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COMPARISON OF CALCULATED AND MEASURED CORONA LOSS CURVES

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ABSTRACT OF PAPER

Corona loss curves made on a number of experimental and practical lines by different investigators have been corrected and plotted. The loss has been calculated by the quadratic law for each case under the same conditions as to spacing, conductor diameter, altitude, etc. and plotted for comparison.

It is of interest to note that the measured values were made at various parts of the country. The time period covers a number of years and the altitude varies from sea level to 10,000 ft. An exact check of calculated and measured losses cannot be expected, as the exact conditions are not always known as to conductor surface, wave shape, etc. Such losses are also difficult to measure, especially on practical lines where the voltage range is quite small and there are a large number of corrections to make. The check is as close as the accuracy of the measurements permit. The variations from the calculated values are in most cases due to the fact that practical measurements have been made on the unstable part of the curve below the visual critical voltage value. The losses at this part of the curve are fully discussed.

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It is of interest to note that the measured values were made at various parts of the country, by independent investigators, and that the time period is a number of years. The altitude varies from sea level to 10,000 ft. An exact check of calculated and measured losses can not be expected, as the exact conditions are not always known as to conductor surface, wave shape, etc. Such losses are also difficult to measure, especially on practical lines, where the voltage range is quite small and there are large corrections to make. In most cases, when such loss curves on practical lines have been given, measurements have not been carried above the *visual critical corona point*.

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Before an examination of the curves is made, attention is called to the following summary of facts which are fully discussed in "Law of Corona I."*

The law of corona takes the general form

$$p = c (e - e_0)^2$$

which means that under conditions otherwise constant, the loss varies as the square of the applied voltage above a certain critical voltage, e_0 or e_d . Figs. 1 and 2 show characteristic curves. The critical voltage, e_0 , is called the *disruptive critical*

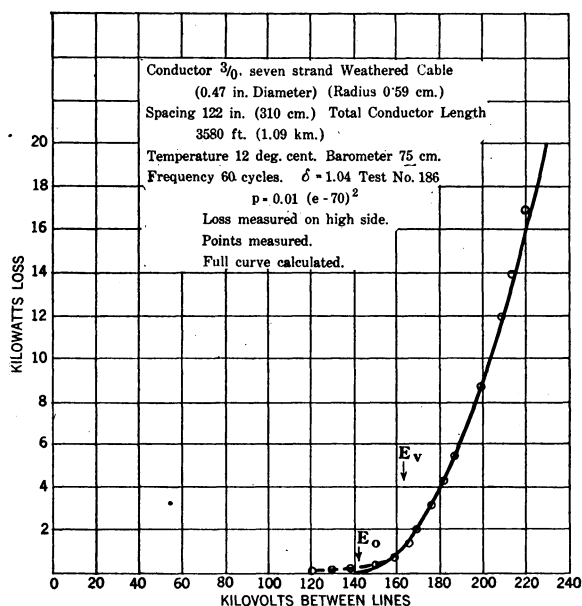


FIG. 1—OUTDOOR SINGLE-PHASE, EXPERIMENTAL LINE. (TESTS MADE BY F. W. PEEK, JR., SCHENECTADY, 1910)

voltage. Visual corona does not start at the *disruptive critical voltage*, but at some higher voltage e_v , the visual critical voltage. Both of these voltages have been calculated and marked on the curves. Theoretically, if the conductors were perfectly smooth, no loss should occur until the visual critical voltage, e_v , is reached, when the loss should suddenly take a definite value. For e_v , and higher voltages, the loss should follow the quadratic law.

*Trans. A. I. E. E., 1911. See also *Law of Corona II* Trans. A. I. E. E., 1912. High Voltage Engineering, *Journal of Franklin Institute*, December, 1913.

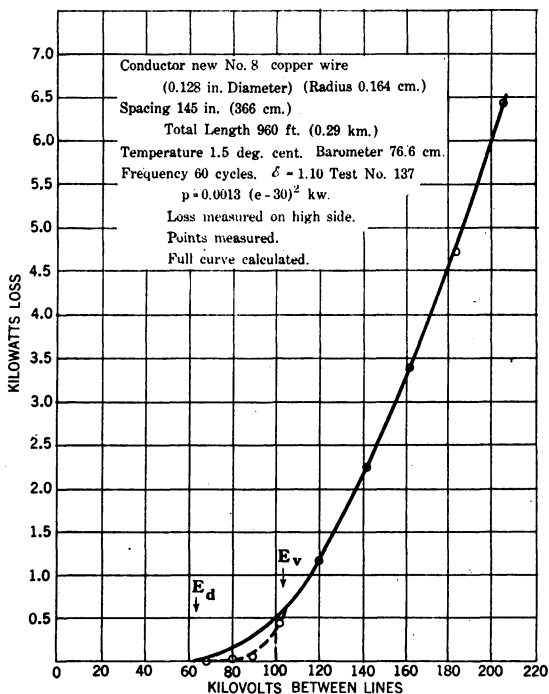


FIG. 2—OUTDOOR SINGLE-PHASE EXPERIMENTAL LINE. (TESTS MADE BY F. W. PEEK, JR., SCHENECTADY, 1910)

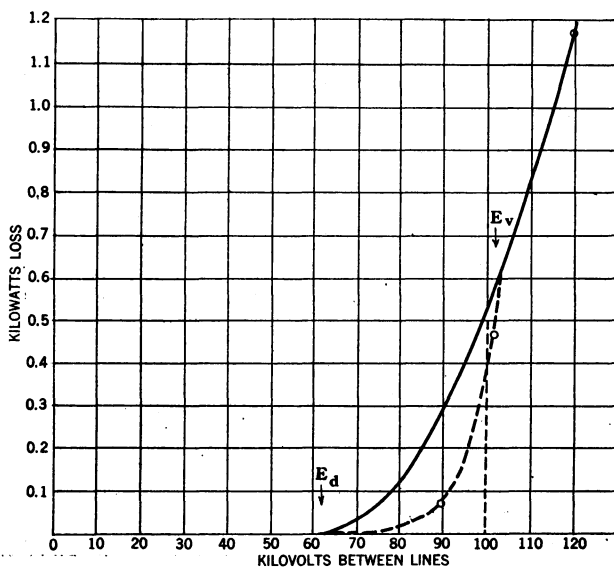


FIG. 3—LOWER PART OF FIG. 2 TO AN ENLARGED SCALE

In practise, due to dirt, points, etc., brushes occur on the conductors at voltages lower than e_v . Between e_v and e_o , due to these brushes, there is a loss. This loss practically follows the quadratic law for large weathered conductors, where e_v and e_o approach each other in value. See Fig. 1. For small conductors and especially new conductors with fairly clean surfaces, the loss between e_v and e_o falls below that of the quadratic law, as

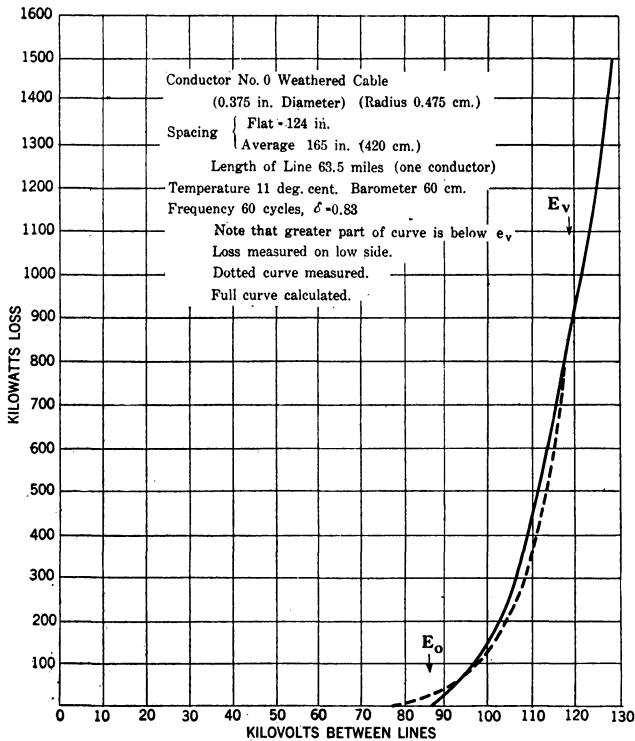


FIG. 4—SHOSHONE-LEADVILLE TRANSMISSION LINE, THREE-PHASE.
(TESTS MADE BY FACCIOLI)

shown in Figs. 2 and 3. If the conductors were highly polished there would be very little loss until the voltage e_v is reached. At this voltage the loss would suddenly take a definite value very nearly equal to that calculated by the quadratic law with e_v as the applied voltage and e_o as the critical voltage in the equation.* In all cases the loss follows the quadratic law above e_v . The part of the loss curve between e_o and e_v

* e_o or e_d must always be used as the critical voltages in quadratic law.

will thus vary from day to day depending upon the chance condition of the conductor surfaces. Over this unstable section of the curve the loss follows the probability law. It is of practical importance only to know the limits of the loss at this part of the curve; e_v should generally be the limit of voltage on practical lines, as otherwise storm losses become excessive.

Thus, from the considerations above, the quadratic law should

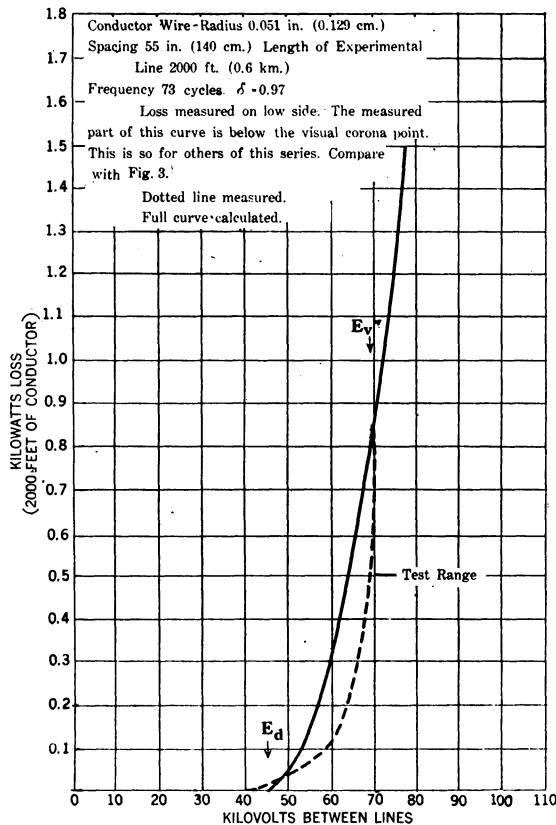


FIG. 5—OUTDOOR EXPERIMENTAL LINE. (TESTS MADE BY MERSHON, NIAGARA FALLS) (SEE TRANS. A. I. E. E., 1908, PAGE 876, FIG. 27)

be closely followed in all cases for voltages higher than e_v . For the part of the curve between e_v and e_o the loss is unstable and dependent upon chance surface conditions, dirt spots, etc. as follows:

1. For large weathered cables, such as are used in practical lines, the quadratic law is closely followed.

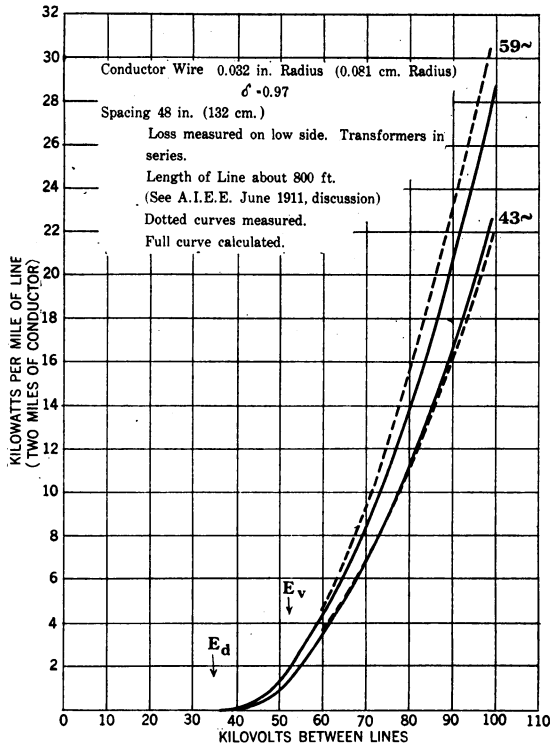


FIG. 6—OUTDOOR EXPERIMENTAL LINE. (MEASUREMENTS MADE BY A. B. HENDRICKS, PITTSFIELD, 1906)

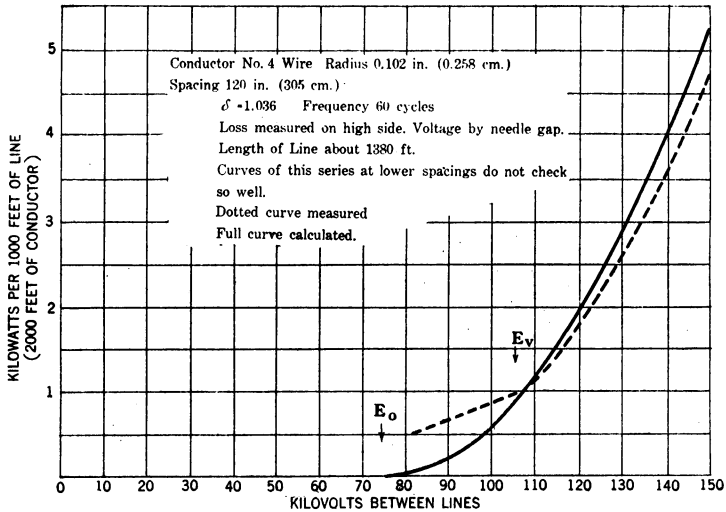


FIG. 7—OUTDOOR EXPERIMENTAL LINE. (TESTS MADE BY HARDING, PURDUE UNIVERSITY). (SEE TRANS. A. I. E. E. 1912, PAGE 1035)

2. For new conductors, and especially small ones, the loss at voltages lower than the visual critical voltage, e_v , falls below the quadratic law.

Figs. 1 and 4 are typical of condition (1), while Figs. 2 and 5 are typical of condition (2).

Figs. 1 to 7 show a remarkably good check between calculated losses and data available from measured losses. Another check, which is given in the N. E. L. A. Bulletin for June, 1912, * might be mentioned here. This paper states that the loss roughly measured on the Eastern Michigan line by station instruments was between 15 and 20 kw. per mile. This line is of No. 0 copper at an average spacing of 174 in. The voltage was 140 kv. at one end and 165 kv. at the other during the test. Under these conditions, the average calculated loss per mile is 15 kw.

The many hundred tests, made on our experimental outdoor and indoor lines, from which the quadratic law was derived, check as in Figs. 1 and 2.

The following formulas were used in making these calculations:

Visual Corona.

$$e_v = m_v g_v r \log_e \frac{S}{r} \text{ kv. to neutral}^\dagger$$

$$g_v = 21.2 \delta \left(1 + \frac{0.301}{\sqrt{\delta r}}\right) \text{ kv. per cm. (effective sine wave)}$$

Corona Loss.

‡For practical transmission lines and frequency near 60 cycles:

$$p = a f (e - e_0)^2 \times 10^{-5}$$

$$e_0 = m_0 \delta_{g_0} r \log_e \frac{S}{r} \text{ kv. to neutral}^\dagger$$

§For small wires and calculation over a greater range of frequency, etc:

*G. Faccioli, "Corona on High Tension Lines," N. E. L. A., Bulletin, June, 1911.

†Kilovolts between lines divided by 2 for single-phase and $\sqrt{3}$ for three phase.

‡Law of Corona I and II, Trans. A. I. E. E., 1911 and 1912.

§High Voltage Engineering, F. W. Peek, Jr., Franklin Institute, December, 1913.

$$p = 241 (f + 25) \sqrt{\frac{r + \frac{6}{S} + 0.04}{S}} (e - e_d)^2 \times 10^{-5}$$

$$e_d = m_o g_d r \log_e \frac{S}{r}$$

$$g_d = g_o \delta \left(1 + \frac{0.3}{\sqrt{\delta r}} \frac{1}{1 + 230 r^2} \right)$$

The probability law

$$p_1 = q e^{-h(e_0 - e)^2}$$

where

p = loss in kilowatts per kilometer of a single-line conductor.

e = effective value of the voltage between line conductors and neutral in kilovolts.

f = frequency.

$$a = \frac{344}{\delta} \sqrt{\frac{r}{S}}$$

r = radius of conductors in cm.

S = spacing between conductors in cm.

$$\delta = \text{air density factor} = \frac{3.92 b}{273 + t} \quad \begin{array}{l} b = \text{barometer in cm.} \\ t = \text{temperature deg. cent.} \end{array}$$

g_o = 21.2 kv. per cm. effective sine wave.

m_o is a constant dependent upon the surface condition.

m_o = 1 for polished wires.

m_o = 0.98 to 0.93 for roughened or weathered wires.

m_o = 0.87 to 0.83 for cables.

$m_v = m_o$ for wires.

$m_v = \begin{array}{l} 0.82 \text{ part corona} \\ 0.72 \text{ complete corona} \end{array} \left. \vphantom{\begin{array}{l} 0.82 \text{ part corona} \\ 0.72 \text{ complete corona} \end{array}} \right\} \text{ cables.}$