A STUDY OF THE RESISTANCE OF DRIVEN GROUNDS

by

Clyde E. Dyer

and

Luther Fillmore McPherson, Jr.

A THESIS SUBMITTED FOR THE DEGREE OF

BACHELOR OF SCIENCE

ELECTRICAL ENGINEERING COURSE

The University of Tennessee

1933

TABLE OF CONTENTS

	Page
Introduction	1.
General Survey of Grounding	2.
Purpose	6.
General Theory	7.
Description of Method and Apparatus Used	9.
Conclusions	17.
Bibliography	19.
Appendix	20.

Introduction.

There are several types of protective devices used in modern electrical transmission and distribution construction to afford protection of transformers, insulators, switches, and other equipment from lightning, and other unusual surges on the lines. The value of all these types of equipment depends upon their ground connections for conducting the lightning and other surge discharges to earth. Proper grounding of equipment, then, is an important problem, and, since conditions of soil and climate affect the resistance of grounds, it is a problem which must be studied for the particular locality where it is desire to place a ground.

To persons interested in effective grounding, and especially to persons interested in good grounding in the territory contingent to Upper East Tennessee, this treatment of the subject should be of interest. Engineers in charge of grounding in the various electric utilities of this section should note the way in which the ground resistance varies with climatic conditions, and how the great fluctuations may be dampened and the resistance lowered by proper treatment.

This paper includes the tabulated results of a series of tests made in a clay soil on the property of W. A. Cook in Holston Hills Addition, Bristol, Tennessee.

Curves of rainfall, temperature, and the resistance of the varied grounds are plotted together against time so that their relations may be more readily seen.

A resume' of grounding practices of electric utilities, past and present, and the developments in securing more effective grounds is made to emphasize the importance of continued study in this line. The tests made in connection with this paper differ from other similar tests in that they show for the same soil the effect of depth as well as the effects of different methods of salt treatment upon the ground rod resistance. They also differ

from other tests in that the location of the rods was isolated from power lines and hence the effects of stray currents on the test results was minimized.

The East Tennessee Light and Power Company of Bristol, Tennessee-Virginia has furnished valuable assistance in the preparation of this thesis in furnishing the use of equipment, time, and reference material. Prof. W. H. MacIntire of the University of Tennessee, Agricultural College, very graciously tested the soil in which the ground rods were driven and offered valuable suggestions for treatment of soils for lowering their resistances. Mr. Wilbur Velsor of the U. S. Forestry Service assisted in furnishing rainfall data for Bristol, Tennessee. We greatly appreciate the assistance of these mentioned above, and of the help of several others in conducting the tests, and in preparing this paper.

General Survey of Grounding.

The importance of low resistance grounds on electrical substation and distribution equipment, for safety and for better operation has not been fully realized by operating companies until comparatively recent years. Up until the last six or seven years most grounds were made haphazardly, and without any test being made of its resistance, it was expected to furnish all the protection needed. Later tests revealed the grounds to have resistances of over one thousand ohms and to be useless in preventing destruction of transformers and other equipment by lightning and other surges.

The November - December 1931 issue of Grounding Notes tells of a company which recently made a survey of its grounding conditions. These conditions illustrate the negligent attitude that many companies have had toward their grounding conditions. A few of the conditions found in the survey were as follows: (1) Some rods, driven too close to the poles had

gone into the poles; (2) Some rods had been sawed off to a fraction of the standard length; (3) Many of the connections between ground rods and ground wires were faulty or broken off completely; (4) Some rods had been placed in the hole and set with the pole, and were loose and ineffective. Even yet many companies have not established standard grounding practices, and neither test their grounds at installation or subsequently, trusting only to chance for proper protection. A Report on Distribution Grounding Practices on Circuits of 13,200 Volts and Below made at the Southeastern Division of N. E. L. A. at St. Petersburg, Florida, April 1931, shows that eight out of eighteen reporting companies did not make a test of ground resistance at installation and seven made no kind of periodic test.

This negligence, however, is fast disappearing. Within the last two years, operating companies have started adopting more or less standard practices. Old grounds are being tested for resistance and inspected for their physical condition, and new grounds are tested at installation and made to conform to whatever standards the companies have adopted.

The 1931 National Electrical Code requires that, "Driven electrodes shall be driven, except where rock bottom is encountered, to a depth of at least eight feet regardless of the size or number of electrodes." "The grounding connection ------- shall be permanent and effective." Multiple grounds must be used when the ground resistance is above twenty-five ohms, and any two rods in multiple must be at least six feet apart.[1] There are different ideas, yet, as to the maximum allowable ground resistance for various types of grounds.

1. Hubbard & Co., Grounding Notes, Vol. 2, No. 6, Pittsburg, Chicago, Oakland. November - December 1931.

One competent engineer recommends the following maximums:

Lightning Arrestors

Primary Distribution, Pole Type	15 ohms
Primary Distribution, Station Type	5 ohms
Signal Circuits	25 ohms
Telegraph Circuits	25 ohms
Telephone Circuits	25 ohms
Radio Receibing Sets	5 to 25 ohms

Power Distribution

Secondary Grounding	25 ohms (N.E.C.)

Building Wiring

Service Grounds	25 ohms (N.E.C.)[1].

Consistant with the lightning arrestor and other protective equipment investments, and with standard safety practices, operating electric companies, should and are adopting and enforcing more rigid grounding standards and are taking steps necessary to bring the ground resistances down to the order of the allowed resistance.

There are, in general, three ways in which lower ground resistance is obtained. The most generally used method is the addition of other electrodes in parallel with the first and at least six feet from it. It is possible in this way to permanently reduce the total resistance as much as forty per cent with two electrodes or more with a greater number of electrodes. The results of a test made by H. M. Towne in Lightning Arrestor Grounds is shown in Figure 1.

1. Hubbard & Co., Grounding Notes, Vol. 1, No. 2, Pittsburg, Chicago, Oakland. March - April 1930.

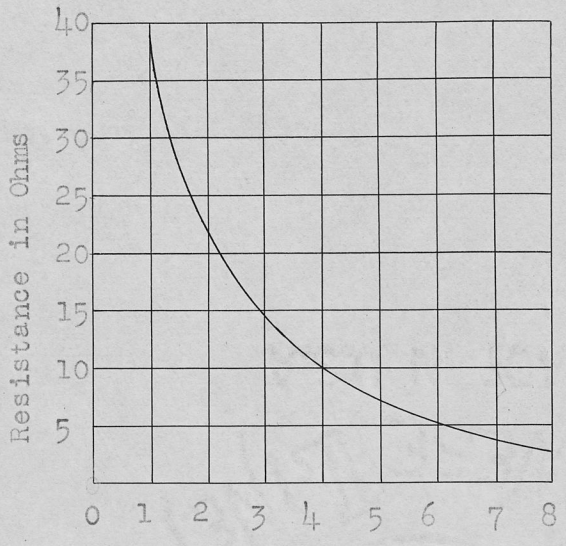


Figure 1.

This curve shows the possiblities of increasing ground conductance through the use of multiple grounds.

The next most common means of reducing ground resistance is through chemical treatment of the soil. Most of the treatments commonly used are not permanent and must be repeated every two or three years depending upon the compactness and drainage of the soil treated. Some of the more common treatments are sodium chloride (NaCl), calcium chloride (CaCl), copper sulphate ($CaSO_4$) and magnesium sulphate ($MgSO_4$). In the interview with Prof. W. H. MacIntire (Appendix) are other suggestions. By chemical treatment it is possible to decrease the ground resistance to almost any desired value depending upon the manner and amount of treatment.

The third way of reducing ground resistance is by special location of the rods. This applies only in special cases where it is impossible to secure the desired earth conductance at the place desired. Substations at generating plants and other places near a large water supply such as lakes

or streams often have driven grounds in either the bed of the stream or lake. Where possible the grounding of certain substations is made in swampy areas. The purpose in either of the above cases is to keep a permanent high moisture content at the ground and thus secure a low resistance.

Purpose.

Since studies of the effects of climatic conditions on the resistance of driven grounds are few; and since none of those published and available are for locations in the vicinity of Bristol, Tennessee-Virginia; and further, because, to be of use in a particular locality, such a study should be made under conditions similar to those of that locality, ground rods were driven and tested periodically for their resistance from November 4, 1932 to April 10, 1933.

It is proposed in this paper to present the results of this study of the resistance of a very acid, clay soil that is common in and around Bristol, Tennessee-Virginia and other parts of Sullivan County, Tennessee; to show the relations of temperature, rainfall, and other climatic conditions to the resistance of driven grounds; and to analyze these results and relations for any general statements that may be made concerning the resistance of driven grounds. From observation, from theoretical consideration of the chemical properties of different types of earth, and from the experiences of other persons and companies, suggestions will be submitted for the location and chemical treatment of driven grounds to secure low ground resistance at places where conditions are similar to those at the location studied.

General Theory.

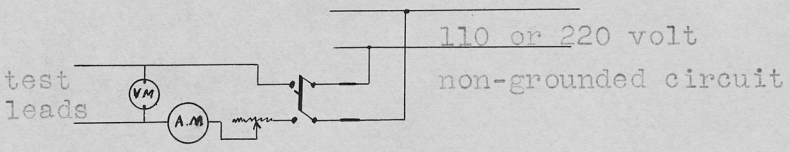
The engineer is continually increasing the effectiveness of protective devices to immunize transmission or distribution lines from lightning failures or interruptions. There are many relatively new operating practices, all of which are dependent upon the effective grounds for conducting the surge to earth. While the grounding problem varies somewhat with different geographical locations, the underlying principles apply universally and a little experimentation will disclose the most economical grounding practice for any local conditions.

The variations of the resistance of soils of different textures and chemical compositions are found in practice to be from a few hundred ohms to a million ohms or more per cubic centimeter. The resistance depends upon the ionic properties of the soil, the amount of moisture in the soil, and the temperature of the soil. The electrical conductance depends upon the electrolyte formed by moisture combining with the soluble acids, alkalies, and salts. It is therefore evident that the specific resistance is determined largely by the amount and kind of chemicals and the amount of moisture in the soil.

If the experimentation includes a chemical analysis of the soil and simultaneous readings of soil temperature, moisture content, and resistance, it will disclose the most economical and effective grounding practice for that location. Many electric utility companies do not make an extensive study of their ground resistances, but whenever a low resistance ground is required it is necessary to make a complete study of the local conditions of the earth.

A study of the ground condition must first of all include a measurement of the ground resistance. Several methods are available for doing this. From the voltage drop and current, measured in a circuit fed by a 110 volt

or 220 volt non-grounded supply, to the ground rod whose resistance is to be measured and to a water pipe or other practically zero resistance ground.



Voltmeter-Ammeter Method

Figure 2.

The ground resistance may be calculated by Ohm's law, $R=\frac{E}{I}$, where R = resistance of ground, I = current in the circuit, and E = voltage drop from the top of the ground rod to the water pipe. A very good method that may be used when there is no water pipe or other known resistance ground available is the three point method. In this method two auxiliary grounds must be driven. For accuracy, these should be at least twenty feet apart and in earth similar to that of the rod being tested. If the rods are A, B, and C (Figure 3), the resistance of each pair is determined by the

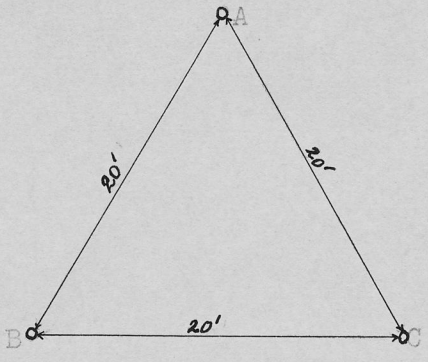


Figure 3.

voltmeter-ammeter method and the resistance of any one of the rods is determined by the algebraic equations below.

$$A = \frac{1}{2}(AB+CA-BC)$$

$$B = \frac{1}{2}(AB+BC-CA)$$

$$C = \frac{1}{2}(CA+BC-AB)$$

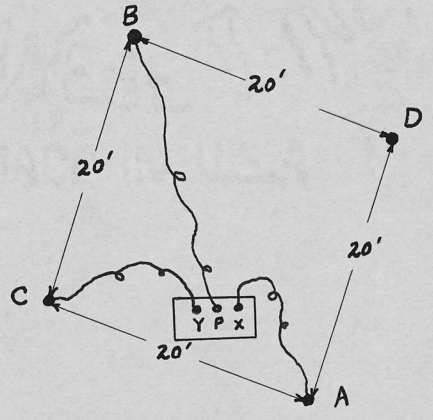
When ther are many gounds to measure, it is desirable to use an instrument that may be easily used, and that reads directly in ohms resistance of the ground being tested. There are several good commercial instruments for this purpose that operate on various principles involving unknown resistances. The choice of method to be used in testing grounds will depend upon the availability of reference grounds, and upon the number of grounds to be tested.

Description of the Method and Apparatus Used.

For the series of tests of ground resistance made in this study, a commercial ground testing instrument, the Type E, Groundometer manufactured by Borden Electric Company of Newark, New Jersey, was used. This meter was chosen because: (1) It reads directly in ohms resistance of the ground being measured; (2) It is accurate to the nearest scale division, that is to say, for resistance less than five hundred ohms it is accurate to the nearest five ohms, for resistances less than one hundred ohms it is accurate to the nearest ohm, and for resistances less than fifty ohms it is accurate to the nearest one-half ohm; (3) It is compact and easily portable, and not too fragile; (4) The instrument was available for these tests at all times, and was more quickly operated than any other instrument or method available.

The use of this Type E Groundometer requires two reference grounds. To avoid the driving of auxiliary ground for each test, all of the ground rods being tested were grouped together so that two of the rods could be

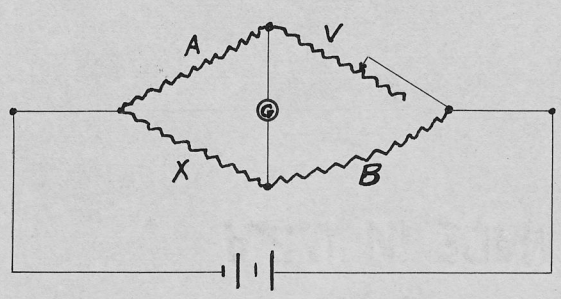
used for reference while one of the others was being tested. (Figure 4). The rods were all driven in similar ground so that the factor of dissimilar earth would be eliminated in the comparison of the resistances of the ground rods. Four five-eighths inch copperweld ground rods were driven. One eight foot rod with no treatment was first driven. To study the effect of the depth of a rod on the resistance, a four foot rod was driven. To study the effect of an average treatment with salt an eight foot rod was driven and fifty pounds of ice cream salt placed in a trench around the rod. To compare the difference in effect in treating the ground periodically with small amounts of dissolved salt, and in treating with fifty pounds of salt at one time, and eight foot rod was driven with a shallow trench around it for pouring a salt solution on the ground periodically. Resistance of each of the grounds was determined each week and the results tabulated with the atmospheric temperature and weather conditions (Appendix) and plotted against time for comparison.



Connections for testing rod A

Figure 4.

The Borden Electric Company Type E Groundometer is fundamentally a Wheatstone Bridge. The auxiliary ground resistances P and Y of the Groundometer circuit (Figure 6) correspond to the resistances, A and B of the Wheatstone Bridge. (Figure 5). But since A and B must be equal the

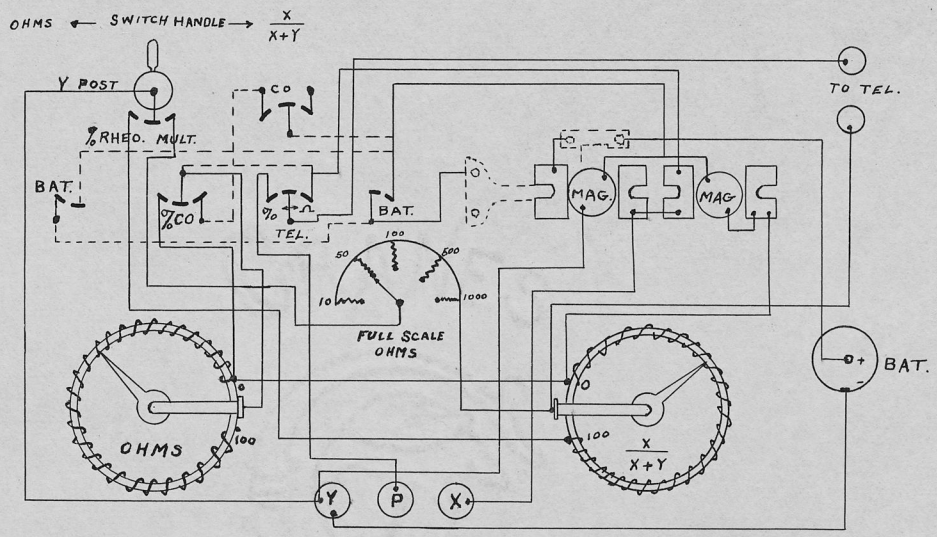


Wheatstone Bridge

Figure 5.

resistance P and Y are balanced by a rheostat which is the percentage dial on the Groundometer. After these resistances are balanced the switch is thrown to the ohms position with the second rheostat in the circuit. This rheostat corresponds to the resistance V of the Wheatstone Bridge, and is graduated to read directly the ohms resistance of X the ground connection being tested. This Galvenometer of the Wheatstone Bridge is replaced by a phone receiver in the Groundometer.

"The arrangement for providing the operating current for the Type E meter and also the arrangement and operation of the magnets and automatic cut outs are most easily understood by reference to the wiring diagram. (Figure 6). The source of energy is a single dry cell and in normal operation, the current passes from this cell through the interruptor and the starting switch to the interruptor magnet and thence back to the battery. From the the starting switch the current flows also through the rheostat magnet to the bridge where it divides, passing through the multiple circuits of the bridge proper, and thence back to the battery."



Type E Groundometer

Figure 6

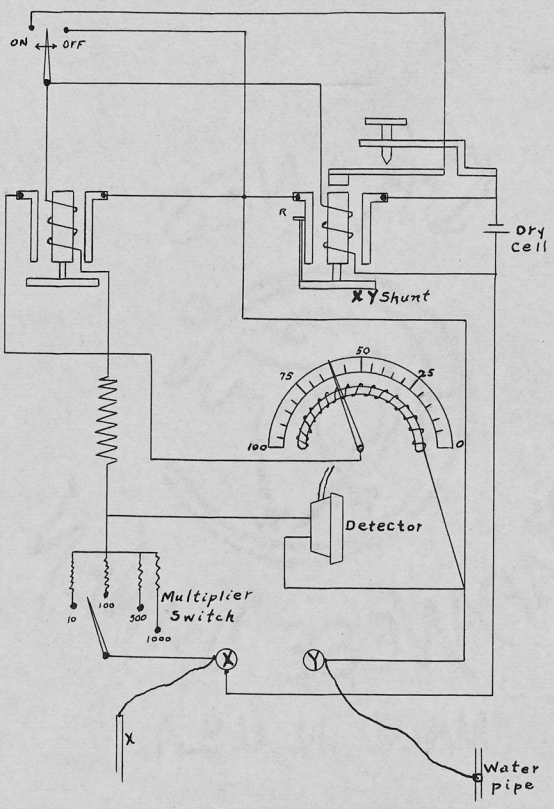
"When the interruptor parts make contact, the current from the battery passes directly through the bridge, there being no resistance in circuit other than the rheostat magnet coil. At the same time the current flows through the interruptor magnet. When the interruptor parts break contact the interruptor magnet, which is iron clad, kicks back through the bridge circuit and the result is a peculiar bridge current which is made up of two components, i.e., the current which flows directly from the battery when the contacts are closed and the kick current from the interruptor magnet which follows immediately upon the opening of the interruptor contacts. As the value of the resistance connected between X and Y, and the amount of resistance in the variable arm decreases, the flow of current through the bridge, which results from the interruptor contacts being closed, gradually increases to a maximum of approximately two-tenths of an ampere, thus providing ample bridge current for the measurement of very low resistances, while on the other hand the kick current from the interruptor magnet is of relatively high voltage and increases the sensitivity of the bridge when the resistance being measured is of relatively high ohmage."

For protection against short circuits through the equipment the Type E Groundometer is equipped with cut outs. "If a Type E Groundometer be connected to electrodes across which there is a difference of potential, resulting in a flow of current through the meter, the action of the cut out is as follows: When the starting switch is in the "off" position, only the interruptor magnet is in the circuit. If the flow of current is light it will be indicated by the interruptor itself vibrating, while if it is of sufficient magnitude to be at all injurious to the magnet winding the armature will be attracted against the iron poles which results in connecting the single dry cell battery directly across the binding posts X and Y, thus forming a very low resistance shunt to the Groundometer and one of sufficient

carrying capacity to protect the meter against serious injury up to a flow of approximately one hundred amperes, for a sufficient period to blow a line fuse or operate a circuit breaker."

"If the meter is switched "on" while current from an exterior source is flowing through the meter, or if such exterior current developes while readings are being taken, the foreigh current passes through the rheostat magnet and through the bridge. The current through the bridge flows almost entirely through the rheostat because its resistance is always relatively low with respect to the resistance of the other two arms in series. The carrying capacity of the rheostat is approximately one-half ampere. However, the rheostat magnet is adjusted to operate on about four-tenths of an ampere, and its operation results in short-circuiting the rheostat and, so far as the bridge itself is concerned, the conditions become the same as though the meter was switched off, the only difference being that both magnets are now in series across the binding posts X - Y, and the interruptor may be operating. If the exterior current exceeds about five amperes, the main line cut out will operate, thus shunting the dry cell battery across the binding posts X - Y."

"From (Figure 7) it is obvious that the meter measures the total resistance of the two electrodes connected to posts X and Y, that is, the resistance of the two electrodes in series. The rheostat scale is divided into one hundred divisions and marked zero to one hundred. If the multiplier switch is placed on the one hundred contact, the pointer on the rheostat indicates directly in ohms, the value of the resistance of the circuit between the X and Y binding posts. If the multiplier switch is on the ten point, then the rheostat pointer indicates ten times the correct value and the reading must be divided by ten and similarly if the multiplier switch is placed in any position other than one hundred, the reading on the scale



Type D Groundometer

Figure 7

must be divided or multiplied by the appropriate factor."

"It is also apparent that if, without changing anything else the value of the fixed resistance is reduced to one-half its original value, the meter still continues to measure the series resistance X plus Y, but it will indicate on the scale, when balanced, only one-half of the previous value. In other words, if a reduction is made in the value of the fixed resistance, there must be a corresponding reduction in the value of the resistance cut into the rheostat when the bridge is brought into balance."

"Assume, for instance, that the resistance of electrode X is twenty-five ohms and the resistance of electrode Y is seventy-five ohms, then if the multiplier switch is on one hundred, the meters will balance when the rheostat pointer is turned to the one hundred position. If now the fixed resistance is reduced twenty-five per cent of its previous value, the meter will then balance when the rheostat pointer is at twenty-five, and twenty-five is the value of the X electrode. This had been brought about by the fact that the fixed resistance was adjusted in such a way that the portion remaining in circuit, twenty-five per cent, bears the same relation to the full resistance (100%) as the resistance of the X electrode (twenty-five ohms) bears to the total resistance of X plus Y (one hundred ohms). This is the basic principle used in the Type E Groundometer in order to obtain a direct indication of the value of the X electrode without the necessity of using a formula or other calculations."[1].

The resistance of the test leads is not important with the possible exception of the one used for connecting the X electrode to the X binding post, since this is the only lead whose resistance is included in the final reading. A test lead of number eighteen rubber covered lamp cord, fifty

1. Borden Electric Company, Type E Groundometer, Bulletin No. 120, Pgs. 3, 4, and 5. Newark, 1930.

feet long, has a resistance of approximately three-tenths of an ohm, which obviously may be ignored, except when testing very low resistance grounds. It should be kept in mind that the instrument is designed for measuring the resistance of non-inductive circuits, and will not give good results for circuits containing more than a small amount of inductance. The most important precaution, however, is in having the correct relative values of the X and Y resistances. Too large a ratio between electrodes is almost sure to result in serious error, irrespective of the type of test meter used, and it is therefore important to know that the ratio is within proper limits.

Conclusions.

From the results of the test we may draw the following conclusions:

(1) The resistance of a four foot rod was found to fluctuate more with weather conditions than the resistance of an eight foot rod.

(2) In the test data rod C was treated with fifty pounds of salt at the beginning of the test, and rod D with five pounds at intervals as shown. After six weeks rod D with only two treatments was of lower resistance than rod C, and remained lower throughout the tests. This indicates that to secure more immediate effect of treatment, the salt should be completely dissolved in water and poured around the rod. However, a theoretical analysis of these treatments leads to the conclusion that the treatment of rod C will be of a more permanent nature than the treatments of rod D. Except in the case of special gounds where it is desire to maintain a low resistance, it is not recommended that the above periodic treatment be used, but rather, that a treatment similiar to that of rod C be used, and examined at set periods so that additional treatments may be made when required.

(3) A test was made of two rods in parallel using all combina-

tions of the rods driven. In each case, the use of two grounds in multiple showed a reduction in the total resistance of ten to forty percent. Since most operating companies use multiple grounds to secure permanent low resistance and since the results of the test indicates that this is an effective way to secure low resistance it is suggested that, if it is economical, this method be tried before chemical treatment, especially if the location is unfavorable to treatment, such as under a paved street.

(4) Climatic conditions which affect the resistance of grounds are temperature and rainfall. The test results show that resistance increases for frozen earth and decreases as the earth temperature increases. A comparison of the rainfall and ground resistances from the curves shows that resistance decreases with an increase in soil moisture and increases with lack of moisture.

By giving the above conclusions proper consideration any rod may be treated to give the desired conductance. This, however, is not always advisable due to the expense in reducing the resistance of some ground rods to the desired value. It is therefore evident that the engineer must base some of his conclusions on personal opinions derived from past experiences.

BIBLIOGRAPHY

1. Borden Electric Company, Type E Groundometer, Bulletin No. 120, Newark, 1930.

2. Electric Apparatus Committee, Southeastern Division of N. E. L. A., Calculations of Ground Currents, H. G. Harvey, Chairman, Atlanta 1929.

3. Electric Apparatus Committee, Southeastern Division of N. E. L. A., Protective Grounding for Generating Plants, Atlanta, April 1929.

4. Ground Currents Sub-Committee, Southeastern Division of N. E. L. A., Report on Distribution Grounding Practices on Circuits of 13,200 Volts and Below, St. Petersburg, 1931.

5. Hubbard and Company, Grounding Notes, Vol. 1, 2, 3, Pittsburg, 1930-33.

6. H. M. Towne, "Lightning Arrestor Grounds", General Electric Review, Vol.35, New York, 1932.

7. H. M. Towne, Improved Methods of Lightning Protection in Power Distribution, C. E. A. Convention, Murray Bay, P. Q., June 1932.

APPENDIX

TEST DATA

Date	Ohms Resistance				Treatments of D*	Temperature Fo	Weather
	A	B	C	D			
11-11-32	150	310	198	177	5 lbs salt	50	Raining
11-13-32	158	355	61	84		34	Clear
11-19-32	145	285	46	68		36	Light rain
11-23-32	159	320	51	65	5 lbs salt	63	Clear
11-27-32	153	294	57	61		32	Ground wet
12-6-32	158	355	59	64		56	Ground dry
12-15-32	150	285	59	59		32	Raining
12-21-32	160	290	69	61		43	Snow
12-30-32	150	255	57	46	5 lbs salt	64	Clear
1-5-33	160	300	66	49		52	Ground wet
1-13-33	150	270	75	48	5 lbs salt	43	Ground wet
1-26-33	135	230	56	44	5 lbs salt	54	Ground wet
2-3-33	140	235	60	42		49	Clear
2-10-33	150	275	70	45	5 lbs salt	28	Ground frozen
2-17-33	150	275	65	44		47	Ground wet
2-24-33	150	250	52	40		64	Clear
3-6-33	175	325	50	45		51	Clear
3-11-33	175	275	55	45	5 lbs salt	39	Cloudy
3-18-33	150	270	50	42		73	Ground wet
3-26-33	153	272	51	47	5 lbs salt	52	Ground dry
4-2-33	145	270	47	36		70	Ground wet
4-10-33	153	300	52	37		80	Ground dry

* Salt dissolved in five gallons of water.

TEST DATA CONTINUED

Date	Ohms resistance in parallel					Ohms resistance single			
	AC	BC	AB	AD	BD	A	B	C	D
1-5-33	48	58	105	41	45	160	300	66	49
1-13-33	49	59	95	39	43	150	270	75	48

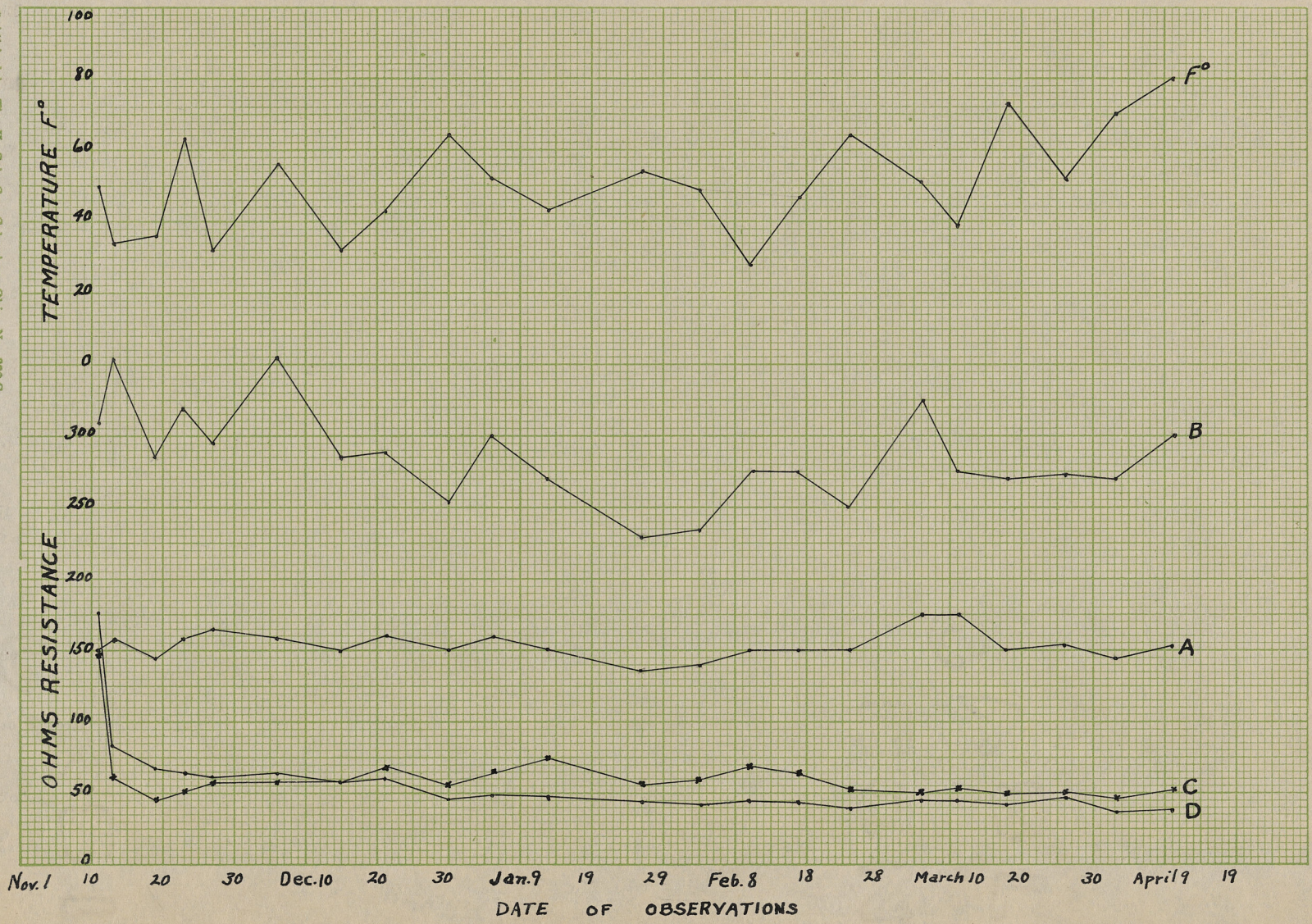
Rod A - 5/8 inch, eight foot copperweld, non-treated.

Bod B - 5/8 inch, four foot copperweld, non-treated.

Rod C - 5/8 inch, eight foot copperweld, one fifty pound treatment at beginning of test.

Rod D - 5/8 inch, eight foot copperweld, with five pound treatments as shown in data.

Published by The H. Cole Co., Columbus, Ohio, No. 290 G.



RAINFALL DATA

U. S. Forestry Service, Bristol, Tennessee

Date		Rainfall
November 1, 1932		0.97 inches
9		0.43
10		0.23
18		0.32
28		0.21
	Total	2.16 inches
December 1, 1932		0.23 inches
5		0.41
8		0.36
13		1.02
16		1.53
18		0.74 plus 2 inches snow
22		0.43
26		1.22
28		0.76
	Total	6.70 inches

Rainfall Data Continued:

January 7, 1933	0.02 inches
10	0.25
14	0.34
19	0.24
21	0.39
26	0.28
31	0.12
Total	1.64 inches
February 4, 1933	1.03 inches
8	0.82
12	0.27
16	2.31 plus 2 inches snow
21	0.42
23	0.34
24	0.58
Total	5.77 inches
March 7, 1933	0.08 inches
8	0.28
9	0.10
10	0.14
15	0.54
18	0.17
19	0.85
20	0.12
21	0.27
25	0.02
26	0.03
28	0.03
Total	2.63 inches

Rainfall Data Continued:

Date	Rainfall
April 1, 1933	0.47 inches
3	0.08
4	0.25
6	0.08
7	0.12
12	0.42
16	0.50
17	0.11
19	1.20
25	0.05
	3.28 inches

RESULTS OF SOIL TEST AND INTERVIEW WITH PROF. W. H. MACINTIRE

The sample of earth from the premises where the ground resistance is being tested was analyzed in the Agricultural Department of the University of Tennessee and found to have a P.H. of 4.5. This indicates an extremely high acid soil, and a very low percentage of calcium salts, and a low percentage of phosphates. This absence of salts from the soil accounts somewhat for the relatively high resistance (in the order of 150 ohms) of the soil. The soil is composed almost entirely of clay with a very small percentage of small gravel. Ordinarily a soil with as much clay as this would have a low resistance because of its compactness, but this, because of the absence of salts is rather high.

Prof. W. H. MacIntire, discussing the subject, suggested that a very good treatment to increase the conductivity would be to add sodium acid sulphate to the soil in a manner similar to that used in treating with NaCl. This, he said would last much longer than the NaCl, possibly ten to twenty years. However, it would not take effect as rapidly as NaCl. Hence, he suggested making a treatment including both salts, the NaCl to give immediate results and the $NaHSO_4$ to give permanence. The reason for the permanence of one and the lack of permanence for the other is that in the latter the sodium enters into the composition with the soil and in the former the sodium stays in composition with the chlorine and washes away.

For soils lacking in compactness, hence having a very high resistance, Prof. MacIntire recommends treating the soils with sodium silicate and sodium phosphate. Sandy or loos loamy soils would need this treatment. The sodium silicate (commonly water glass) he recommends that it be poured into a hollow ground rod, perforated to allow solution to penetrate the soils. The sodium phosphates when added would combine with any calcium in the soils and form a sticky, clayey soil favorable to a good conductivity. All these are low in cost.

A P P R O V A L

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.

Name J.G. Tarboux

Title Professor of Electrical Engineering