EXPERIMENTAL STUDY ON LIGHTNING BREAKDOWN CHANNELS IN THE SOILS

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Abstract: **Present day models do not satisfactorily describe the surge behavior of earth under the passage of lightning currents which result in a single breakdown channel. This paper presents preliminary results of an investigation into the factors that affect lightning current propagation in different soils under single channel formation. The results presented in this paper were obtained using an indoor experimental system and examine the influence of soil characteristics and source capacity and voltage on lightning channel characteristics.**

It is hoped that these results will be useful in establishing models which describe both single and multiple channel formation in soils.

1.Introduction

According to traditional lightning theory, when lightning reaches the surface of earth, it spreads into the soil, which may be represented by an equivalent hemispherical electrode of radius equal to that of the sparking channel. Several models that describe the behavior of earth under impulse currents are based on this assumption [1][2]. But it is known, from the results of both indoor experiments and field data concerning outdoor lightning strikes resulting in damage to underground cables that impulse currents propagate along a single channel during the total propagating period or for part of the total traversed distance [3][4]. Present day models do not satisfactorily describe either situation [1]. In order to investigate the factors which influence formation of single and multiple paths and the breakdown mechanism of soils, we have been carrying out cooperative research work. to date we have addressed the following aspects:

1) When an impulse current generator discharges into different kinds of soils, what are the factors that decide whether the current propagates along a single or multiple channels?
2) What is the influence of moisture, compaction and resistivity?
3) What is the influence of generator capacitance and voltage?
4) Finally, does the lightning current exhibit a tendency to flow along pre-formed channels?

This paper presents results concerning single channel formation. Other results will be published in future papers.

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2.Experimental system

The indoor experimental system was comprised of an impulse current generator discharging into a hemispherical pot of radius 100 mm into which different soils were packed. (Figure 1).

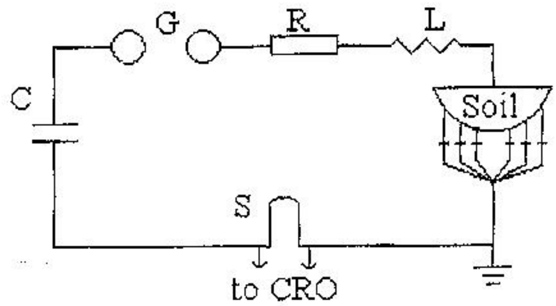

Fig. 1 Indoor experimental system
C: generator capacitors, 0.87μF 60kV
R: 0.3Ω, L: 4.5μH
S: shunt 29.95mΩ

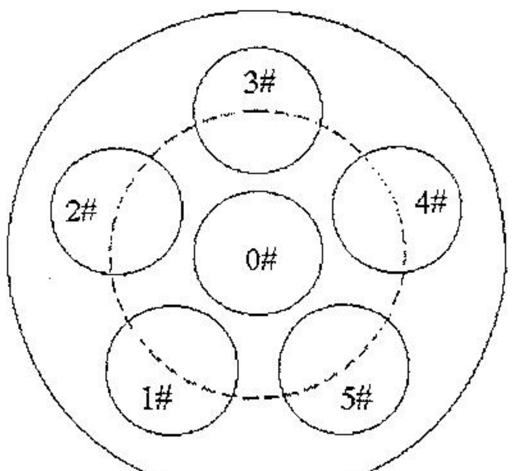

Fig. 2 Location of six electrodes (vertical view)

At the bottommost point and at a height of 45 mm from the bottom, six 40mm radius round plate electrodes are located symmetrically (one at the bottom point and five along the circle, Figure 2). The six electrodes cover about ¾ of the area of hemispherical surface and their outputs are linked together to a point that is earthed. The current entrance electrode is an 18 mm-diameter rod placed at the center of hemisphere just above the soil surface in order to provide a sparking connection. It is held symmetrically with respect to the six measurement electrodes and is also constrained so that it does not move under the impulsive force produced by discharging.

Magnetic links were used to determine which electrode was hit by the lightning channel. Branch currents were estimated by proof current__angle curve of magnetic link.

The signal across a shunt was connected to TDS220 oscilloscope (Bandwidth: 100MHZ, Sampling rate: 1GS/S, Record length: 2500 points) to display and print the total current waveform.

The resistivity and moisture of soil were measured using the methods reported in [5]. Soil compaction was calculated by dividing the total weight of soil by the volume of the hemisphere.

3.Experimental results

Although experiments were carried out in a soil model indoors, the following two observations are common to several outdoor lightning incidents which resulted in damage to communication cables in the Guangdong province of China [4]. This commonality is very important since it lends credibility to the results generated indoors using a small model.

1) When a soil is broken down it results in holes or ditches in the soil.

2) The conditions that cause multiple channel formation are more severe than those which cause single channel formation.

3.1 Influence of soil's characteristics

Soil resistivity is the basic parameter that affects breakdown channels. Since different soils have different compaction and moisture content, their resistivities are different, and hence their breakdown voltages for single channel formation are different. The general tendency exhibited is that the lower the resistivity, the smaller the minimum breakdown voltage for a single channel. --See Table 1

From Tables 1 and 2 it is also seen that when moisture or compaction increased, the soil's resistivity decreases and its minimum breakdown voltage for single channel formation decreases also.

A dry soil has a very high resistivity, and its breakdown voltage is very high, but only a little water sprinkled on the surface of soil (simulating natural rain) causes a significant decrease in the breakdown voltage of a single channel. Table 1 shows that sand with zero moisture content could not be broken down even when the generator voltage was increased to 46 kV. From data concerning dielectric strength published in [3], it can be calculated that the break down voltage for this case is approximately 70kV. However, after only about 15 to 20 drops of tap water were evenly sprinkled on the surface of the soil the breakdown voltage decreased to 35 kV with resulting peak value of current of 500A.

*Table 1:*Minimum breakdown voltage for single channel in different soils

Soil type	Moisture (%)	Resistivity (Ωm)	Minimum breakdown voltage (kV)
Sand	19	109	9
	5	6000	25
	0	9000000	*
Red soil	22	22	7
	14	844	15
	3.5	88000	32
Black soil	19	859	17
	13	1919	22
Cultivated soil	13	1742	17

*Table 2:*Influence of compaction

Soil type	Moisture (%)	Compaction (g/cm^3)	Resistivity (Ωm)	Min. Break. volt. (kV)
Black soil	9.7	1.073	2121	23
		1.182	1110	21
		1.307	655	20
Cultivated soil	13	0.947	1742	17
		1.086	964	16
		1.236	305	15

3.2 Influence of impulse generator capacitance and voltage

When the generator capacitor's DC voltage is at the minimum value for a particular soil's breakdown, it results in the formation of a single channel. If the voltage is increased, only one channel forms but the value of current increases. If the voltage is increased beyond a certain value, the current path has a tendency to split into two branches.

TABLE 3: Influence of generator capacitance
Cultivated soil, 13.7%moisture, $1.27 g/cm^3$ 190Ωm

Capacitance (μF)	Minimum breakdown (kV)	Total current (A)	Breakdown channel & its current (A)
0.87	13	734	0# 730
0.35	21	267	5# 233

When the generator capacitance is decreased, the breakdown voltage for formation of a single channel increases and the total current decreases. On the other hand, the voltage value for multiple path formation does not change appreciably despite the fact that both total and branch currents decrease. -See Table 3.

3.3 Location of channels:

If the soil condition is restored to its original condition after each discharge of the generator, each plate electrode is equally likely to be the recipient of a channel which forms randomly. The reason is that the six electrodes are situated equidistantly from the top entrance electrode from an electromagnetic field point of view. This observation was confirmed for various values of generator capacitance.

If the soil is left undisturbed after each discharge, the next discharge (for same value of generator voltage) propagates in the soil along or close to the channel formed upon previous application of voltage. Under such circumstances all channels form close to each other. Table 4 shows that the breakdown channels are confined to a small volume formed by the entrance electrode and plate electrodes #2 to #4.

Table 4: Location of channels

Cultivated soil, 11.68%moisture, 1.214g/cm^3, 409Ωm, 25kV

Number	Current in breakdown channel (A)					
	0#	1#	2#	3#	4#	5#
1			830			
2			1200			
3				800		
4					780	
5				900		
6					900	

3.4 Total current waveform

Figure 3 shows a typical waveform of the total current. Because breakdown resistance varies under different condition, it affects the total current waveform.

The Time lag Tl is the time difference between the application of a voltage sufficient to cause soil breakdown and occurrence of breakdown itself.

For any type of soil, Time lag Tl decreases as generator voltage is increased. When the voltage applied corresponds to the minimum voltage for single breakdown channel formation, Tl reaches a maximum that may be several hundred microseconds. When the capacitor voltage exceeds a certain value, Tl becomes shorter than 3 microseconds and does not change significantly thereafter. If other conditions are not changed the lower the resistivity of soil, the shorter the Tl.

The duration of impulse current Td is also affected by applied voltage. As the generator capacitor voltage is increased beginning from the minimum value necessary for single channel formation, the duration Td shows a tendency to decrease. After the voltage exceeds a certain value, the duration changes very little. -See Table 5

Table 5: Tl and Td

Black soil, 13% moisture, 1919Ωm

Voltage (kV)	Tl (μS)	Td (μS)	Im (A)	No.of breakdown channel
22	260	18	467	1#
30	28	12	935	0#
32	5	14	1068	5#
35	3	10	1469	5#

With respect to some soils, when the generator voltage is increased, the waveform of total current exhibits a negative overshoot. --See Figure 4.

4.Conculsions

--Resistivity is the basic parameter that affects formation of breakdown channels. With regard to homogeneous soils the influence of moisture and compaction is reflected by resistivity changes.

--The mechanism of breakdown is different for dry soils, soils that are wetted only at the top and homogeneously wetted soils.

--In model studies breakdown is more likely to occur along or close to preformed channels if the soil is left undisturbed between discharges of the impulse current generator.

--Breakdown channel has different equivalent resistance under different condition, so it affects the total current waveform.

5. References

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