Investigation of Corona Induced Fire in High Voltage DC Lines

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ABSTRACT
Increased demand for power has led to use of higher voltages in order to meet the market. However transmission line designers, have to take into account the sensitivity of environmental impact assessment requirements as they develop the new lines. It's from this regard that the interest of this paper is formulated. The paper, investigates the possibility of bush fires in the right of way of high voltage transmission lines, resulting from the interaction of DC corona electrical fields and dry grass under the lines.

The electrical energy delivery system depends on the conducting and insulating materials. The most commonly used material being air on which a lot of research has been carried. Response of an insulating medium to a time dependant electric field is determined by the complex permittivity, which is the intrinsic property of the material, $\varepsilon = \varepsilon_r' + i\,\varepsilon''$. Were ε_r' is the real part that represent the measure of the ability of the medium to redistribute its charges so as to oppose the applied field. The imaginary part $i\,\varepsilon''$ is equivalent to the dielectric conductivity which is a loss in energy as the materials are not perfect insulators. The paper will show investigation of insulating characteristic of dry grass.

1 INTRODUCTION
Overhead transmission line still stands out as one of the most important components of today's electric power system. The fundamental purpose of the transmission system is to deliver power from generating units to the distribution system that ultimately supplies the loads because most of the sites suitable for power generation are located in remote areas. Lines provide the means for the potential generation sites to be commercially exploited. Transmission systems is also essential in enabling power utilities to exchange power for economic advantages and allow emergency assistances to be rendered when generating plants are out of service because of damage or routine maintenance.

Since the inception of the electrical industry in 1882, there has been a drive by transmission line designers to orient toward higher voltages in order to transmit bulk power over a longer distance. This has further been escalated by the difficulties in obtaining newer way leaves. Environmental awareness has complicated the processes of obtaining way leaves forcing most power companies to upgrade existing lines to higher voltages. Utilization of higher voltages has in turn increases the requirements to mitigate environmental effects to acceptable standards [1,2,3,4]. It has therefore become very vital to develop adequate knowledge of the environment under the power line particularly the corona voltage and current characteristic during the line design stage [5,6,7,8].

Corona means a disk of light that appear around the sun [9], the term has been used by physicist and engineers to name the partial discharge that develop in regions of high concentration of electric field. Corona is a self sustained electrical discharge that proceeds from an avalanche process in which neutral molecules are ionized by electron impact under the influence of the applied electric field. The ionization is localized over a portion of the distance between the electrodes. Atmospheric air is composed mainly of 79% nitrogen, 21% oxygen and different impurities [9]. The electronegative nature of oxygen molecules conditions the corona discharge. Oxygen molecules easily capture free electrons and form negative ions which hamper the electron avalanche process.

Corona discharge is accompanied by a number of observations such as a visible light, audible noise, electric current, energy loss, radio interference mechanical vibrations, and chemical reactions [9,10,11,12].

DC transmission has numerous advantages but imposes a lot of design challenges to Engineers with regards to space charges and increased corona effect. Occurrence of corona, leads to ionized air generating space charges. Space charge is composed of ions and charged particle.

Under the DC voltage the direction of the electric field does not change in time, resulting into the space between the electrodes being filled up by drifting charges with a polarity similar to the coronating pole. The unipolar ions that are generated interact, with airborne aerosol to produce charged particles. Electric field and wind act on the space charges to produce Ionic current in space [1,2,9,13] as the charged particles and electrons are moved by electric field and wind. Wind extends the region of ionic current flow beyond the right of way required for HVDC transmission lines [13]. The extension could be up to several hundred meters from the conductors, depending on the wind speeds. This leads to the presence of sparks that could be observed at a distance from the DC transmission line. On the contrary, AC transmission lines, space charge generated is confined to small volume immediately surrounding the conductors [9,13,14,15]. The space charge is constrained in the neighborhood of the stressed electrodes and oscillates with periodic reversal of the electric field. Therefore its effect is negligible on the overall field distribution.

Electric field and current density profiles under the transmission line are strongly influenced by line configuration, magnitude of line voltage, wind and humidity. It is extremely difficult to carry out stable short time measurement for a practical line because of unpredictable wind and weather conditions. Electric field strength at ground level is mostly influenced by space charge that is produced by corona discharge and not wind. Away from the ROW its wind speed that account for the ionic current flow because electric field has little effect as it reduces with distance from the conductor center line [1,9].

2. Can Corona Induce Fire on Dry Grass

In order to investigate the research question, it is necessary to develop an electrical equivalent model for the dry grass. The results from the grass test are used in developing a mathematical model with finite element software, in order to replicate the UKZN HVDC test line.

Distribution of grasses is determined by local conditions and general climate. Three samples with height above 100cm were selected in this test. These grass samples also have a high presence on a large area of the region with HVDC line in South Africa according into reference[17].The grass samples scientific names are given in table 1.

Moisture content affects both electrical and thermal characteristic of cellulose material like grass [18,19,20,21]. It was therefore essential that moisture content in the grass samples is established. The method used to determine moisture content was the oven dry method [22]. The results of moisture content and grass sample family names are shown in table1 below

Table 1

SAMPLE	GROUP	MOISTURE CONT
A	HYPARRHENIA AUCTA -H.RUFA	11%
B	HYPERRHENIA FILIENDULA	11%
C	HYPARRHENIA HIRTA	11%
D	CYMBOPOGON VALIDUS	12%

Parallel capacitor method was used to measure the dielectric constant of grass by compressing grass samples into a regular shaped test cell with a fixed volume that was connected to Capacitor Resistance meter (CR) [18,21]. One of the major challenges faced in this method, was the requirement of special fixtures which generally depended on the material type. With compounds and powders which could be compressed into a test slab or disk of a given thickness test are easier. The use of an automatic CR meter made the measurement of capacitance (C) and loss (D) to be easier because results were readout directly making the method faster and reasonable. Test results and the methodology were validated by testing of new transformer oil using the same test cell as for the grass test. Oil being an insulating liquid widely used and has a permittivity that has been measured and established universally to be ranging from 2.2 to 2.3. The dielectric permittivity of oil was found to be 2.27 which was within the standard range. This meant that the method and equipment used in testing grass gave results that are acceptable. The graph below shows the distribution of normalized value of dielectric permittivity of grass sample A. The statistical evaluated value for the dielectric permittivity constant for sample A was 3.6 with a statistical error of 9% while the conductance was 0.007×10^{-6} S [23,24]

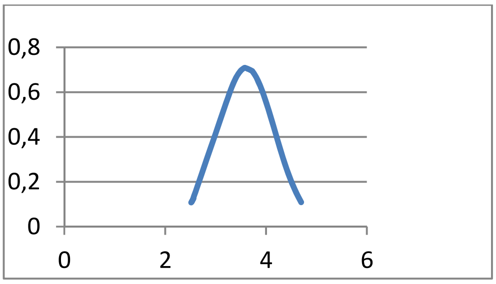
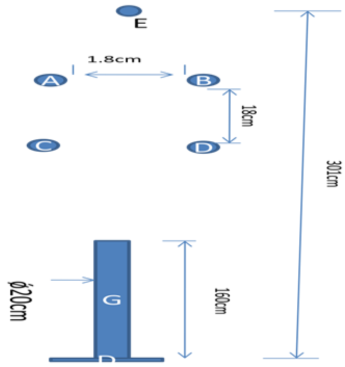


Fig [1] – Normalized Permittivity for Grass Sample A

Having obtained the electrical equivalent of dry grass, a model was created in quick field from which the simulation results were used to validate the experimental data obtained from the test line. However the investigations were limited to a monopole line only due to the limitations in the test line facilities available.

3. SIMULATION AND PRACTICAL TEST.



Fig[2] Section View of Line Model

Table 2

Letter	Notation
A,B,C,D	Conductor
E	Earth Wire
G	Simulated Grass
D	Copper Plate

The line to ground geometry was modeled as shown in a section view of the transmission line in fig [2] depicting the four conductor bundle case. Relative permittivity obtained in “the grass test” was assigned to the material that simulated grass in the model. The simulated grass had its base on a grounded metal plate simulating earth. Dirichlet boundary condition were used in the model by providing the electrostatic potential V(r) on the conductor surface and taking grounded plate to be at 0V. The line voltage was varied from 10 kV to 400 k V in intervals of 10 kV on ten different heights of grass sample A but only heights 40 cm has the results are shown in this paper fig[4]

In a practical experiment, bundles of grass sample were clamped to a radius of 20cm and height ranging from 20 to 200cm was placed under HVDC test line. The grass bundles were suspended on an insulated copper plate representing the earth mass. The copper plate was then connected to the pico-meter via a shunt resistor. A corona and thermal camera were installed in the test room. The results are shown in fig [6].

4 RESULTS

4.1 Simulation

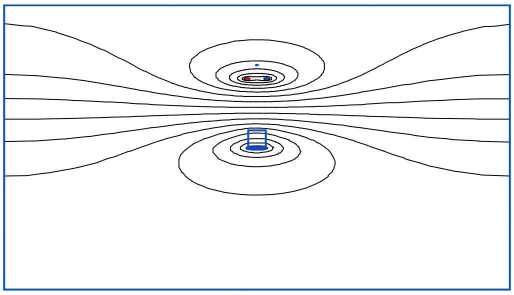
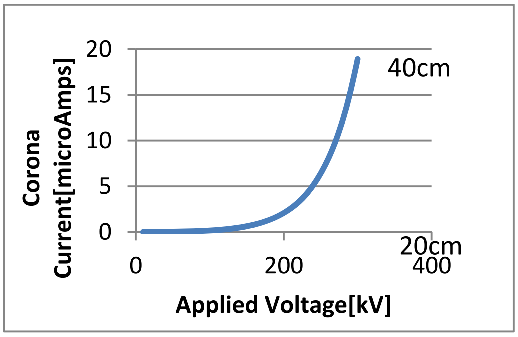


Fig [3] – Equal Potential lines

The lines indicate the areas with equal potential between the grounded base of the simulated grass and the suspended 4 conductor bundle.



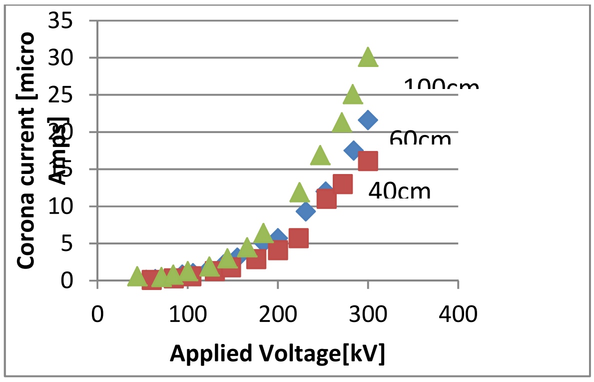
Fig[4]-Corona current against the applied voltage

The graph shows the corona current from the simulation of grass sample A with heights of 40 cm above the ground.

4.2 TEST LINE

Fig[5]- Burnt Grass Sample.

The grass sample A of height 195 cm above the grounded copper plate that got burnt.The grass sample was burnt in two location .The burnt are located at 85cm from the grass base and at the footing point. The burning was very visible as can be seen in fig[5].



Fig[6]–Corona Current against Applied Voltage

Measured induced corona currents for grass heights 100, 60 and 40cm above the grounded copper plate. The currents measured on the 40cm grass height compared very well with the simulated grass results for the equivalent height. The values are a perfect match.

Fig[7]- Corona on Grass Sample A

A typical high corona intensity case for grass sample A of height 195 cm above the grounded copper plate.

5 DISCUSSION

Insulated objects under a HVDC transmission line are charged by corona generated ions through a process called ion flow electrification [3,4,9,13]. This has now become a critical design limitation for power lines with regard to determining the conductor height above the ground.

The results from both the simulation and experimental test have shown corona currents flowing on grass. The magnitudes of the currents obtained compared very well between the practical test line and the mathematical simulation. This meant that the grass electrical equivalent was done correctly. The grass model is very important in that extreme condition that cannot be performed in practical case can now be tested theoretically.

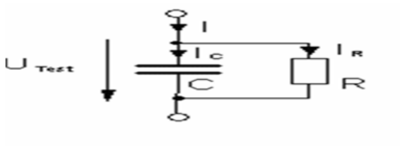


Fig [8] Electrical model of dry Grass

Fresh grass is different from dry one because of mineralized fluids it contains which makes it to conducting electric current. Fresh grass under the Power line is treated as a conductor with equal-potential on its surface. The fact that the surface of a conductor is equal-potential implies that in the immediate vicinity of this surface the field electric field at each point is directed along the normal

Dry grass is a dielectrics material meaning it theoretically does not have any practical ability to conduct electric current. This leads to the assumption that in theory insulators do not have any losses but the practical position is that, a leakage current exists which is defined as dielectric loss. These losses act as a thermal source under high-voltage or frequency conditions. Dry grass being a practical dielectric material is modeled to comprising of capacitor in parallel with a resistor as shown in fig [8]. A reasonable potential is held across the resistor on which heat is generated by the current that flows through

Applying this theory to dry grass it can reasonably be agreed that with suitable ambient conditions and moisture content attained there exist possibilities that grass can ignite as shown in fig [5].

The resistance of a bunch of dry grass is not uniform in all practical sense there are some regions with higher resistance that could cause high voltage concentration. The high resistance regions generation heat from induced corona current. These areas develop a local arcing which gradually develops to a thermal runaway and fire eventually. This fact can be observed from the results on the grass under the HVDC test line which showed that only certain localized portions of the grass got burnt.

The grass was not burn at the tip where there was visible corona effect as shown in fig[5]. The portions that got burnt are at the base where grass made contact with the grounded copper plate and in the middle of the grass stack. This meant that the combustion of grass was due to the corona current flow in and around the dry grass. Thermal imaging also showed the gradual temperatures rise on the grass samples as the corona current increased.

CONCLUSSION.

Under a very high electric field and dry weather conditions corona can cause fire on dry grass. Further woks is to be done on this research topic in order to establish the critical field above which corona could cause fire.

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