

THE DETECTION OF CORONA
IN DAYLIGHT

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CONTENTS

	Page
PREFACE.....	1
I. PURPOSE.....	2
II. GENERAL THEORY.....	3
1. Definition.....	3
2. Theory.....	3
3. Characteristics.....	5
4. Methods of Attack.....	7
a. Ozone and Oxides of Nitrogen.....	7
b. Sound.....	7
c. Light.....	7
Power Loss.....	8
III. DESCRIPTION OF THE METHOD AND APPARATUS USED.....	10
1. Apparatus.....	10
2. Method.....	10
3. Theory.....	10
4. Procedure.....	11
IV. OBSERVATIONS AND DATA.....	13
1. Observations.....	13
2. Data.....	14
3. Calculations.....	16
V. CONCLUSIONS.....	17
1. Statement.....	17
2. Application.....	17
3. Summary.....	18
BIBLIOGRAPHY.....	19
APPROVAL.....	20

PREFACE

Because of the large power losses due to corona on high-tension transmission lines, the problem of finding a method of detecting it has become a very pressing one to the electrical engineer of today. Much has already been written on the theory and characteristics of corona but it is only recently that the problem of corona detection has been attacked.

This problem has been attacked in experiments described in this thesis and, although it has not been solved in as practical a manner as would have been desired, some of the material obtained might be of help to someone else who is interested in solving the problem.

I.

PURPOSE

The purpose of undertaking the experimental work about to be described was to invent, if possible, some practical device which would indicate the presence of corona on a wire. By a practical device is meant one that can be used by an ordinary workman in the field. Such a device should be able to stand rough usage and, at the same time, must be very sensitive. It should be easy to use and should, at a safe distance from the transmission line, be able to detect the least trace of corona.

While a device in accordance with the above specifications has not been invented by the author, a small amount of material has been obtained which may aid someone else to invent such a device. The best device used by the author to detect corona was the electroscope. The electroscope, therefore, was to have been the nucleus of his invention and, on this account, this thesis turned out to be more or less a study of the effect of corona on the electroscope.

II.

GENERAL THEORY

1. Definition

"Under ordinary conditions and for low voltages, air is very nearly a perfect insulator and its dielectric properties are almost the same as for a vacuum. In other words, the conductivity of air is practically zero, the permittivity unity and the energy loss extremely small. For higher voltages the air insulation may break down, either partially or completely, causing important changes in the electric and dielectric circuit.

"For illustration, consider two parallel, smooth, bare wires, spaced as in a commercial high-tension transmission line with dry, clean air as the dielectric. Let the room be dark, or if the wires are strung in the open, let the observations be taken at night. If the voltage be gradually increased until the gradient near the wires reaches 30 kv. per cm. a faint purplish light may be seen at or near the surface of the wires, and a hissing sound may be heard. By still further increasing the voltage both the luminous glow and the hissing sound increase in volume and intensity. The phenomenon, of which the light and sound are indications, is called the corona."*

2. Theory

Corona is always accompanied by a copious ionization of the air around the conductor and is highly conducting. According to Whitehead,** there are three possible sources of ions; namely,

* Magnusson's "Alternating Currents," page 391.

** See Bibliography (2), page 19

(a) the conductor itself, (b) the separation of the two component charges of molecules of gas near the surface of the wire by the intensity of the electric field, and (c) the separation of the two component charges by the collision of the molecules. Today, source (c), called ionization by collision, is the most generally accepted theory of corona.

To explain corona by the theory of ionization by collision, assume two parallel wires in exactly the same circumstances as they were considered above. Around these wires there will naturally be a very few free electrons and negative ions of molecular size, produced by the frequent collisions of molecules in the air. Now, let an alternating e.m.f. be impressed upon these wires, one of which is called A and the other B. During half a cycle A will be positive and B negative, and during the next half a cycle B will be positive and A negative, and so on. The neutral molecules of gas around the wires will be set into rapid vibration due to the attraction of their positive charges to the negative wire and their negative charges to the positive wire. At the same time, the electrons and negative ions will be given a high velocity by their attraction to the positive wire and repulsion from the negative wire. When the e.m.f. is increased the velocity of the free electrons and negative ions will be increased, as will also the amplitude of vibration of the neutral molecules. There will be frequent collisions between these different particles and, if the voltage is increased until the gradient near the surface of the wires reaches 30 kv. per cm., the negative ions, which are large in comparison with electrons will attain a velocity great enough to dislodge electrons from

neutral molecules when these collisions occur. The electrons do not have enough mass to dislodge other electrons from molecules at this low velocity but they will have velocity enough during these collisions to cause them to unite with neutral molecules, thus forming positive ions of large mass. These newly-formed ions will in turn produce more ions by collision and the general process of ionization by collision will have begun, as will be indicated by the appearance of the purplish glow and the beginning of the hissing sound, both of which are characteristic of corona.

3. Characteristics

At the point when corona begins, there is a marked increase in the current and further increases in the voltage are accompanied by rapid increases in the current, and also increases in the brilliancy of the glow and in the hissing sound of the corona. What is now taking place around the wires can be readily visualized from what has already been said concerning ionization by collision. There is a large mass of positive and negative ions moving at high velocities around the wires. The velocity of these ions evidently depends upon their mass, the electrons and smaller ions having a very high velocity in comparison with the heavier and more complex ions. During the half cycle in which wire A is positive and wire B negative, negative ions are attracted to wire A and positive ions to wire B, and vice versa during the next half a cycle.

Frequent collisions between these fast-moving ions are continually taking place but it is only in the space around the conductors at which the gradient is 30 kv. per cm. that

ionization by collision can take place. 30 kv. per cm. being the dielectric strength of air, air at all points around the conductors, where the gradient is at or above this value, is broken down and rendered perfectly conducting. This portion of ionized air is filled with the visible glow of the corona, the glow probably being caused by the vibration and collision of the ions.

In the ionized air around the conductors the masses of the ions vary in size from the smallest mass of the electron to masses so large that they can almost be seen with the naked eye. The difference in size of ions is caused by the different combinations and combination of combinations of ions that may take place. Therefore, any peculiarity apt to occur in corona may be accounted for by the almost unlimited complex combination of ions that is possible.

During corona discharge, some of the ions reach the conductor and are neutralized, resulting in a loss of current; others recombine froming neutral molecules; and still others are forced through the air outside of the corona by the electric gradient. The greater part of the power loss caused by corona occurs outside of the corona due to the forced passage of molecular ions through the air.* Also the sharp stoppage of the electroscope discharge on interruption of the corona indicates that any after affect of ionization must be of duration less than one-half a period.* It seems, then, that free ions do not continue long in air after the corona has stopped but immediately combine to form neutral molecules.

* See (2) in Bibliography, page 19.

A characteristic of corona that has not been mentioned in the foregoing discussion is the formation of ozone and oxides of nitrogen. The ozone can immediately be detected by its characteristic odor. It is evident that this production of ozone and oxides of nitrogen is due to the ionized condition of the elements oxygen and nitrogen in the air.

4. Methods of Attack

A fairly heavy corona can be readily seen in the dark a reasonable distance away from the spectator. But when it is placed on a high-tension transmission line and viewed against the background of the sky, it is not very easily seen except on very dark nights. Sight, therefore, cannot be depended upon as a very reliable means of detecting corona, especially on high-tension transmission lines.

If a satisfactory method of detecting corona in daylight is sought, four of its characteristics offer possible methods of attacking such a problem. These characteristics are (1) the formation of ozone and oxides of nitrogen, (2) sound, (3) light, and (4) power loss.

a. Ozone and Oxides of Nitrogen.---Some sensitive chemical reaction might be discovered which would quickly indicate the presence of either ozone or the oxides of nitrogen produced by corona. Ozone is a powerful oxydizing agent and turns a potassium iodide and starch solution blue.

b. Sound.---A device might be invented which would detect corona by the hissing sound produced.

c. Light.---A device for detecting corona by the rays emitted might be invented. For instance, the spectroscope

might show in the corona spectrum some peculiarity which is characteristic only of corona.

d. Power Loss.---Some device, as for instance the radio, might be used to detect corona by the disturbance caused by the discharge. It is well known that the sparking on a motor-generator set will create a great disturbance in radio reception.

Also some device like the electroscope might be used. The electroscope is a very sensitive instrument and it is reasonable to expect that, if a charge is placed on it, this charge will be neutralized by the ions from corona, thus causing it to discharge. In fact, the electroscope has already been used by scientists as a means of detecting corona.*

* (2) in Bibliography, page 19.

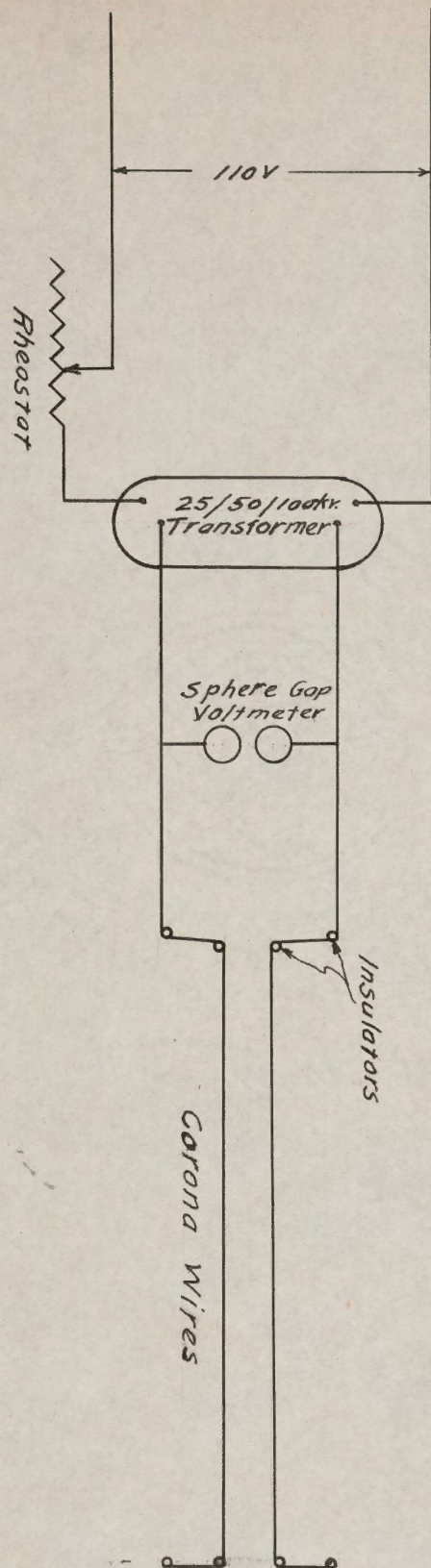


Fig. 1.

III.

DESCRIPTION OF THE METHOD AND APPARATUS USED

1. Apparatus

A diagram of the apparatus used for producing corona is shown in Fig. 1. This apparatus consisted of a 25/50/100-kv. transformer, a rheostat in series with the low-tension side and two parallel, bare, unpolished, copper, corona wires, 0.685 mm. in diameter, approximately 13 ft. in length, and spaced 3 in. apart. The corona wires, or wires for producing corona, were stretched horizontally on porcelain insulators. The source of e.m.f. was the 110-volt city lighting system.

2. Method

Of the different characteristics on which the construction of a practical device for corona detection in daylight might be based, its power loss characteristic was selected as the one offering the greater possibilities. For the detection of this power loss the electroscope was chosen because of its sensitiveness, its simplicity, and the fact that it had already been used with satisfactory results by scientists as a detector of corona.

3. Theory

If the electroscope is charged and left undisturbed, the charge will remain upon it for several days. Eventually, however, enough ions in the air will come into contact with the knob to neutralize the charge. And, if the electroscope is placed near a high-tension transmission line, it will retain

its charge as before if there is no corona on the line. But, if there is corona on the line, ions from this discharge will hit the knob of the electroscope and immediately neutralize its charge. Now, if the electroscope without a charge is placed near the corona, it will be bombarded by ions from the discharge and will immediately receive a charge. The action of corona on the electroscope is accelerated and will take place at greater distances of the electroscope from the corona if a wind is blowing the ions to the electroscope.

4. Procedure

The following course of procedure was pursued in studying the effect of corona on an aluminum-leaf electroscope:

The electroscope was charged positively and then negatively, and in both cases the effect of the corona on it was studied. Readings were taken of the rate of discharge of the negatively-charged electroscope at various distances from the corona and for voltages, ranging from the visual corona voltage to the maximum voltage that could be impressed without causing a spark-over. These readings were roughly taken, the aim being only to obtain the approximate relative rates of discharge of the electroscope for various distance from the corona. A fan was then used to blow ions from the corona to the electroscope and a second set of readings taken as before. Finally, the voltage at the corona starting point, called the visual corona voltage, was found from the sphere gap voltmeter. The value for this voltage could not have been very accurate because at the time the readings were taken the

corona voltage was changing on account of the heating of the rheostat. A water resistance would have been much better to have used. The visual corona voltage was not necessary to the experiment in hand but was desired only in order to be compared with the value calculated from Magnusson's formula.*

* (8) in Bibliography, page 19.

IV.

OBSERVATIONS AND DATA

1. Observations

The aluminum-leaf electroscope with a negative charge remained unaffected so long as no corona was produced but it began to discharge the instant corona started. If the corona was suddenly stopped, the discharge of the electroscope also suddenly stopped but, if the corona was allowed to continue, the electroscope discharged to zero and then gained a positive charge. When the electroscope had a positive charge the corona tended to increase this charge.

The amount that the electroscope was affected by corona depended upon the size of the corona and upon the distance of the electroscope from the corona. By using an electric fan to produce a wind from the corona wires to the electroscope, the effect of the corona on the electroscope was greatly increased, as was also the distance that the electroscope could be placed from the corona and still be appreciably affected. With the fan creating a wind this distance was increased to about 6 ft.

The visual corona voltage as found from the sphere gap voltmeter was 10 kv. The maximum voltage used was around 22kv., which was approximately the spark-over voltage.

2. Data.

The data below will give a general idea of the relative effect of corona on the electroscope under the different conditions. When speaking of a charge of 9/16 in., 11 in., etc., the figures

refer to the distance apart of the leaves of the electroscope, as read from a scale with the eyes a definite distance from the electroscope.

Readings taken in still air. Distance of electroscope from corona 7 in. Zero reading of electroscope $3/16$ in. No charge on electroscope.

Size of corona	Charge in in. on electroscope with corona	Time in sec. to charge	Charge in in. left when corona is suddenly stopped
Beginning	$15/16$	30	$13/16$
	$1-1/16$	50	$14/16$
	1	40	$14/16$
Maximum	$15/16$	15	$10/16$

Same as above except with electroscope 2 ft. from corona.

Corona had very little effect on the electroscope.

Same as above except with electroscope 2 ft. from corona and with a charge of -2 in.

The corona had very little effect on the electroscope only discharging it to $-3/4$ in. in 5 min.

Readings taken with an electric fan 5 in. from the wire and producing a wind from corona to electroscope. Distance of electroscope from corona 7 in. Zero reading of electroscope 3/16 in. No charge on electroscope.

Size of corona	Charge in in. with corona	Time in sec. to charge	Charge in in. left when corona is suddenly stopped
Beginning	5/16	10	1/4
	5/16	10	1/4
Maximum	5/16	10	1/4

Same as above except with electroscope 2 ft. from corona and with a charge of -2 in.

Size of corona	Time in sec. to discharge
Beginning	5
	5
	4
	3
Maximum	3

With fan. Charge -2-1/2 in. Electroscope 7 in. from corona.

Size of corona	Time to discharge
Beginning	2
	2
	1.5
Maximum	1.1

With fan. Charge $-3/4$ in. Electroscope 6 ft. from corona.

Size of corona	Time in sec. to discharge
Beginning	20
	20
	15
Maximum	15

3. Calculations

$$E = 21.1 \frac{(1 + 0.301)}{\sqrt{0.0342}} r \log_e \frac{d}{r} \text{ kv. to neutral.}^*$$

where E = visual corona voltage

$r = 0.0342$ = radius of wires in cm.

$d = 7.625$ = distance between centers

$$E = 21.1 \frac{(1 + 0.301)}{\sqrt{0.0342}} 0.0342 \log_e \frac{7.625}{0.0342}$$

$$= 21.1 \frac{(1 + 0.301)}{0.185} 0.0342 \log_e 223$$

$$= 21.1 (2.625) 0.0342 (5.4025)$$

$$= 10.25 \text{ kv.}$$

E (as read from the sphere gap voltmeter) = 10 kv.

* Magnusson's "Alternating Currents," formula (546).

V.

CONCLUSIONS

1. Statement

The abrupt stoppage of the electroscope from discharging when the corona was suddenly stopped indicates that free ions do not last long after ionization by collision has ceased but immediately recombine to form neutral molecules.

Theoretically the negative ions would be expected to have greater effect upon the electroscope because they have smaller mass and, consequently, travel faster and farther from the corona. If such had been the case, the electroscope positively-charged would have been discharged and negatively-charged it would have tended to receive a greater negative charge from the negative ions of the corona. The opposite was true. This fact seems to indicate that positive ions have heavier positive charges than negative ions have negative charges, or else positive ions are more numerous than are negative ions.

The effect of wind on ions is very marked. It blows them farther away from the corona, making it possible to detect corona by the electroscope at much greater distances from the corona than is possible in still air.

2. Application

The results of the experiments performed indicate that a practical device for detecting corona on high-tension transmission lines can be made with the electroscope as a basis for the invention. The device may have a means incor-

porated within itself for creating a draft to draw ions to the electroscope, or it may take advantage of the wind.

3. Summary

The effect of ionization is very short-lived.

The negatively-charged electroscope is discharged and the positively-charged electroscope is charged by corona.

Wind blowing from corona to electroscope makes detection at greater distances from corona possible.

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APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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