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RADIO AND ELECTRICAL ENGINEERING DIVISION

INVESTIGATION OF CORONA ON OVERHEAD TRANSMISSION LINE CONDUCTORS AT HIGH VOLTAGE D. C.

- A PROGRESS REPORT -

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OTTAWA

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ABSTRACT

An investigation is in progress on the corona loss and radio interference characteristics of standard transmission line conductors energized with high voltage direct current. Corona loss has been measured on a single "Drake" ACSR conductor (1.108 in. dia.) and on a two-conductor Drake bundle with 18-inch spacing between conductors. These conductor arrangements were installed, in turn, on a 370-foot outdoor line. A special shielding circuit permits conductor corona losses to be metered separately from both insulator leakage losses and the corona losses from connecting cable and grading ring assemblies.

One type of test on this installation is conducted by recording corona loss currents while varying the voltage applied to the conductor in increments during periods of constant weather. A second type of test is conducted by recording loss currents while holding constant voltage on the test line for long periods under variable weather conditions.

From results obtained to date, it appears that in dry weather single-conductor losses and two-conductor bundle losses are equal, but negative losses are higher than positive losses by a factor of 2 to 3. In wet weather, losses are considerably higher than in dry weather, and positive and negative losses from the two-conductor bundle, and negative losses from the single conductor, are all equal. (Corona loss data in wet weather for the single conductor at positive voltage is not yet available.)

At present, test station facilities are being extended by the erection of a second line to enable simultaneous comparative measurements on conductors to be made; more comprehensive corona loss measurements are under way, and an investigation of radio interference is in progress.

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INVESTIGATION OF CORONA ON OVERHEAD TRANSMISSION LINE CONDUCTORS AT HIGH VOLTAGE D-C — A PROGRESS REPORT

- R.M. Morris and B.O. Pedersen -

INTRODUCTION

The use of direct current in high voltage transmission systems offers a number of possible advantages over the conventional alternating current system, particularly where long lines or cables are employed [1]. In the future, therefore, the d-c method may become more attractive in Canada where there is an increasing requirement for long distance power transmission [2]. Although in Sweden a system employing high voltage direct current has been operated successfully [3], and several others in England [4] and Russia [5] are under development or construction, there are many aspects of the high voltage direct current technique which seem to warrant further investigation. One important class of problem relating to the overhead transmission line is the performance of conductors and insulation at very high voltage. Determination of corona characteristics of transmission conductors has been of particular interest in our laboratory, and such an investigation, being compatible with other projects of the laboratory, was begun some months ago. The objectives of the present work are to determine corona losses and radio noise from some standard conductor sizes and configurations as a function of weather conditions, and to study the laws governing these phenomena.

Early investigations of d-c corona on outdoor lines were carried out by Henning in Sweden [6] and Passerieux in France [7]. More comprehensive tests have been carried on in Sweden during the past ten years. The results of these, together with a review of the present situation relating to high voltage direct current insulation levels and corona phenomena are given in a very recent and comprehensive thesis by Witt [8]. In our present investigation it is intended to obtain more data on the phenomena, particularly under bad weather conditions, to make an improvement in measuring technique if possible, and to extend the measurement to higher voltage levels.

At this time corona loss measurements on a single "Drake"* conductor and on a two-conductor Drake bundle have reached a stage where a preliminary report seems useful. Radio noise measurements are being made and will be reported later.

MEASURING TECHNIQUE

A novel feature of the measuring system is the use of a circuit which permits conductor losses to be measured separately from all other losses. The Drake conductor on which losses are to be measured was manufactured especially for the project and is standard in all respects except for an insulated inner wire. As shown

* ACSR conductor, 1.108" dia., 795,000 cm al. area, stranding al. 26, steel 7

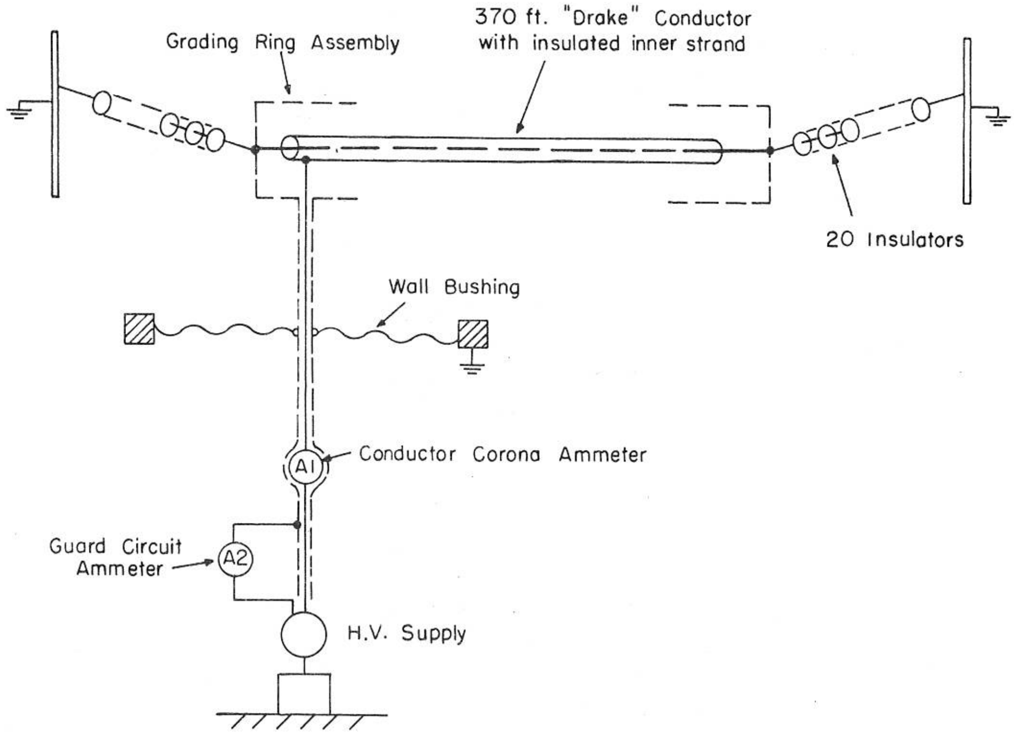


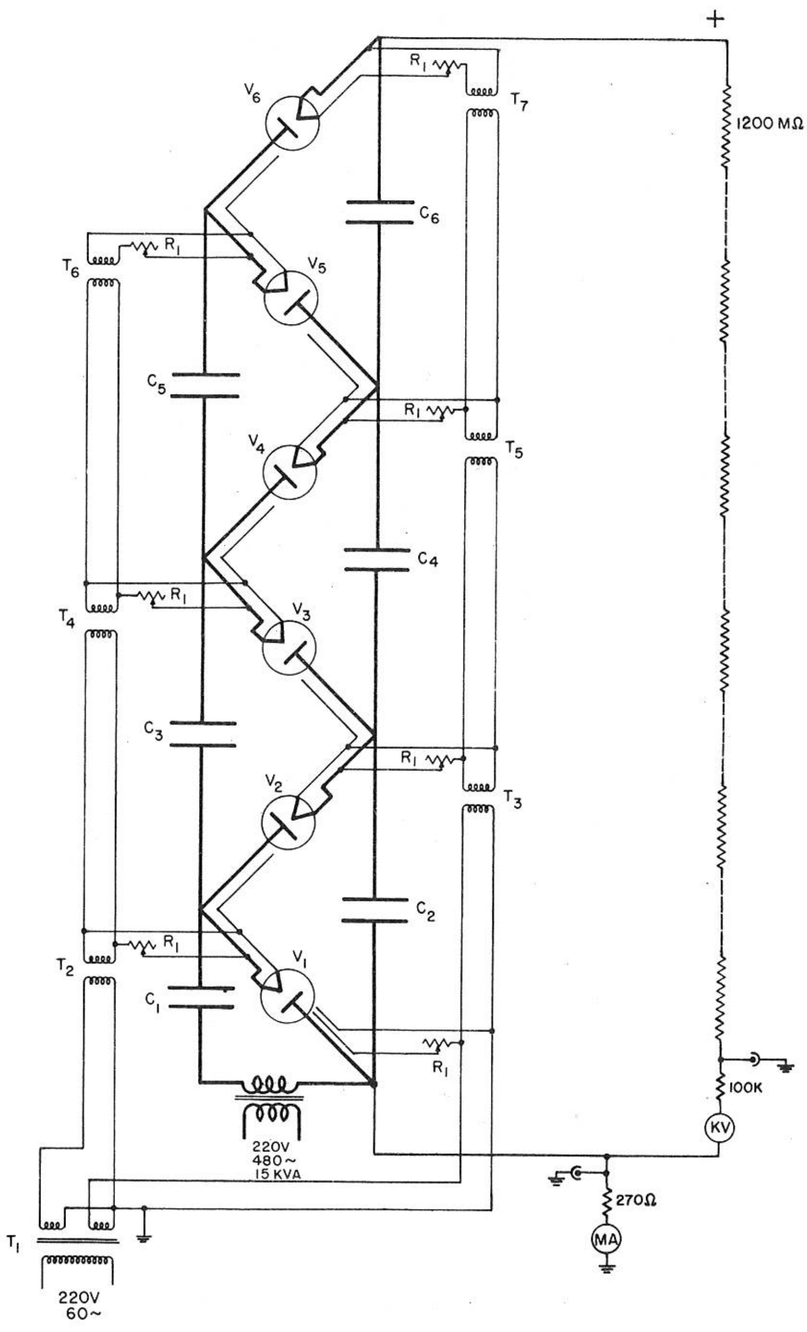
FIG. 1 CORONA-LOSS MEASURING CIRCUIT

in Fig. 1, a completely "guarded" circuit supplies conductor corona loss current. The guard circuit consists of the outer conductor of the coaxial supply connection from the high voltage supply to the line, and of grading ring assemblies at both ends of the line which are connected together by the insulated inner wire of the line conductor. In this way, line loss current is metered separately from guard circuit current, which includes insulator and bushing leakage currents.

Line voltage is measured by means of a high voltage resistor stack in series with a microammeter, as shown in Fig. 2. Losses are computed as the product of current and voltage.

APPARATUS

The test line consists of a 425-foot span with 370 feet of active conductor length, and average height above ground of 40 feet. A hoisting arrangement at each support permits rapid replacement of conductors or changes in conductor configuration. The test line appears with single conductor and with a two-conductor bundle in Plate I. Guard circuit and insulator assemblies are shown in Plate II for the two configurations. The shielding rings visible in these figures are a pair of 38"-outside-diameter



C_1 — 2 Capacitors in series, each .02 μfd, 50 KV

C_2, C_3, C_4, C_5, C_6 — 4 Capacitors in series, each .02 μfd, 50 KV

V_1 to V_6 — G.E. Kenotron KR-5

R_1 — 0.5 Ω, 15 amp.

T_1 — 220V, 60~ primary; 15V – 15V secondary

T_2, T_3, T_4, T_5, T_6, T_7 — 15V – 15V, 40A filament Transformers

FIG. 2 SCHEMATIC DIAGRAM OF HIGH VOLTAGE SUPPLY rings made of 3"-diameter aluminum tubing. The coaxial connection from the supply to the line is a $4\frac{1}{2}$"-diameter tube which acts as a shield, and an internal wire which carries the line loss current.

The high voltage supply is a Greinacher chain rectifier system which was formerly used as a supply for an ion accelerator. Fig. 2 is the schematic diagram and Plate III (a) is a photograph of the physical arrangement of this supply. In the laboratory this unit produced 600 kv under no load, and 480 kv under a load of 13 milliamperes. The output may be changed in polarity by physically reversing the rectifier tubes.

Recording milliammeters for conductor and guard circuit currents are inside the spherical high voltage terminals (Plate III (a)) of the rectifier set. These meters are Esterline-Angus clockwork-driven instruments of 1 milliampere range. An indicating panel-type current meter is connected in series with each of the recording meters. These two panel meters are in an external shielded position on the terminal, where they can be observed from the control room through a telescope.

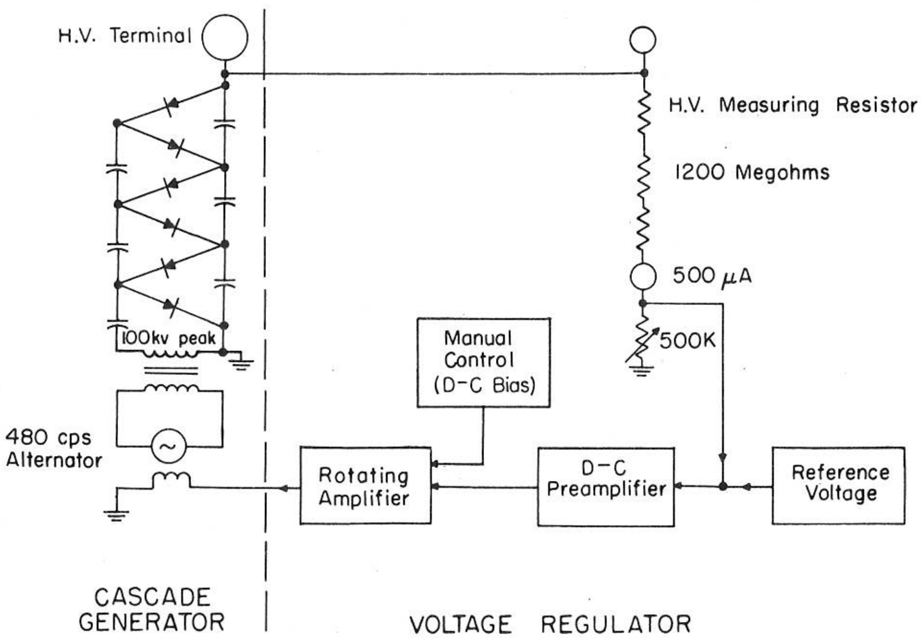


FIG. 3 VOLTAGE STABILIZING SYSTEM FOR HIGH VOLTAGE SUPPLY

The rectifying system is supplied from a 480-cps motor alternator set. A feedback-type stabilizing system (Fig. 3) holds the output voltage to any pre-set value. The control signal for the stabilizer is obtained from the high voltage resistor stack, which also serves as the output voltage measuring device. This resistor stack consists of 1200 one-megohm composition resistors, connected in series and wound in a spiral on a 12-foot-high Bakelite tube. The resistor stack is mounted within the structure of the rectifier set, where it is shielded by the large terminals and other components of the set. The resistor stack is completely corona-free in this position.

The high voltage supply is housed in a wooden building constructed for the purpose. An 8' × 8' sheet of commercial grade Fiberglas built into the end wall of the building, and protected from the weather by an overhanging wooden canopy, serves as a feed-through bushing for the line supply. This bushing has imposed an upper operating limit of 500 kv on the system in tests made to date.

A small control room (Plate III (b)) in the high voltage building contains a control console and metering equipment for the high voltage machine, and recorders for the meteorological instruments. A weather station has been set up at the test site and is gradually being equipped with suitable instruments. Station equipment at the present time includes a resistance-type recording thermometer, a recording dew point instrument, a recording hygrometer, a wind speed and direction recorder, and a barograph. A standard tipping-bucket rain gauge will be installed when available, to record rate of precipitation.

A small hut has been constructed at the 40-foot level of a tower which serves as one support for the test line. From a window in this hut, overlooking the line, visual observations and photographic records may be made under all weather conditions.

RESULTS

Two line configurations employing the ACSR Drake conductor, one being a single conductor and the other a two-conductor bundle with 18-inch spacing between conductors, have been tested to date. The special Drake conductor with insulated central wire was used for the single conductor line. It had been badly scratched during manufacture and shipping, making it necessary to polish the conductor surface before the line was put into operation. For the two-conductor line a length of standard Drake conductor was added. Tests on the single-conductor line have been less extensive than those on the bundled-conductor line.

Two types of test, a voltage increment test and a constant voltage test, have been used in the investigation.

Voltage Increment Tests

In order to establish the dependence of corona loss on voltage during constant weather conditions, the line voltage is varied in increments of 50 kv during a short period of time, while the corona loss current is being recorded. Fig. 4, which was constructed by superimposing sections of a continuous recording, shows typical results of such a voltage increment test. The corona current at each voltage level is averaged and a graph of corona loss versus line voltage may then be constructed. A great many voltage increment tests have been made for the two-line configurations under a variety of weather conditions. However, for the purposes of this report, since the weather data which has been available is somewhat incomplete, it seemed advisable to define only two broad categories of weather, "dry weather" and "wet weather". A grouping of the corona loss results into dry and wet weather categories should prove useful, if the major effect of weather is due to drops of precipitation formed on the line conductor during periods of rain or snow. Figs. 5 and 6 show the results of voltage increment tests on the single-conductor line and bundled-conductor line, respectively, for both negative and positive polarity; the results are grouped into dry and wet weather tests. Although the spread of results in each group is considerable, the mean of the dry weather results and the mean of the wet weather

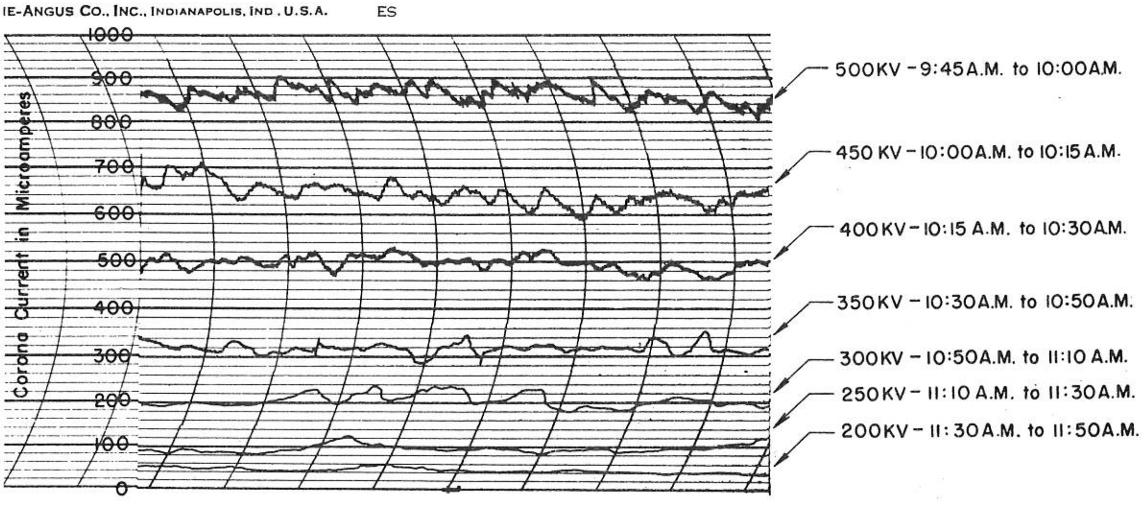


FIG. 4 TYPICAL "VOLTAGE INCREMENT " TEST RECORDS (overlaid charts)
(negative polarity, wet snow, 370-foot "Drake" ACSR line in two-conductor bundle, 18" spacing)

results are well separated in each case. For convenience, the mean curves have been redrawn on a single graph in Fig. 7. This figure summarizes most of the findings of this investigation to date. Some preliminary conclusions may be drawn:

a) in dry weather, single-conductor losses are equal to the losses from a two-conductor bundle, but negative losses are higher than positive losses by a factor of 2 to 3;

b) in wet weather, the losses are considerably higher than in dry weather, positive and negative losses for the two-conductor bundle and negative losses for the single conductor all being equal. (No wet weather data for the single conductor at positive voltage has so far been obtained.)

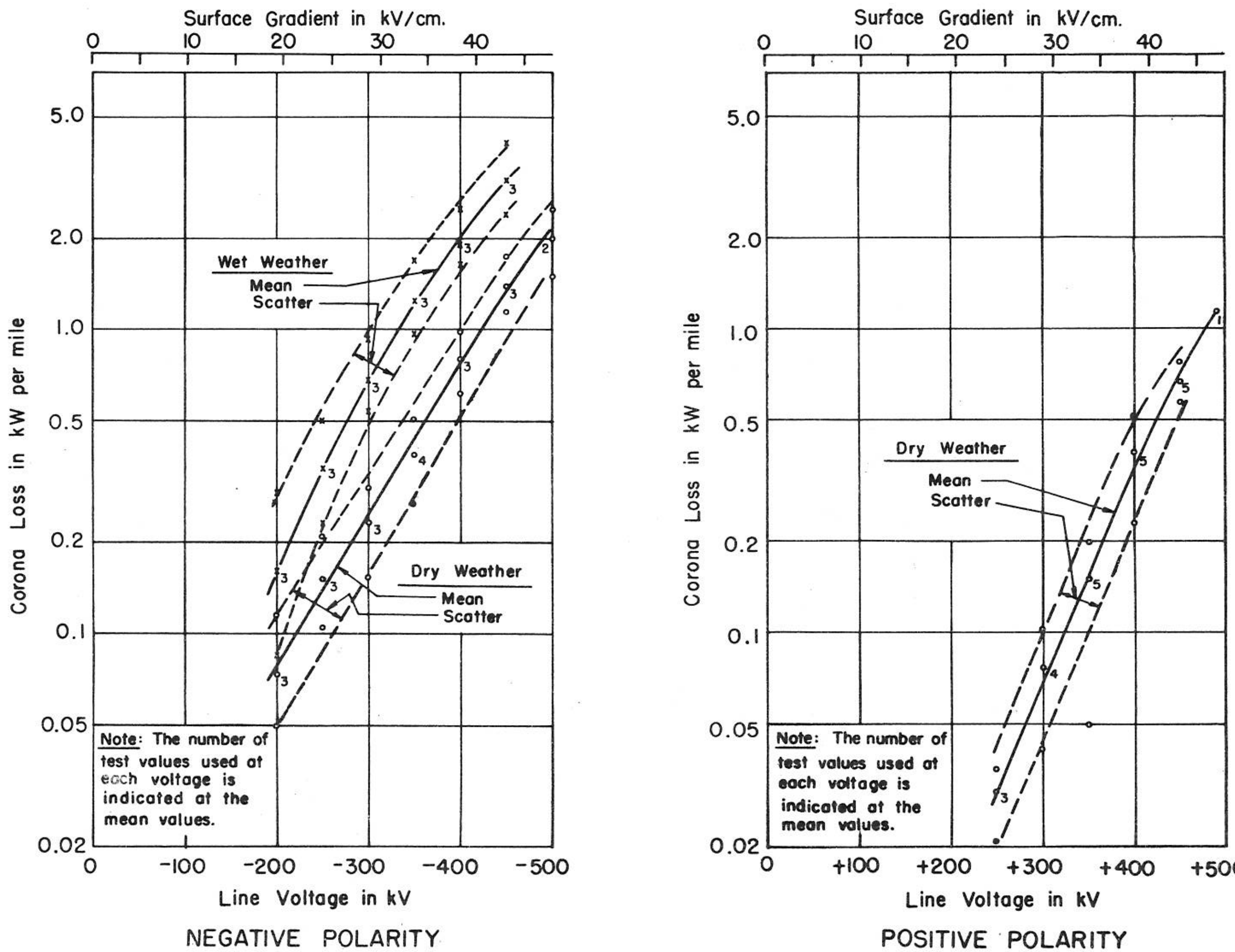


FIG. 5 VOLTAGE INCREMENT TEST RESULTS — SINGLE-CONDUCTOR LINE

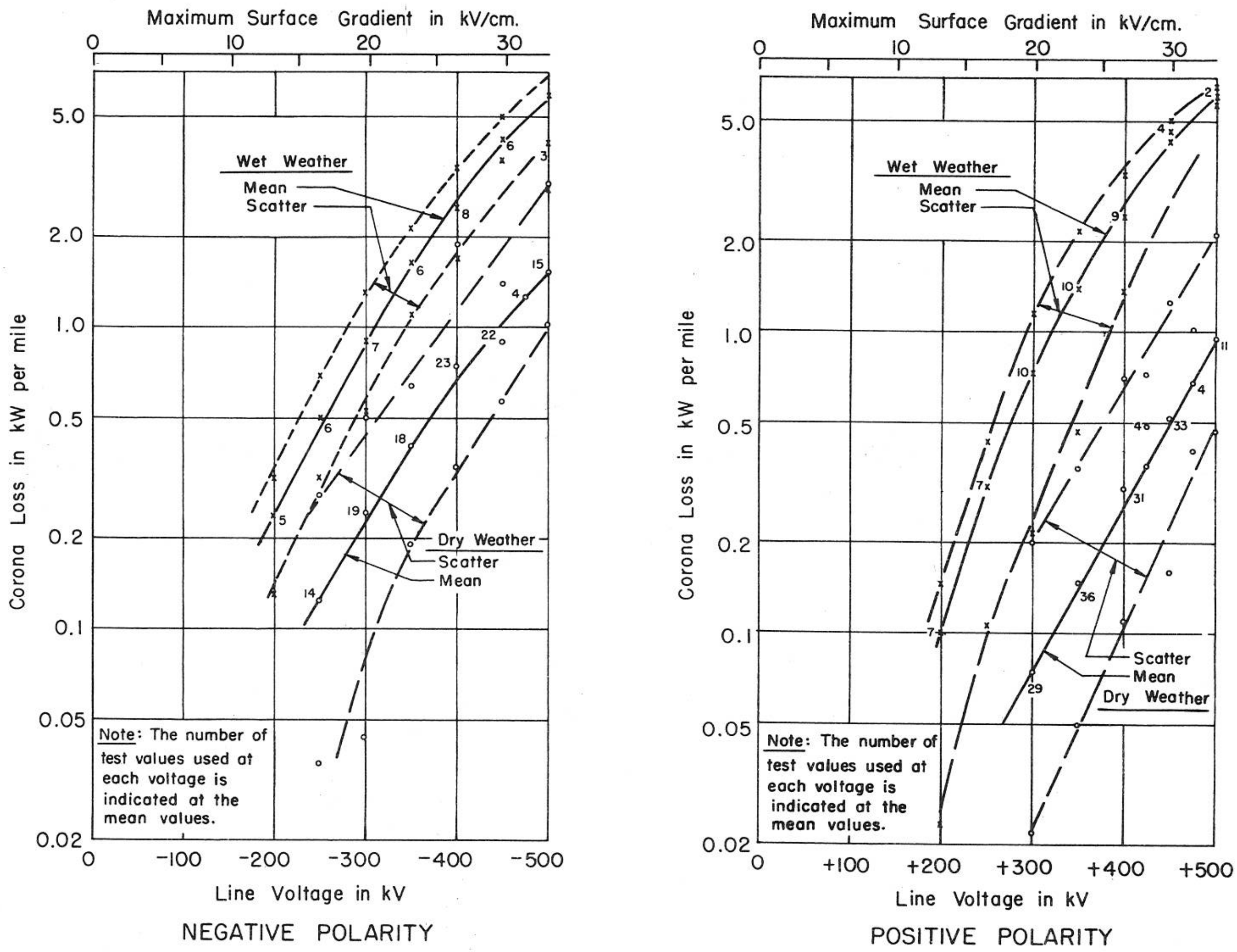


FIG. 6 VOLTAGE INCREMENT TEST RESULTS — TWO-CONDUCTOR BUNDLE

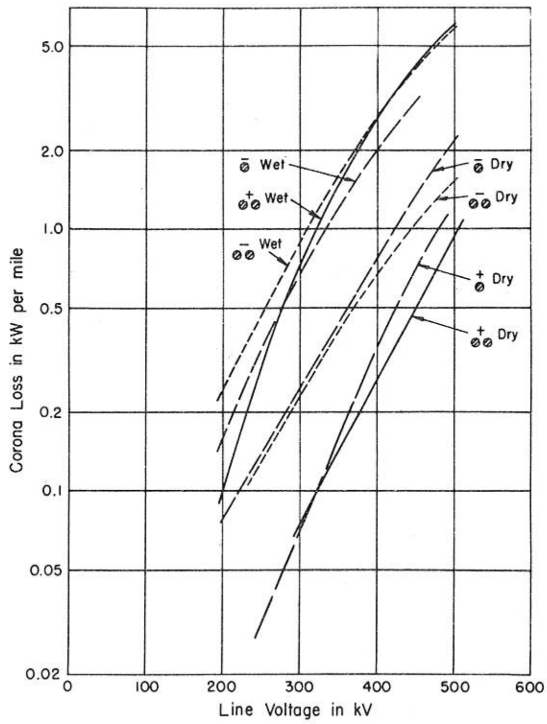


FIG. 7 SUMMARY OF VOLTAGE INCREMENT TESTS RESULTS

Constant Voltage Tests

A second method of determining the influence of weather on corona losses, is to hold the line voltage constant for long periods of time, while losses and weather data are being recorded. The results of two such constant voltage tests are shown in Figs. 8 and 9, all quantities having been replotted to a common time scale. The difficulty of assessing the effect of the different variables in atmospheric conditions is apparent from the figures. In Fig. 8, high wind seems to lead to high corona loss, while there is no correlation between relative humidity and corona loss. In Fig. 9, the relative humidity appears to be the dominant influence on the losses. It is evident that considerably more data of this type must be studied before any conclusions as to the effect of humidity, wind, temperature, etc., may be reached.

To supplement the electrical measurements, the corona discharge has been recorded photographically, by means of time exposures of the line taken at night. Plate IV (a) shows the line at 480 kv positive in dry weather. Many distinct corona sources are visible. Plate IV (b) shows the appearance of the line at 450 kv positive in heavy rain. The corona discharge is visible as a uniform glow along the whole length of conductor. For purposes of comparison, the unenergized line is shown in Plate IV (c).

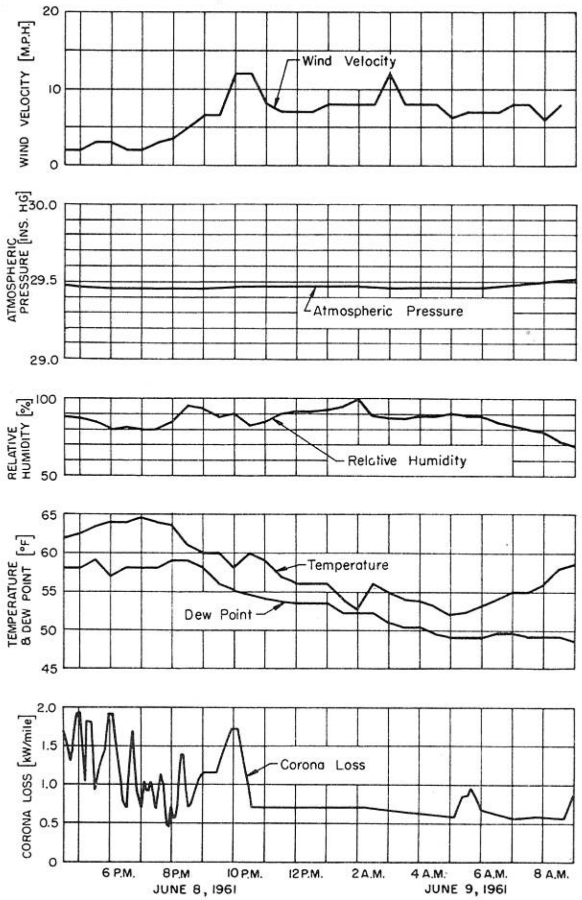


FIG. 8 SAMPLE RESULTS — CONSTANT VOLTAGE TEST
AT + 400 KV (June 8-9)
two-conductor bundle

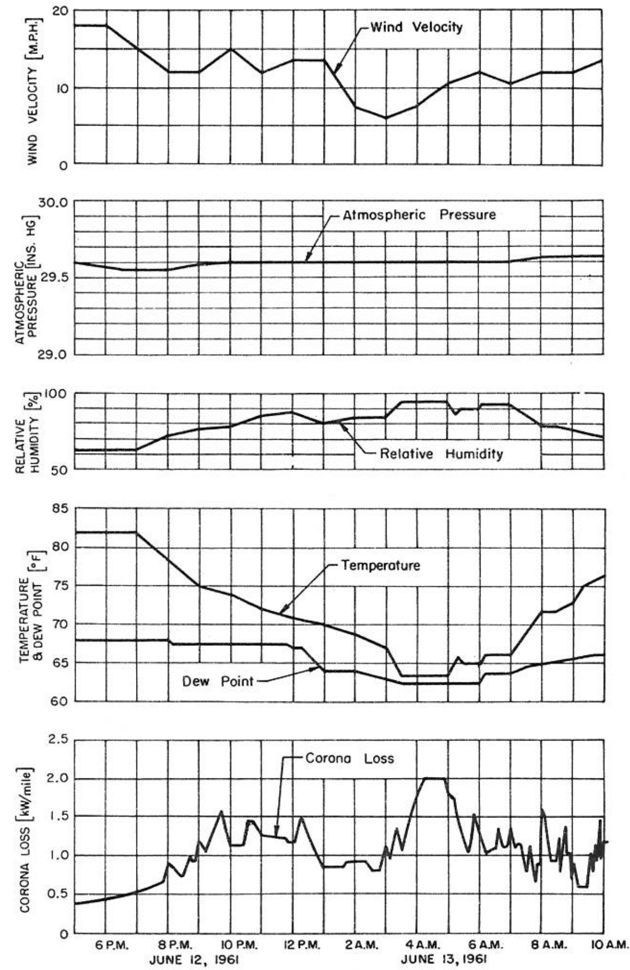


FIG. 9 SAMPLE RESULTS — CONSTANT VOLTAGE TEST
AT + 400 KV (June 12-13)
two-conductor bundle

PLANS FOR FUTURE WORK

Two new phases of the work are under way:

1) Investigation of radio interference from the d-c line is progressing. An examination of standing-wave patterns and frequency spectra of radio interference from the line is being made. The problem of applying the results of measurements on a short test line to a long transmission line is being studied.

2) A new line is being erected at 90° to the existing line. The old and new lines will be of the same length and will be energized simultaneously from the same source. Their loss currents will be metered separately. The equipment will then enable simultaneous comparative measurements to be made of new and aged conductors of the same type, or of two different line configurations. Immediate plans are to compare the single Drake conductor which has been energized for a total of four months, with an identical length of new Drake conductor. Later, a two-conductor Drake bundle will be compared with the single Drake conductor.

A continuous effort will be made to improve weather instrumentation in order to determine the effect of various weather variables on corona characteristics.

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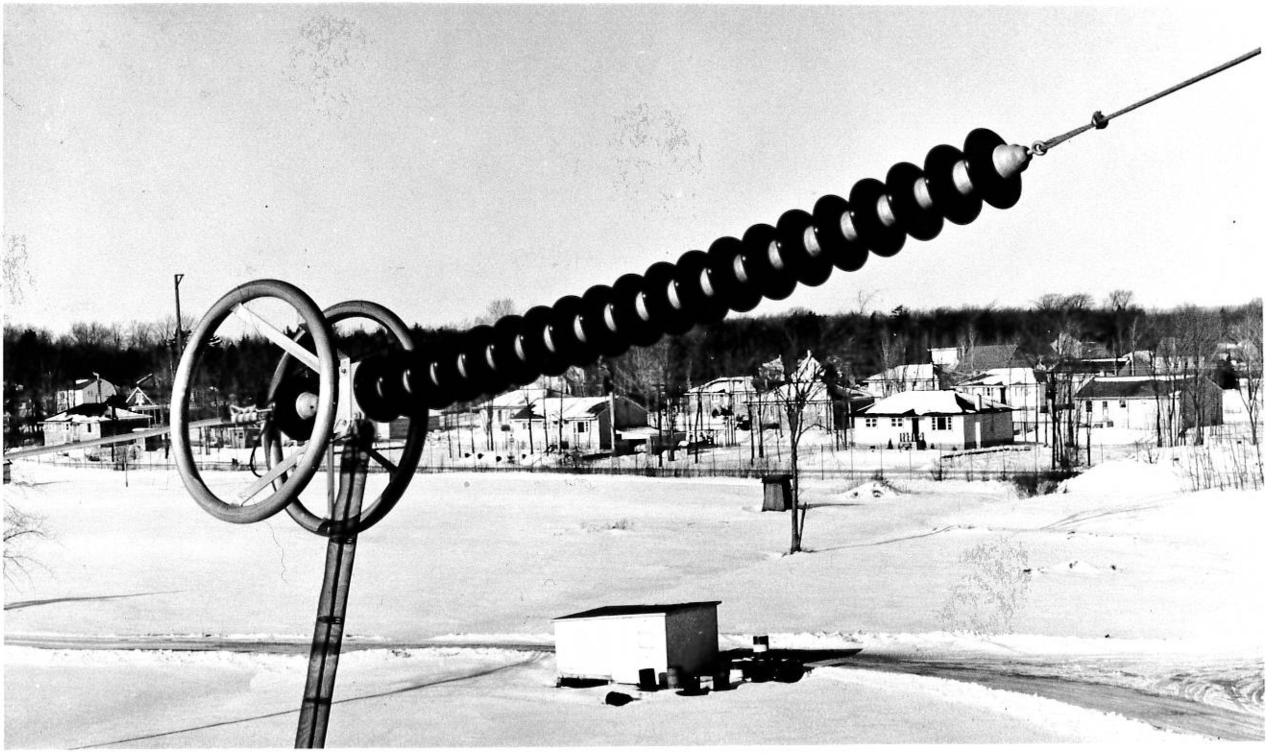
PLATE I — TEST LINE
(above) single "Drake" conductor installed
(below) two-conductor "Drake" bundle installed; spacing 18 inches



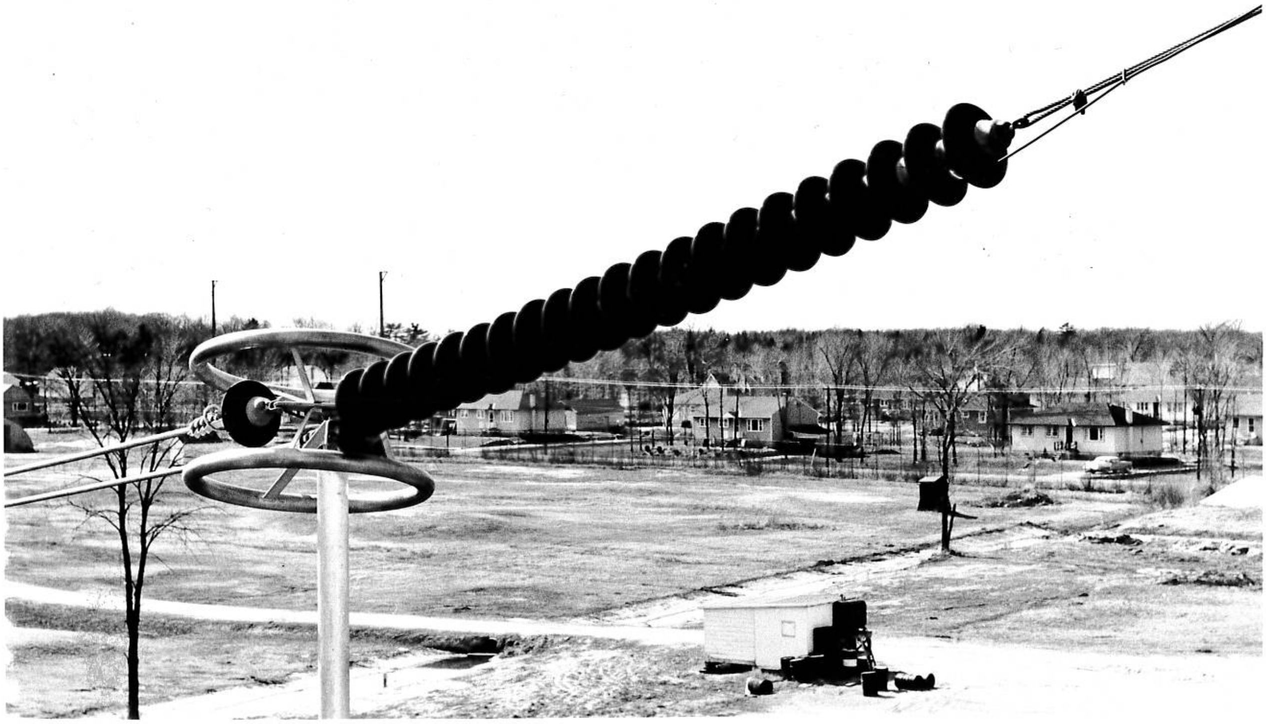


PLATE II — LINE CONNECTION AT SUPPLY END
(above) single conductor (below) two-conductor bundle

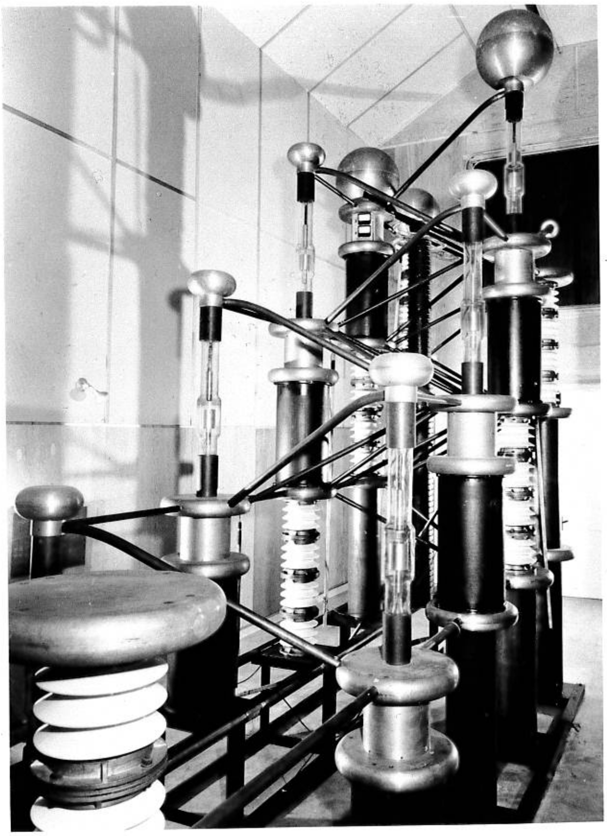


PLATE III — (above) High voltage supply and interior of high voltage building
(below) Control room

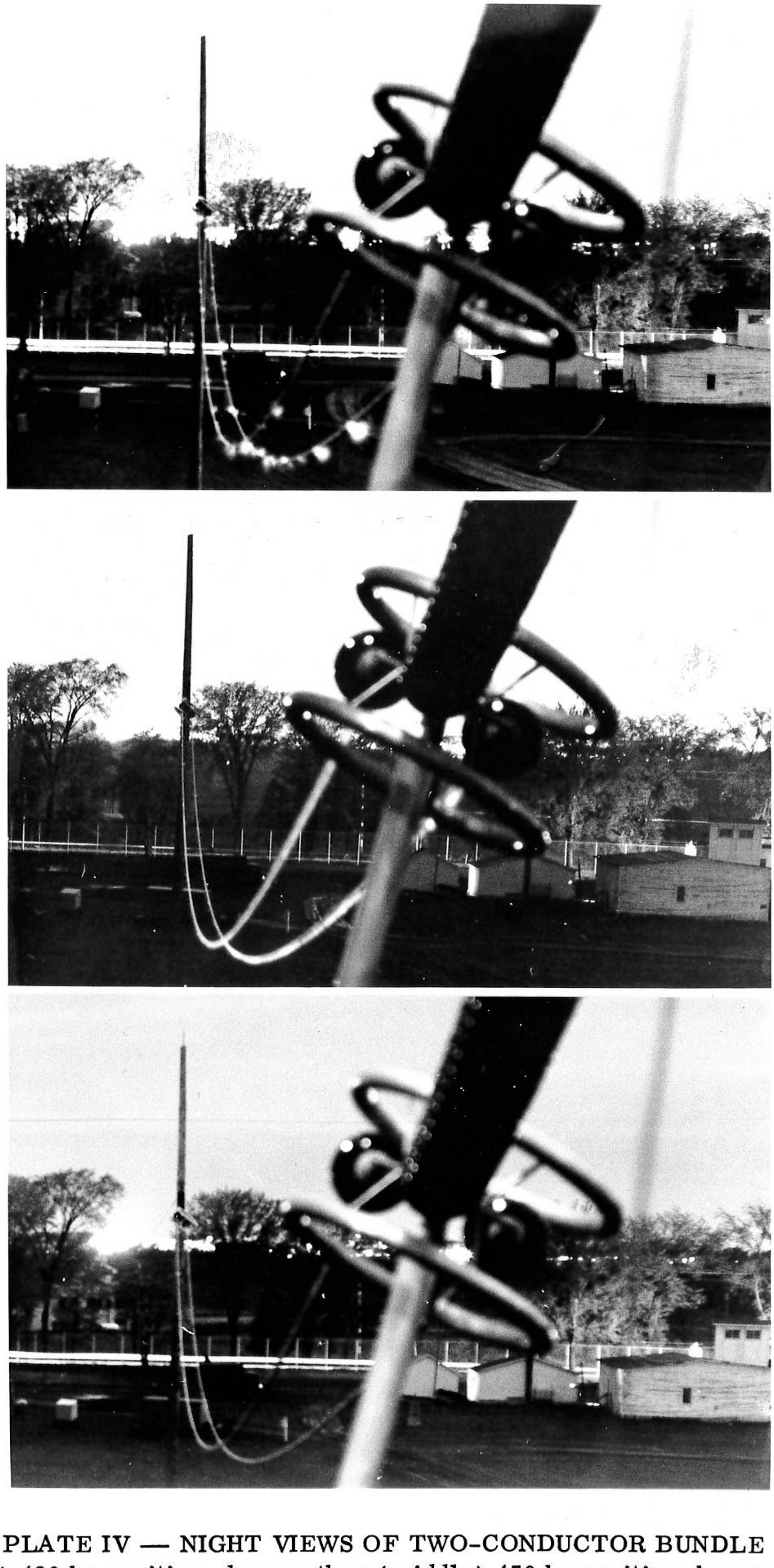


PLATE IV — NIGHT VIEWS OF TWO-CONDUCTOR BUNDLE
(top) 480 kv positive; dry weather (middle) 450 kv positive; heavy rain
(bottom) unenergized line