SUSPENSION INSULATOR TESTING.

By G. Yoganandam.

SYNOPSIS.

Experiments on the effect of a defective and dusty insulator upon the voltage gradient along the string are described. A new method of testing is described in which an auxiliary string of insulators is used. Experiments on a full-size section of a 75-kV. three-phase, aluminium steel-cored cable, transmission line are described. Comparative results are given showing the simplicity and usefulness of low voltage testing when a valve detector is employed.

INTRODUCTION.

The experiments described below represent the continuation of the investigations on voltage gradients, etc., which have been described (*J. Ind. Inst. Sc.*, 1927, **10** *B*, Part I and Part II). This paper is a supplement to these papers which should be referred to for a description of the apparatus used for the experiment.

EXPERIMENT I.

CHANGES IN THE VOLTAGE DISTRIBUTION CAUSED BY DEAD UNITS IN AN INSULATOR STRING.

It is sometimes the case that one, or more, of the units forming a string of suspension insulators becomes partially or completely dead owing to the development of defects, such as cracks, in the dielectric. This not only reduces the number of effective units in the string but also makes the voltage distribution very unequal, on account of the additional capacities to earth of the metal parts of the dead units, and further, the maximum gradient varies with the position of the dead unit or units in the string. Measurements relating to the voltage distribution, on a string of six 10-inch cap and pin type suspension insulators with one dead unit placed in different positions, are given in Table I. As might be expected from theoretical considerations, the maximum voltage gradient, *i.e.*, the percentage voltage borne by the 'live' line unit, is greatest when the second insulator from the line end is made dead. These tests were made by the auxiliary transformer method with valve circuit detection of balance.

TABLE I.

Voltage Distribution on a string of six Suspension Insulators with one dead unit.

Line-voltage 28.8 kV. (r.m.s.) at 60 cycles per second.

Insulator	Voltage across each unit in per cent of total.						
No. 1 Line	26.0	Dead	30.5	30.0	28.2	27.8	29.6
,, 2	18.0	27.8	Dead	21.1	20.3	20.3	20.3
,, 3	15.6	20.6	22.2	Dead	18.9	17.4	18.0
,, 4	14.1	18.0	16.0	17.2	Dead	16.3	15.8
,, 5	12.2	15.8	15.0	14.9	15.8	Dead	16.3
,, 6	14.1	17.8	16.3	16.8	16.8	18.2	Dead
	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Temperature 83°F..........Wet bulb 73.5°F.

Barometric Pressure........26.9 inches of mercury.

Altitude...................3,050 feet above sea-level.

Relative Humidity..........65 per cent.

EXPERIMENT II.

EFFECT OF DUST ON THE INSULATORS UPON THE VOLTAGE DISTRIBUTION.

The line unit of a string of five insulators was covered with a thin layer of dry dust, after which the voltage distribution was measured. The results which are given in Table II show that the effect of the dust was to lower the impedance of the insulators and improve the voltage distribution to a small extent.

TABLE II.

Effect of dust coating the Line Unit, on the voltage distribution along a string of five units.

Line-voltage 28.8 kV. (r.m.s.) at 60 cycles per second.

Insulator	Voltage across each unit in per cent of total	
	Without dust	*With dust*
No. 1 Line ..	29.6	27.8
,, 2 ..	20.3	22.5
,, 3 ..	18.0	16.7
,, 4 ..	15.8	16.0
,, 5 ..	16.3	17.0
	100.0	100.0

Atmospheric conditions the same as in Table I.

EXPERIMENT III.

AUXILIARY INSULATOR-STRING METHOD OF MEASURING VOLTAGE DISTRIBUTION.

This new method requires two transformers, not necessarily identical, an auxiliary string of insulators and a high tension voltmeter connected, for instance, as shown in Fig. 1.

The exploring lead being removed, the auxiliary transformer T_2 is excited until the H.T. voltmeter reads some desired voltage. The lead is now connected (Fig. 1) and the main transformer T_1 then is excited until the H.T. voltmeter reading is exactly the same as before. If V_1 be the voltmeter reading and V the voltage of the transformer T_1 then $\frac{V_1}{V} \times 100$ is the voltage of the metal cap (No. 1, Fig. 1) above earth as a percentage of the applied voltage V on the string of insulators S_1. By connecting the movable contact to different metal caps along the auxiliary string (S_2) and the other movable contact to different caps of the main string (S_1) the voltage distribution on the latter may be determined. If the voltage distribution is known approximately the transformer T_2 can be excited to such a value as to keep the voltage applied to string S_1 nearly constant during the measurement of the distribution. Comparative results obtained by this method and the auxiliary transformer method using a valve-circuit balance detector are given in Table III.

TABLE III.

Comparison of three methods of measuring the Voltage Distribution, under High-Tension conditions, on a string of five suspension insulators.

Test Line-Voltage 28.8 kV. (r.m.s.) at 60 cycles per second for I & II.

Insulator	I Auxiliary Transformer Method with valve balance detector	II Auxiliary Insulator String Method	III Resistance Potentiometer Method at low tension 146 volts (r.m.s.) (See p. 48)
No. 1 Line ..	29.6 per cent	30.0 per cent	30.2 per cent
,, 2 ..	20.3 ,,	19.5 ,,	18.9 ,,
,, 3 ..	18.0 ,,	15.8 ,,	16.8 ,,
,, 4 ..	15.8 ,,	15.8 ,,	15.1 ,,
,, 5 ..	16.3 ,,	18.9 ,,	19.0 ,,
	100.0 ,,	100.0 ,,	100.0 ,,

Temperature 86°F........Wet bulb 73.5°F.

Barometric Pressure....... 26.9 inches of mercury.

Relative Humidity........55 per cent.

EXPERIMENT IV.

VOLTAGE DISTRIBUTION ON INSULATOR STRINGS IN AN EXPERIMENTAL SECTION OF A 75 kV. TRANSMISSION LINE AT THE INDIAN INSTITUTE OF SCIENCE.

The experimental transmission line consists of three stranded aluminium, steel-cored, conductors supported by strings of four new ten-inch cap and pin type Canadian Porcelain insulators. The conductors are spaced seven feet apart as shown in Fig. 2 which gives the principal dimensions.

The insulator strings are suspended from channel iron cross-arms clamped across wooden poles supplied by the Electrical Department of the Government of Mysore.

Measurements were made on the centre string S_2 (Fig. 2) under different conditions using the Auxiliary Transformer and valve circuit balance as this was found to be the most suitable method. This string of insulators (S_2) was insulated from the earthed cross-arm by mica sheet and a lead was taken from the cap of the topmost insulator to the valve circuit inside the laboratory. The lines L_1 and L_2 were excited by the auxiliary and main transformers, respectively, and the outer line L_3 was excited by the 3rd transformer in the laboratory for the purpose of studying the effects of neighbouring charged lines on the voltage distribution. In order to ascertain whether a wooden transmission line pole causes more or less inequality in the voltage distribution than a steel tower, an earthed metal sheet 6 feet by 3 feet was suspended, parallel to the string, close to the pole P_2 (Fig. 2) so that measurements could be made with and without the earthed metal. The voltage distribution on two identical strings of insulators carrying the transmission lines into the laboratory was measured indoors. The results of the above comparative tests will be found in Tables IV and V from which the following conclusions may be drawn:—

(1) The voltage distribution on a string of insulators under ordinary outdoor conditions, as described, is more uniform than that on a string tested indoors because of the increased capacities of the insulators to the earthed walls, etc., in the latter case.

(2) Wooden poles with top ground wire are slightly more favourable to uniform voltage distribution than steel poles or towers.

(3) The effect of charged conductors near a string of insulators is to increase the percentage voltage on the line unit by an amount which depends upon the phase relationship between the voltages on the string and the neighbouring conductor.

TABLE IV.

Voltage Distribution on strings of four ten-inch suspension insulators.

At 60 cycles per second.

Insulator	Applied voltage 23 kV. (r.m.s.) outdoor string (middle)	Applied voltage 44.4 kV. (r.m.s) outdoor string (middle)	Applied voltage 23 kV. (r.m.s.) indoor string (middle)	Applied voltage 23 kV. (r.m.s.) indoor string (one of the outer strings)
No. 1 Line ..	29.4 per cent	29.0 per cent	34.2 per cent	31.9 per cent
" 2 ..	24.8 "	24.1 "	22.8 "	24.4 "
" 3 ..	21.2 "	21.9 "	21.4 "	21.85 "
" 4 ..	24.6 "	25.0 "	21.6 "	21.85 "
	100.0 "	100.0 "	100.0 "	100.0 "

Temperature 84°F........Wet bulb 74°F.
Barometric Pressure ......26.9 inches of mercury.
Relative Humidity... ....63 per cent.

TABLE V.

Effect of Neighbouring Charged Lines on the Voltage Distribution.

Outdoor Tests on the middle string of four insulators with an applied line-voltage of 23 kV. at 60 cycles per second.

Insulator	Wooden pole only	Earthed plate parallel to the string	No earthed plate but one outer line excited to 23 kV. (r.m.s.) in-phase with middle line	No earthed plate but outer line excited 180 degs. out of phase with middle line
No. 1 Line ..	29.2 per cent	31.7 per cent	31.9 per cent	31.2 per cent
" 2 ..	25.0 ,,	24.4 ,,	24.2 ,,	23.7 ,,
,, 3 ..	21.4 ,,	20.5 ,,	22.3 ,,	21.4 ,,
,, 4 ..	24.4 ,,	23.4 ,,	21.6 ,,	23.7 ,,
	100.0 ,,	100.0 ,,	100.0 ,,	100.0 ,,

Temperature 83°F..........Wet bulb 73.5°F.

Barometric Pressure ....26.9 inches of mercury.

Relative Humidity ....65 per cent.

EXPERIMENT V.

MEASUREMENT OF VOLTAGE DISTRIBUTION AT VERY LOW PRESSURES.

The voltage change along a string of five insulators was measured by the Resistance Potentiometer method with a valve circuit balance detector at *146 volts* r.m.s. using the circuit shown in Fig. 3. R_1 in Fig. 3 (*J. Ind. Inst. Sc.*, **10** *B*, Part II) was increased to 1 megohm to give sufficient deflection in the microammeter.

If the voltage distributions measured at 146 volts and at 28.8 kV. (see Table III, Cols. II & III) are compared, it will be seen that there is very little difference between the observations made at 146 or at 28,800 volts. The low voltage test is most convenient and expeditious for many purposes.

The experiments described above were repeated in order to make sure that the small differences in the readings obtained were not experimental errors and the greatest care was taken to ensure that the conditions remained constant during the experiments.

In conclusion, I wish to place on record my gratitude to the Indian Institute of Science for granting me facilities for carrying out this work, to Professor J. K. Catterson-Smith for his help and encouragement throughout its progress and to Mr. A. R. Narayan Rao for his assistance during the measurements.

Department of Electrical Technology,
Indian Institute of Science,
Bangalore.

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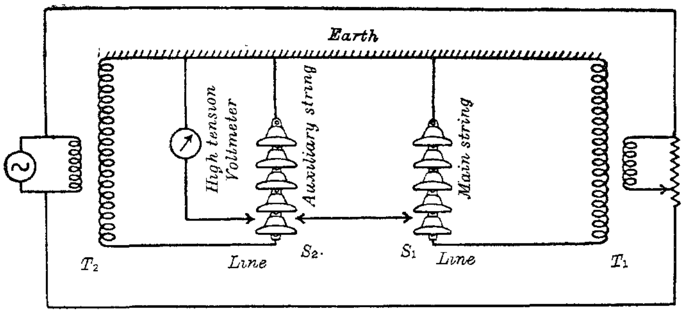

FIG. 1. *Auxiliary string method.*

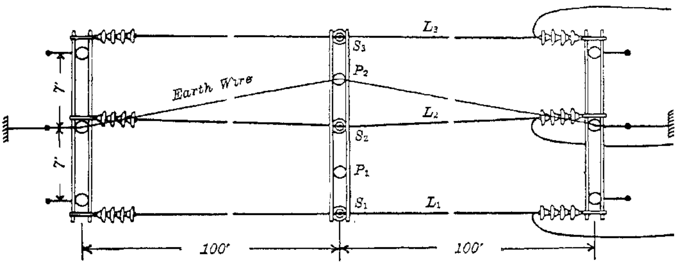

FIG. 2. *Plan of Experimental Transmission Line.*

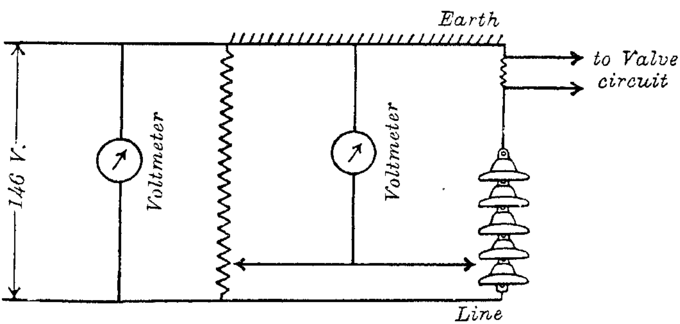

FIG. 3. *Resistance potentiometer circuit.*