being conducted by Eskom at present to verify the midspan clearance requirements to avoid cane fire flashovers. More measurements of flame heights in actual field conditions are being done, together with more tests of the type done at NETFA previously. For urgent and critical lines, a midspan clearance of 36m will be used for both 400kV and 765kV lines.

## 7 CONCLUSION & RECOMMENDATIONS

When designing the line a case by case strategy will used to check if clearance is easily obtainable from taller towers and hilly terrains. This will then be weighed against obtaining a cane free servitude.

The main factor governing the clearance required is the flame height, this is determined by the local conditions as well as how the farmer burns, what time he burns and conditions like wind and moisture content when burning. Therefore the following recommendations are made:

- More flame height measurements be done to increase confidence in the expected flame height prediction
- More flashover and withstand gradient tests be conducted, for both phase to phase and phase to ground conditions
- Enter into further discussions with the local sugar cane industry to ensure a win-win outcome for both Eskom and the Cane industry.
- Development of new taller 400kV and 765kV towers

## 8 REFERENCES

[1] K Sadurski, “Sugar Cane Fire Research: Determination of minimum clearances for 275kV and 400kV transmission lines”, report no TRR/E/95/EL169, Eskom Technology Group Research report, 1995

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