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CONTENTS.

TESTS ON SUSPENSION INSULATORS AFTER TEN YEARS SERVICE.

BY

A. S. Venkateswaran and U. Ganguly.

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ABBREVIATIONS OF TITLES.

Abbreviation.	*Name of Periodical.*
Arch. f. Elek.	Archiv für Elektrotechnik.
Elec. World	Electrical World.
Elek. u. Maschin.	Elektrotechnik und Maschinenbau.
J. Amer. Inst. Elec. Eng. ...	Journal of the American Institute of Electrical Engineers.
J. Ind. Inst. Sc. ...	Journal of the Indian Institute of Science.
J. Inst. Elec. Eng.	Journal of the Institution of Electrical Engineers.
Proc. Inst. Rad. Eng.	Proceedings of the Institute of Radio Engineers.
Rad. Elec.	Radioélectricité.
Rev. gen. d'Elec.	Revue générale de l'Electricité.

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TESTS ON SUSPENSION INSULATORS AFTER TEN YEARS SERVICE.

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SYNOPSIS.

A number of suspension insulator strings consisting four standard ten-inch units were tested, after ten years service, for deterioration. The results of flash-over tests on the units and on the strings are given together with measurements of the voltage gradient by means of a condenser bridge and an auxiliary transformer. Some of the sources of error and difficulties encountered are discussed.

INTRODUCTION.

The use of suspension type line insulators has provided a solution of most of the mechanical and electrical problems involved in the insulation of high tension transmission lines. These strings of porcelain discs, each fitted with a metal cap and pin, afford an almost ideal type of flexible support for the high tension conductor and possess insulating properties which appear to be practically unaffected by time of service. In the case of one large transmission line in the South of India it has been found that a certain number of failures do occur, amounting to about one per cent per annum, and it was considered desirable to carry out some tests upon strings of these insulators which had been in service for some ten years. These strings were removed from points in a 75-kV, 25-cycle, three-phase line, where the failures had been found most frequent, and were tested in the laboratory at 60 cycles per second.

Each string consisted of four standard ten-inch cap and pin type porcelain discs for which the following information was sought:—

(*a*) Deterioration, if any, of individual strings of four discs.

(*b*) ,, ,, ,, discs.

(*c*) Effect, if any, of changing the positions of the discs.

(*d*) Increase in the factor of safety on adding a fifth new disc, in series, at the line end.

(*e*) Increase in the factor of safety on adding a fifth disc, in parallel with the line end insulator.

In order to ascertain the above information the following tests were conducted in the department of electrical technology, Indian Institute of Science, making use of the equipment recently installed in the high tension testing laboratories :—

(*a*) Flash-over tests on single units and on strings made up of 2, 3, 4, and 5 units.

(*b*) Voltage distribution tests on strings under approximately working conditions.

HIGH TENSION TESTING APPARATUS USED.

The high voltages were obtained from testing transformers each having a capacity of 10 kVA. at 115 kV. at 60 cycles per second. When star connected the line-voltage may be raised to 200 kV. (r. m. s.), or alternatively a single-phase arrangement of two transformers in series, with the mid-point grounded, gave up to 230 kV. (r. m. s.), with a pure sinusoidal wave-form. These transformers are supplied from a specially designed three-phase motor-driven alternator providing a terminal voltage of pure wave-form.

The transformers are fitted with an auxiliary volt coil which is connected to a voltmeter for the purpose of indicating the high tension terminal voltage during a test. Pressures below 40 kV. were also measured directly by means of electrostatic voltmeters, and a Tinsley-Drysdale alternating current potentiometer was available for measurements up to 5000 volts.

EXPERIMENTAL RESULTS FOR FLASH-OVER TESTS.

Deterioration of four-unit strings after ten years service.

A number of the strings were found to contain one defective insulator and must therefore have been in service under severe working conditions. Not only is the line-to-earth voltage then carried by three discs instead of four but also the voltage gradient is influenced by the defective insulator present in the string. The defect was not always discoverable by a megger test but showed up at a moderate test voltage.

Subsequent tests made in the field along the transmission line, by means of a portable testing transformer, revealed the existence of a large number of faulty strings. In all, this amounted to about 9 per cent of the insulator strings tested, after a period of service of 10 years. The exact nature and cause of the failure in these insulators has not yet been ascertained, the immediate needs of the service being met by the removal of defective insulators.

Those strings which did not contain a faulty insulator were found, when subjected to dry flash-over tests in the laboratory, to be practically as good as when new. It must be pointed out that no particular tests could be carried out to indicate the presence of any form of fatigue in the body of the porcelain. At a later date it is hoped that some measurements may be made, using high frequency and high voltage testing apparatus, with the object of tracing signs of fatigue.

Strings tested.—(*a*) Five strings each containing four Locke insulators were supplied by the Chief electrical engineer to the Government of Mysore. These had been in service since 1916 in the main transmission line to the Kolar Gold Fields.

(*b*) One string of new Canadian porcelain insulators.

Atmospheric conditions.— Wet and dry bulb temperature readings were taken before and after tests and the average relative humidity recorded.

The effect of moisture on the surface of the porcelain was found to cause variations of over 5 per cent. in the flash-over readings. The flashing-over was repeated until the observations agreed to within one or two per cent. and then four observations were made and their average recorded.

Procedure.—After a preliminary flash-over test a somewhat lower voltage was applied and the time which elapsed before the flash noted. If this was less than three minutes the test was repeated at a rather lower value of voltage. The test voltage applied to the insulators was raised at 4 kV. in 10 seconds.

It is to be noted that the tests at voltages exceeding 115 kV. are not quite normal as regards the potential of the system on account of the mid-point of the transformers in series, and not one end-terminal as should have been the case, being grounded owing to the design of the testing transformers each of which is provided only with one high tension bushing.

The observations made on individual insulators and on strings of assembled insulators after ten years service are given in the Tables I, II, III, IV, V, VII, VIII and IX. Corresponding test data for unused insulators of the same type are given in Table VI below.

TABLE I.

STRING NO. I, CONTAINING FOUR LOCKE SUSPENSION TYPE INSULATORS, TESTED AFTER 10 YEARS SERVICE IN KOLAR TRANSMISSION LINE.

(a) Dry flash-over test on individual insulators.

Insulator number	Flash-over Voltage Kilo-volts		Relative Humidity per cent.
	r. m. s.	crest	
1	80·7	114	54·5
2	77·1	110	,,
3	81·0	114	,,
4	Defective unit.		

(b) Voltage withstood by individual insulators, without flashing-over, for 5 minutes after reaching the full pressure, this voltage being built up at 4 kV. in 10 seconds.

Insulator Number	Flash-over Voltage Kilo-volts		Relative Humidity per cent.	Remarks
	r. m. s.	crest		
1	77·5	95·0	54·5	Broke down 45 secs. later.
,,	76·0	93·0	,,	
2	75·5	92·5	,,	Broke down 1 m. 15 secs. later.
,,	74·0	90·5	,,	
3	76·5	93·8	,,	

TABLE II.

STRING NO. I.

(a) Dry flash-over test on complete strings consisting of insulator units arranged in the order shown in Col. 1.

Insulator assembly	Flash-over Voltage Kilo-volts		Relative Humidity per cent.
	r. m. s.	crest	
Nos. 2 and 3 (Line-end) ...	154	214	48·4
,, 3 and 2 ,, ,, ...	151	214	,,
,, 1, 2 and 3 ,, ,, ..	202	286	43·8
,, 1, 2, 3 and 4 ,, ...	212	299	,,

(b) Voltage withstood by each string of insulators, without flashing-over, for 5 minutes after reaching full pressure.

Insulator assembly	Flash-over Voltage Kilo-volts		Relative Humidity per cent.	Remarks
	r. m. s.	crest		
Nos. 2 and 3 ...	144	177	48·4	Broke down 30 secs. later.
,, ,, ...	143	175	,,	
,, ,, ...	142	175	,,	
,, 3 and 2 ...	142	175	,,	
,, 1, 2 and 3 ...	197	242	43·8	Broke down 5 m. later.
,, ,, ...	196	240	,,	
,, 1, 2, 3 and 4 ...	209	257	,,	

NOTE.—With the string of four insulators in the order shown it was found that if the voltage was built up with short stops during the process the flash-over voltage was 218 kV

TABLE III.

STRING No. II, CONTAINING FOUR LOCKE INSULATORS, TESTED AFTER 10 YEARS SERVICE IN KOLAR TRANSMISSION LINE.

(a) Dry Flash-over test on individual Insulators.

NOTE.—No. 4 was the line-end insulator of the string when in service.

Insulator number	Flash-over Voltage Kilo-volts r. m. s.	Flash-over Voltage Kilo-volts crest	Relative Humidity per cent.
1	81·3	115	75·9
2	83·7	118	,,
3	81·5	115	,,
4	83·7	118	89·7

(b) Voltage withstood by individual Insulators, without flashing-over, for 3 minutes after reaching the full pressure.

Insulator Number	Flash-over Voltage Kilo-volts r. m. s.	Flash-over Voltage Kilo-volts crest	Relative Humidity per cent.	Remarks
1	77·9	110	75·9	Broke down 1 m. 15 secs. later.
,,	77·2	109	,,	
2	81·0	114	,,	Broke down 50 secs. later.
,,	79·1	111	,,	
3	79·7	112	,,	Broke down 10 secs. later.
,,	77·9	110	,,	
4	81·0	114	89·7	Broke down 1 m. 10 secs later.
,,	78·8	111	,,	

TABLE IV.

STRING NO. II, WITH DISCHARGE HORN FITTED AT LINE-END.

(a) Dry Flash-over test on complete strings consisting of four insulator units, arranged in the order shown in Col. 1, with the voltage built up steadily.

Insulator assembly	Flash-over Voltage Kilo-volts		Relative Humidity per cent.
	r. m. s.	crest	
Nos. 1, 2, 3 and 4 (line-end) ...	226	319	59·6
,, 2, 3, 4 and 1 ,, ,, ...	231	326	,
,, 3, 4, 1 and 2 ,, ,, ...	237	334	,,
,, 4, 3, 2 and 1 ,, ,, ...	227	320	,,
,, 1, 3, 4 and 2 ,, ,, ...	231	326	,,

(b) Voltage withstood by each string of insulators, without flashing-over, for three minutes.

Insulator assembly	Flash-over Voltage Kilo-volts		Relative Humidity per cent.	Remarks
	r. m. s.	crest		
Nos. 1, 2, 3 and 4 ...	218	308	59·6	Broke down 1 m. later.
,, ,, ...	217	306	,,	
,, 2, 3, 4 and 1 ...	226	319	,,	
,, 3, 4, 1 and 2 ...	233	329	,,	Broke down 50 secs. later.
,, ,, ...	232	327	,,	
,, 4, 3, 2 and 1 ...	226	319	,,	
,, 1, 3, 4 and 2 ...	228	322	,,	Broke down 1 m. 55 secs. later.
,, ,, ...	227	319	,,	

TABLE V.

STRING NO. III, CONTAINING FOUR LOCKE INSULATORS, TESTED AFTER 10 YEARS SERVICE IN KOLAR TRANSMISSION LINE.

(a) Dry flash-over test on individual insulators.

Insulator number	Flash-over Voltage Kilo-volts		Relative Humidity per cent.
	r. m. s.	crest	
4	82·3	115	51
3	defective unit		
2	defective unit		
1	83·6	118	,,

(b) Voltage withstood by individual insulators, without flashing-over, for 3 minutes.

Insulator number	Flash-over Voltage Kilo-volts		Relative Humidity per cent.	Remarks
	r. m. s.	crest		
4	78·5	111	51	Broke down 1 m. 2 secs. later.
,,	76·9	109	,,	
3	defective unit			
2	defective unit			
1	79·9	113	,,	Broke down 40 secs. later.
,,	78·43	111	,,	

NOTE.—Two of the units in this string being defective, the test on the complete string was not carried out.

TABLE VI.

String No. IV, containing Four New Insulators

(a) Dry flash-over test on individual insulators.

Insulator type and number	Flash-over Voltage Kilo-volts		Relative Humidity per cent.
	r. m. s.	crest	
New Locke ...	79·9	113	51
Canadian Porcelain No. 1.	95·7	135	,,
,, ,, No. 2.	94·3	133	68·6
,, ,, No. 3.	91·5	129	,,

(b) Voltage withstood by individual insulators, without flashing-over, for 3 minutes.

Insulator type and number.	Flash-over Voltage Kilo-volts		Relative Humidity per cent.	Remarks
	r. m. s.	crest		
New Locke ...	75·9	107	51	Broke down 32 sec. later.
,, ,, ...	73·9	104	,,	,, ,,
Canadian Porcelain No. 1...	89·7	127	,	Broke down 1 m. 33 sec. later.
,, ,, ,,	87·2	123	,,	
,, ,, No. 2...	88·9	126	68	Broke down 1 m. 10 sec. later.
,, ,, ,,	87·2	123	,,	
,, ,, No. 3...	88·6	125	,,	Broke down 1 m. 11 sec. later.
,, ,, ,,	87·2	123	,,	

TABLE VII.

String No. V, containing Four Locke Insulators tested after 10 years service in Kolar Transmission Line.

(*a*) *Dry flash-over test on individual insulators the voltage being built up slowly at the rate of about 2 kV. per second.*

Insulator number	Flash-over Voltage Kilo-volts r. m. s.	Flash-over Voltage Kilo-volts crest	Relative Humidity per cent.
4	82·2	116	61·9
3	82·8	117	,,
2	85·4	121	,,
1	79·4	112	,,

(*b*) *Voltage withstood by individual insulators, without flashing-over, for 3 minutes.*

Insulator number	Flash-over Voltage Kilo-volts r. m. s.	Flash-over Voltage Kilo-volts crest	Relative Humidity per cent.	Remarks
4	80·5	114	61·9	Broke down 2 m. 54 sec. later.
,,	79·9	113	,,	,, 50 sec. later.
3	77·6	110	,,	
,,	77·0	109	,,	Broke down 1 m. 3 sec. later.
2	80·3	113	,,	
,,	79·6	113	,,	Broke down 2 m. 22 sec. later.
1	76·7	108	,,	
,,	76·1	108	,,	

TABLE VIII.

String No. V.

(a) Dry flash-over test on complete strings consisting of four insulator units arranged as shown in Col. 1.

Insulator assembly	Flash-over Voltage Kilo-volts		Relative Humidity
	r. m. s.	crest	per cent.
Nos. 1, 2, 3 and 4 ...	219	309	64·2
,, 2, 3, 4 and 1 ...	221	312	,,
,, 3, 4, 1 and 2 ...	222	314	,,
,, 4, 3, 2 and 1 ...	223	316	,,
,, 4, 1, 2 and 3 ...	226	319	,,

(b) Voltage withstood by each string, without flashing-over, for 5 minutes.

Insulator assembly	Flash-over Voltage Kilo-volts		Relative Humidity	Remarks
	r. m. s.	crest	per cent.	
Nos. 1, 2, 3 and 4 ...	212	300	64·2	Broke down 1 m. 15 sec. later
,, ,, ...	211	298	,,	
,, 2, 3, 4 and 1 ...	212	300	,,	
,, 3, 4, 1 and 2 ...	216	306	,,	Broke down 53 sec. later
,, ,, ...	215	304	,,	
,, 4, 3, 2 and 1 ...	216	306	,,	
,, 4, 1, 2 and 3 ...	220	311	,,	

TABLE IX.

STRING NO. VI, CONTAINING FOUR LOCKE INSULATORS, TESTED AFTER 10 YEARS SERVICE IN KOLAR TRANSMISSION LINE.

(a) *Dry flash-over test on individul insulators.*

Insulator number	Flash-over Voltage Kilo-volts		Relative Humidity per cent.
	r. m. s.	crest	
4	85·3	121	43
3	80·7	114	,,
2	84·5	119	,,
1	82·8	117	,,

(b) *Voltage withstood by individual insulators, without flashing-over, for 3 minutes.*

Insulator number	Flash-over Voltage Kilo-volts		Relative Humidity per cent.	Remarks.
	r. m. s.	crest		
4	81·2	115	43	Broke down 1 m. 35 sec. later.
,,	79·6	113	,,	
3	77·3	109	,,	Broke down 37 sec. later.
,,	76·5	108	,,	
2	79·7	113	,,	
1	78·3	111	,,	Broke down 40 sec. later.
,,	77·6	110	,,	

Variation of Flash-over Voltage (Dry) with Number of Insulator Units, in Series, forming a String.

The following results, shown in Table X, were obtained from the string arrangements given in Col. 2, with and without an arcing horn fitted at the line end.

The tests were restricted to a maximum of five discs in series, because the test pressure was limited to 280 kV. (r. m. s.) at 60 cycles.

The insulator discs used for the tests were Nos. 1, 2, 3 and 4 from string II and No. 5 from string No. V [see Tables III, IV, VII and VIII (*a*) and (*b*) for data regarding the flash-over voltage of single insulators].

It was observed that the addition of the arcing horn did not alter the flash-over voltage (dry) of single insulators. It may be noted that when testing individual units one transformer only was employed on account of the relatively low voltage required and hence one side of the insulator (supporting arm) was grounded and connected to the grounded side of the transformer. The line-side of the insulator leading direct to the high tension terminal. This normal arrangement, as mentioned earlier, was not possible when flashing over strings at very high voltages, [Cols. 3 and 4, Table X].

The observations are given in Table X in which Cols. 3 and 4 give the test flash-over voltage and Col. 5 the arithmetical sum of the flash-over voltages (from Tables III, etc.) for comparative purposes.

TABLE X.

Flash-over voltage (dry) for strings containing up to five units. Nos. 1, 2, 3 and 4 from string No. II and No. 5 from string No. V in which it was No. 1 unit.

Relative humidity 66 per cent.

Number of units in string	Assembly arrangement	Flash-over Voltage, Kilo-volts, r. m. s. — With arcing horn.	Flash-over Voltage, Kilo-volts, r. m. s. — Without arcing horn.	Arithmetic sum from Table III, etc., without horn and 62 per cent. humidity.
5	Nos. 1, 2, 3, 4, & 5	286	...	410
4	,, 1, 2, 3 & 4	241	274	330
3	,, 1, 2 & 3	176	222	246
2	,, 1 & 2	125	160	165
1	No. 1	78	82·6	81·3

Conclusions:—(1) These experiments indicated the possibility of the existence of a considerable number of faulty insulators in the four unit strings and, as mentioned above, this was found to be the case. A portable high-voltage testing set was taken along the transmission line for the purpose of locating defective insulators *in situ*. The causes of this deterioration are probably of a mechanical nature as there is a very large factor of safety when four discs are employed on a 75 kV. line. The voltage to ground is 46 kV. and the dry flash-over voltage is about five times this value. Even under unfavourable wet conditions the flash-over voltage is about 90 to 100 kV.

The actual faults, even if caused by unequal expansion of the metal and porcelain, have not been traced.

(2) These tests, on a limited number of insulators, did not afford conclusive evidence of serious deterioration of all the insulators which had been in use for ten years. It appeared that the effect of frequent arcing, and leakage along the glazed surface of the porcelain discs, was to roughen the glazed surface and set up a condition favourable to corona and surface leakage. Any deterioration that had taken place, apart from those units which had become completely faulty, appeared limited to about 10 per cent. reduction in the flash-over (dry) voltage.

(3) It appeared safer, in rearranging the four-unit strings of insulators for further service, to exchange the positions of insulators No. 4 (line-end) and No. 2 as the latter is subjected to the least voltage.

Further, it was considered advisable to add an unused insulator placed (as No. 5) at the line end, thus securing a considerable additional factor of safety.

Voltage Gradient along the Insulator Strings.

A series of experiments were undertaken with the object of ascertaining the extent to which the line-to-earth voltage was shared by the four insulators comprising the string and whether the 10 years service had caused any marked change in the gradient.

It is well known that under working conditions the voltage is not shared equally even by identical units on account of the capacity of the metal portions, caps and pins, of the string of insulators to ground and to line.

The capacity to ground has the effect of causing a larger capacity current to flow through the line-end insulator, with the result that the line-end insulator then carries a larger proportion of the total voltage.

In the same way capacity between the metal parts and the high tension line causes larger capacity current to flow in the ground-end insulators and tends to raise the voltage across the insulators at the ground-end. In exceptional circumstances the earth and line capacities might be equal with the result that all insulator units would carry equal currents and voltages.

It is evident and well-known that the voltage distribution depends upon, amongst other things, the proximity of earthed conductors such as the tower structure, ground wires, etc., at earth potential and upon the arcing horn and other conductors at high potentials. A variety of methods of measuring the potential along a string of insulators with respect to earth have been described but it is difficult to select one which does not possess serious defects.

In this instance the apparatus available and the desirability of conducting the experiments at as high a voltage as possible were the determining factors in the choice of the methods adopted.

The methods employed were :—

(1) A condenser bridge balance and

(2) An auxiliary transformer balance.

In both methods the voltage to be measured was balanced by a known voltage, the point of balance being indicated by the absence of a spark on making contact at the insulator string.

Working in the dark and noting the disappearance and reappearance of the spark as the balancing voltage was varied enabled reasonably close measurements to be made.

It was found, however, that in spite of all the precautions which were taken, there was considerable lack of agreement between the voltage gradient measured by the two methods. Too much reliance therefore could not be placed in the data obtained and it was concluded that the true voltage gradient probably fell between that obtained by the two methods.

The measurement of voltage gradients with greater accuracy has been dealt with by G. Yoganandam, and R. K. Sen (*J. Ind. Inst. Sc.*, 1927, **10** B, 21) and G. Yoganandam, (*J. Ind. Inst. Sc.*, 1927, **10** B, 43) the former also giving a theoretical treatment of the problem of predetermining the gradient under specified conditions.

Experiment on the Comparison of the Condenser Bridge Balance and Auxiliary Transformer Balance Methods.

(1) *Condenser bridge at high voltages.*

A string made up of old insulators and another of new insulators were tested under approximately working conditions, as regards string capacities, at 46 kV. between line and earth. Under these conditions the line-end insulator is subjected to a larger share of the total voltage than other units in the string.

The percentage of the total voltage (46 kV.) across the line-end insulator is shown in Fig. 1 for various numbers of old insulators, up to seven, and in Fig. 2 for various numbers of new insulators up to five. It will be seen that (1) the two methods give very different results and (2) there is no great difference between old and new insulators in this respect.

(2) *Condenser bridge at low voltages.*

On account of the somewhat rough determination of balance afforded by the 'spark' indicator it was decided to carry out some experiments with the condenser bridge at 6000 volts line-to-earth. An electrostatic voltmeter was used to measure the voltage across the two variable (uncalibrated) condensers forming the bridge.

The condensers used were made up of three tin-plate (24" × 20") surfaces, the middle one being movable with respect to the two outer plates, so that one capacity increased as the other decreased. The plates were suitably mounted on pin-type (180 kV.) insulators supported on a teak wood platform 3'—6" above earth. It is scarcely feasible to use an electrometer or other form of alternating current galvanometer to indicate balance and consequently reliance was placed upon the absence of alteration in the voltmeter (across condenser) deflection when contact was made to any point on the string of insulators. In making an observation, preliminary tests were made to ascertain the approximate setting of the condenser bridge, after which it was adjusted until on making or breaking contact (to insulators) no change in the voltmeter reading could be detected. This method of detecting balance was found to be considerably more sensitive than was expected.

Moving the contact along the string and taking differences in successive balance voltages gives the voltage across each insulator.

Experimental Data by Low-voltage Condenser Bridge.

The insulators which had been in service for ten years were assembled to form a string, numbering up to seven units, and subjected to 6000 volts (r. m. s.) line-earth pressure. The voltage at the cap of each insulator was observed and the average of many readings recorded and plotted as shown in Fig. 3. It will be seen that this method gives the surprisingly high figure of over 40 per cent. as the share of the total voltage borne by the line-end unit even for a 5-unit string. It should be noted here that the auxiliary transformer method gives much lower percentages for the voltage borne by the line-end unit, thus in the case of a 5-unit string only 25 per cent. was carried by the line insulator, under the test conditions.

The graphs in Fig. 4 refer to the same measurements made on unused insulators and do not show any large departure from those in Fig. 3 for the ten-year old units.

All these tests indicate that under the conditions of these tests the second unit from the ground-end is the least stressed.

(3) *Auxiliary transformer high-voltage (46 kV.) measurements of potential gradient.*

In carrying out these measurements two identical high tension transformers were used, one supplying the line-to-earth pressure across the string of insulators and the other the 'in-phase' pressure required to balance the potentials at various points along the string. Precautions were taken to ensure a negligible phase-difference in these two voltages; details of the circuits employed are shown in Fig. 2 of Messrs. Yoganandam and Sen's paper referred to on page 15. The experiments were conducted at night, as darkness favoured accuracy in observing the condition of balance which was found by means of the 'spark' indicator previously described.

Experimental Results for Ten-year Old Insulators.

The strings of insulators along which the voltage gradient had been measured by the condenser bridge balance were used for similar tests making use of the auxiliary transformer balance method. The data obtained is shown in the graphs of Figs. 5 and 6 for used and unused insulators respectively.

The data plotted represent the mean of a very large number of observations but in spite of every precaution taken it was recognized that the 'spark' method is limited in its accuracy.

It is extremely difficult to make certain that the spark has disappeared when viewed at a distance of about ten feet, but nevertheless practice assists the experimenter to obtain readings under these conditions.

As pointed out on page 17 the auxiliary transformer method gives lower percentages for the voltage across the line-end insulator and it is believed that its indications are more nearly in accordance with the true conditions.

GENERAL CONCLUSIONS FROM VOLTAGE-GRADIENT EXPERIMENTS.

Tests carried out at 45,700 volts, 60 cycles, with normal suspension conditions.

1. The insulators forming a string of five units share the line-to-earth voltage in the following average proportions :—

(Ground unit)	No. 1	....	19 per cent.
	No. 2	...	16 ,, ,,
	No. 3	....	18 ,, ,,
	No. 4	....	21 ,, ,,
(Line unit)	No. 5	....	26 ,, ,,
			100 ,, ,,

2. The insulators forming a string of four units share the line-to-earth voltage in the following average proportions :—

(Ground unit)	No. 1	....	23 per cent.
	No. 2	....	22 ,, ,,
	No. 3	....	25 ,, ,,
(Line unit)	No. 4	...	30 ,, ,,
			100 ,, ,,

3. The distribution of voltage along the strings appeared to be practically the same for new or old insulators.

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APPENDIX.

Experiment on the Effect of Increasing the Capacity of the Line-end Unit of a Four-unit String.

A number of methods of grading the capacity of the units forming a string of suspension insulators are in use, one of the simplest being the addition of a second insulator in parallel as indicated in Fig. 7 (B).

As a matter of interest the voltage gradient for this arrangement was measured by the condenser bridge balance and the observation plotted in graph (B) Fig. 7.

The same figure shows the gradient, graph (A), for four units only in series for comparison.

An arcing horn was fitted at the line-end in each case.

Although arrangement (B) Fig. 7, gives a far more uniform distribution of voltage along the string it is not of much practical value because the flash-over voltage is less than that withstood by the five insulators if they are connected in series.

The flash-over test results for the two arrangements are given in Table XI below.

TABLE XI.

Flash-over voltage (dry) for the two arrangements of insulators shown in Fig. 7.

Insulator assembly	'Flash-Over' Kilo-volts r.m.s.	Kilo-volts withstood for three minutes r.m.s.	Relative Humidity per cent.
1, 2, 3 & {4 / 5 (line end)	251	218	64
1, 2, 3, 4 & 5 ,,	285	sufficient voltage not available.	66
1, 2, 3 & 4 ,,	244	217	66

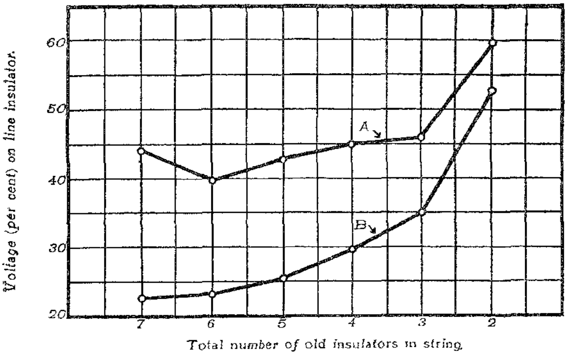

Fig. 1. *Variation of line-unit voltage.*

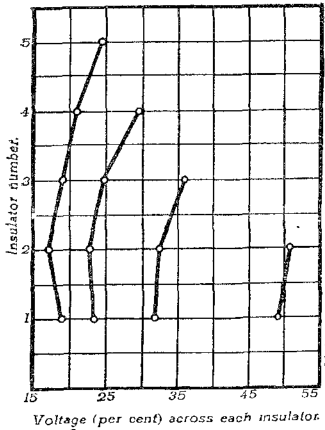

Fig. 6. *Auxiliary transformer method and new insulators.*

Curve A refers to tests by condenser bridge and Curve B by auxiliary transformer methods.

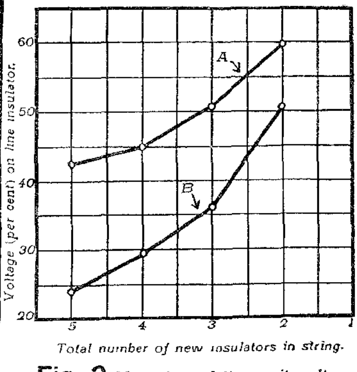

Fig. 2. *Variation of line-unit voltage.*

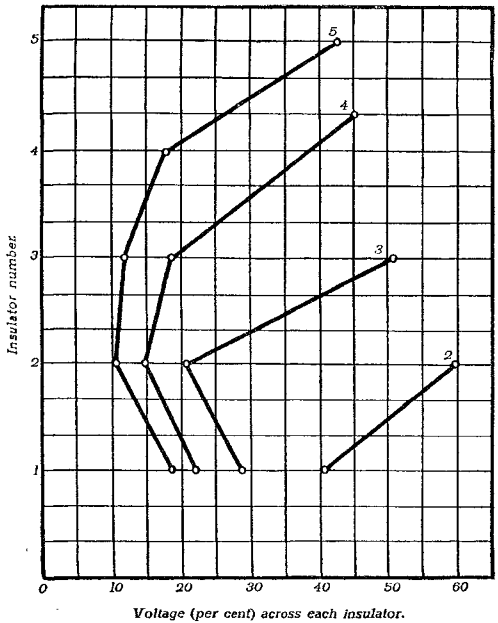

Fig. 3. *Low-voltage condenser bridge and old Insulators.*

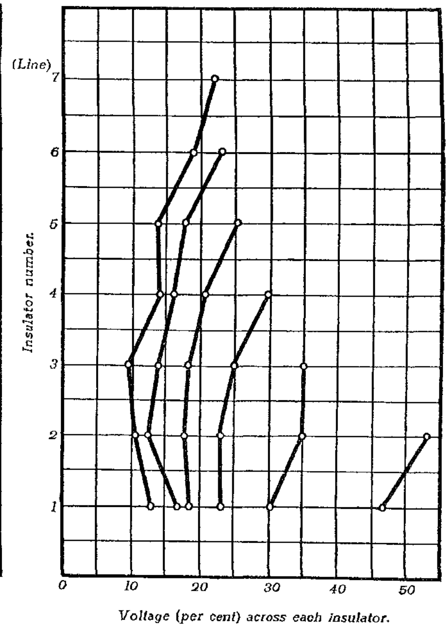

Fig. 5. *Auxiliary transformer method and old Insulators.*

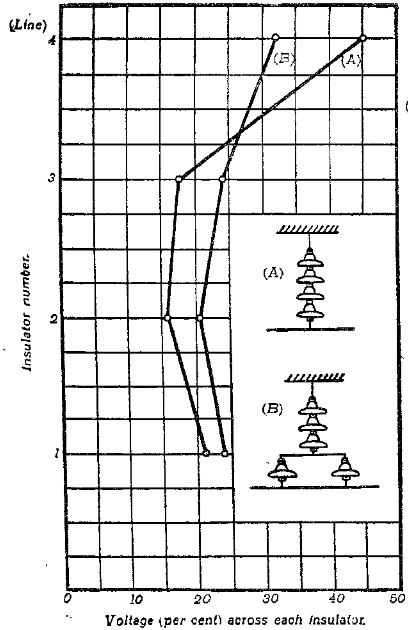

Fig. 7. *Graded capacity.*

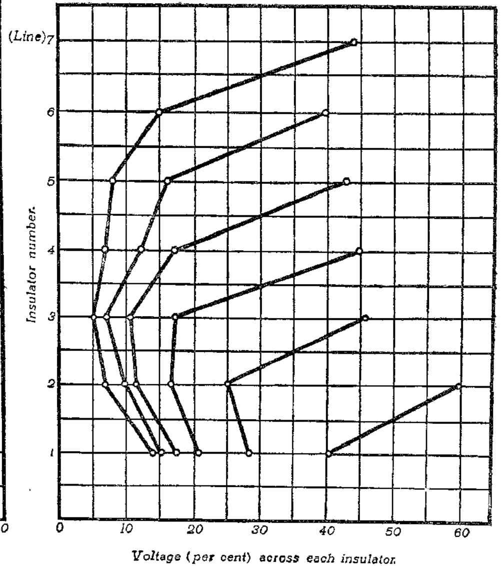

Fig. 4. *Low-voltage condenser bridge and unused insulators*