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FIELD CONTROL OF INSULATORS
FOR MODERN HIGH VOLTAGE LINES

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In the choice of transmission line insulators, engineers give consideration to various factors, weighing them according to the requirements of the line. Electrical characteristics analyzed include: (a) permissible outages caused by lightning, (b) possible values of switching surges, (c) normal frequency leakage current characteristics over the surface of insulators, and (d) electric overstress. This discussion summarizes methods of controlling the voltage stress at the line end of suspension insulators and evaluates this reduction by laboratory radio influence tests.

Because of possible differences in exposure and protective measures, the electrical characteristics of line insulation may have little relation to those of station insulation. Many engineers believe that the choice of line and station insulation should be made independently. Properly chosen protective devices at the station provide the necessary coordination.

Within the usual choice of the length of standard suspension insulator strings as determined by (a), (b) and (c), the problem of electric overstress remains practically unaffected. Experience demonstrates that correctly designed suspension insulators and suspension and strain clamps with no special shielding devices have satisfactory voltage stress characteristics when installed on 230 kv transmission lines. Although early 230 kv lines used elaborate grading rings, it has been found that they are not necessary. In fact, for some of the early lines which have been modernized, the rings have been removed and scrapped.

When higher transmission line voltages are considered, engineers become increasingly concerned about the electric stress on the insulators. As is well known, the voltage distribution across a long string of suspension insulators is not uniform. The line insulator of an 18-unit string may support about 20 per cent of the impressed voltage. As voltage is increased to 400 kv line-to-ground, it might be thought that the line insulator will be required to support 80 kv, but this does not occur because as the voltage is increased the overstress at the line end of the insulator string causes localized air breakdown. This corona

increases the effective capacitance of the line end insulators. A self-corrective action occurs and voltage distribution is automatically modified.

At transmission line voltages above 230 kv the increased electric overstress may be objectionable because of increased radio influence and because of some possible increased rate of corrosion on hardware adjacent to the air breakdown. Although some power loss occurs, it is negligible when compared with other transmission losses.

Corona and Radio Influence

Overstress causing air breakdown may be detected as the radio influence generated by the electrostatic discharge or as audible or visible corona. For a string of insulators tested in the dark with increasing voltage, corona may first be seen as a faint glow at the high stress point. This often will be at the edge of the pinhole of the line unit, may not be audible and has little effect on radio influence. At higher voltages this glow becomes more luminous and streamers may form on the porcelain adjacent to the pinhole. The radio influence increases in a somewhat regular way proportional to voltage. For conductors or line hardware the first glow is faintly visible and audible, and occurs at high stress points such as loose strands or nicks on the conductor or exposed bolt ends or sharp corners on the fittings. With increasing voltage the glow becomes brighter until it fans out suddenly into a brilliant plume. Both the radio influence and audible noise increase ten or more times when the plume bursts out.

Corona observations depend on personal factors and are subject to wide variations because of conditions of humidity and illumination. A trained observer may be able to detect faint glows of corona on suspension insulators at voltages far below those causing noticeable radio influence. In the laboratory, radio influence voltage is measured by the EET-NEMA-RMA recommended method. This provides a more reliable means of evaluating degrees of overstress for comparable designs. The effect of humidity on radio influence values is far less than on corona. In the field

radio influence is measured by antenna pick-up as radio frequency field strength. This is related to the laboratory radio influence data, but service conditions and coupling between the rf source and antenna may vary so widely that a fixed relationship between field strength (microvolts per meter) and laboratory radio influence voltage (microvolts at 1000 kc) is true for only one condition. A comparison of field experience at lower voltages with laboratory radio tests on the lower voltage equipment provides a conservative basis for recommending laboratory test levels for equipment for new and untried extra high voltages.

Electrostatic Stress Control

In the investigation of shields for use with insulators and hardware for the Tidd 500 kv test project, side control rings were developed which reduce the stress on both insulators and hardware. Similar smaller rings are used for 330 kv applications. (Figure 1.) That these rings effectively reduce voltage stress at critical insulator and clamp areas for clean,

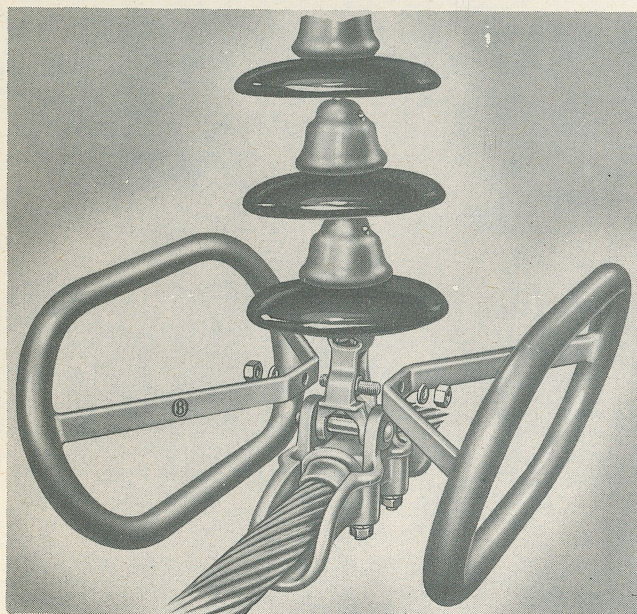


Figure 1.

330 kv Side Control Rings Shield both Insulators and Suspension Clamp.

dry conditions is shown by the reduced radio influence values and by the improved voltage distribution (Figure 2). Careful laboratory tests have been made to obtain optimum control effect with little reduction in flashover and with adequate clearance between rings and porcelain.

Mechanical considerations also are important. The side rings are tilted toward the clamp to improve tower clearance when the string swings toward the tower. Open construction reduces the possibility of snow packing or ice bridging. With a single stud on

the socket fitting, either ring may be removed without disturbing the rest of the assembly. There is no possibility of interference between conductor and ring because of galloping or broken conductors.

Since the basic electrical problem in control ring design is to encompass the critical hardware and

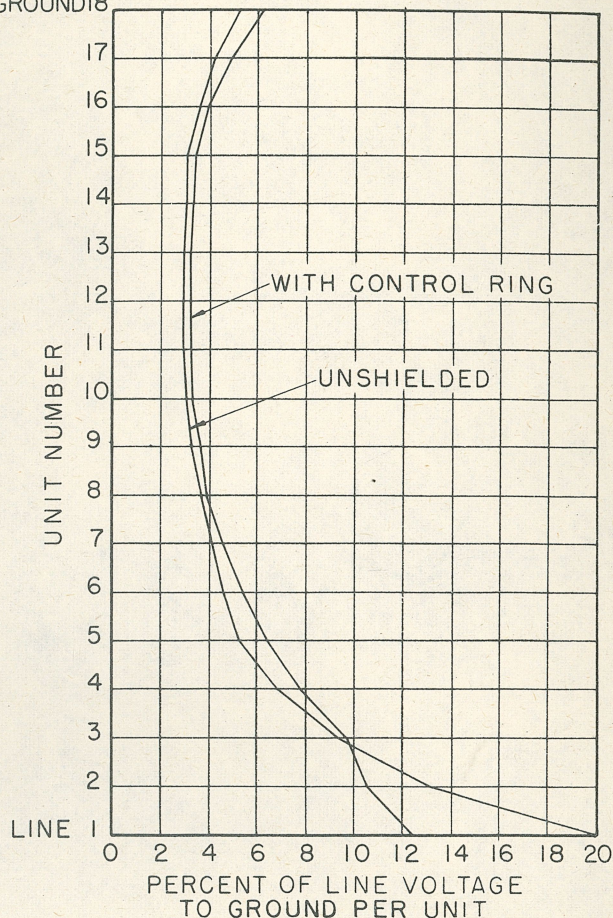
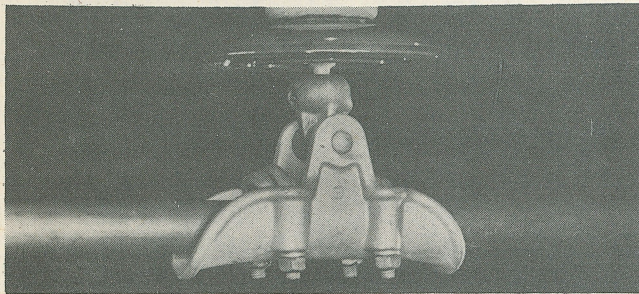
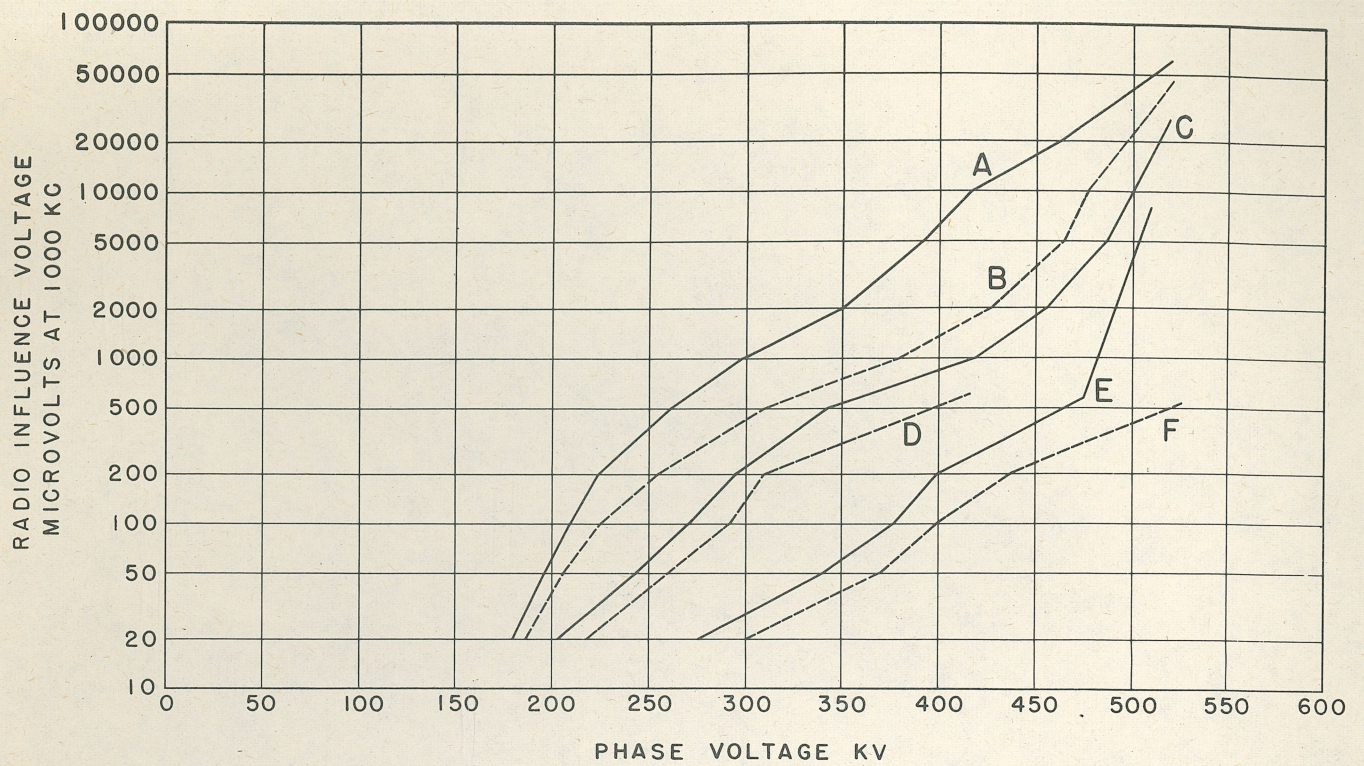


Figure 2.

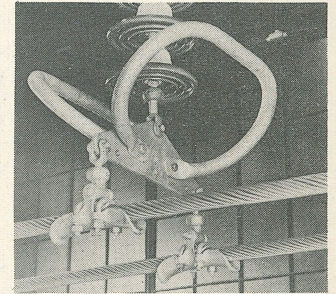
Voltage Distribution of an 18-unit Suspension Insulator String with and without Side Control Rings.

insulators with a stress shield, a wide range of shapes with various levels of control may be conceived. A shorter length of pipe or tube may be used with diminished control effect. Different grades of control designs and radio influence tests on each style demonstrating the level of stress reduction are described by Figure 3. Refinements beyond the side ring principle realize little further reduction. Note that all of these devices may be installed or removed without disconnecting the conductor from the insulators. An analysis of clearance to the tower for insulator swing conditions will show that for these shields the clearance is at least as favorable as for the tilted side control rings.

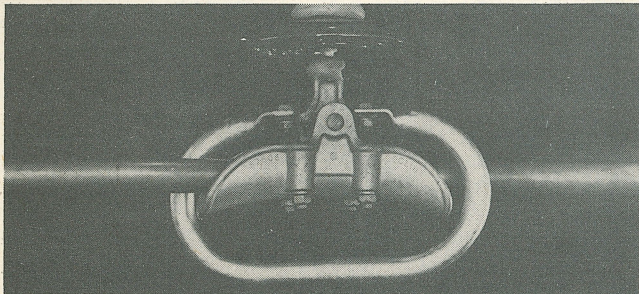
From these examples it is apparent that the only limitation on the ring shape is economical bending ability with minimum radii determined by permissible voltage stress. To prevent the formation of stress



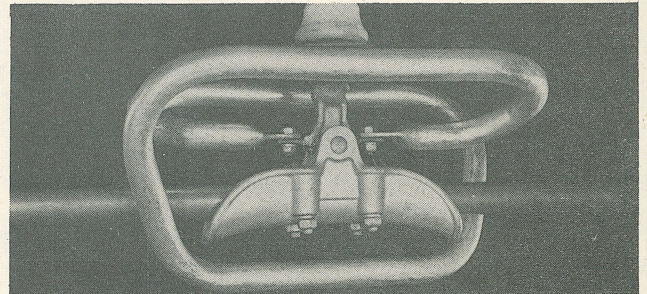
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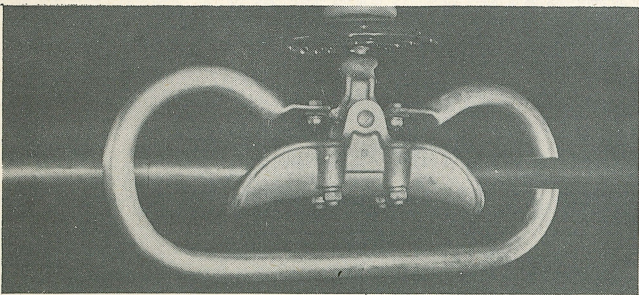
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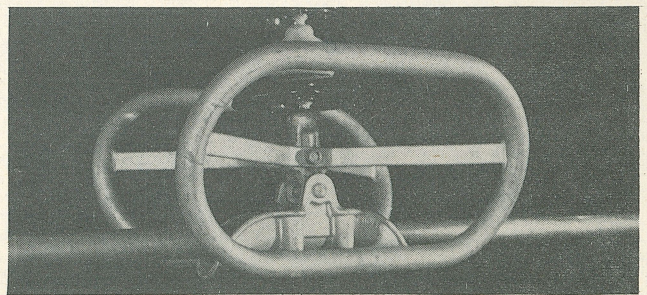
B



E



C



F

Figure 3.

Typical Radio Influence Characteristics of an 18 unit Suspension Insulator String with Various Grades of Control Rings.

raisers on the pipe care in manufacture is required. On critical radii, points as high as 1/32" may cause overstress.

A criterion for the extent of control required for insulator strings at extra high voltages is that the dry radio influence voltage shall be no greater than that for satisfactory insulator applications at lower voltages. The data from Figure 3 provide information from which such determinations may be made. Laboratory and test line information have indicated that this standard is conservative and that this principle of control is satisfactory for use with standard insulators and line hardware at voltages far beyond those presently considered.

Comparative Voltage Stress of Conductors, Insulators and Line Hardware

Conductor size is determined by consideration of transmission loss, corona loss and radio influence. At extra high voltages conductor diameter suggested by radio influence has met the requirements of the other factors except for unusual applications. Therefore, laboratory radio influence tests on conductors provide data from which an adequate diameter for higher voltages may be determined. Figure 4 shows

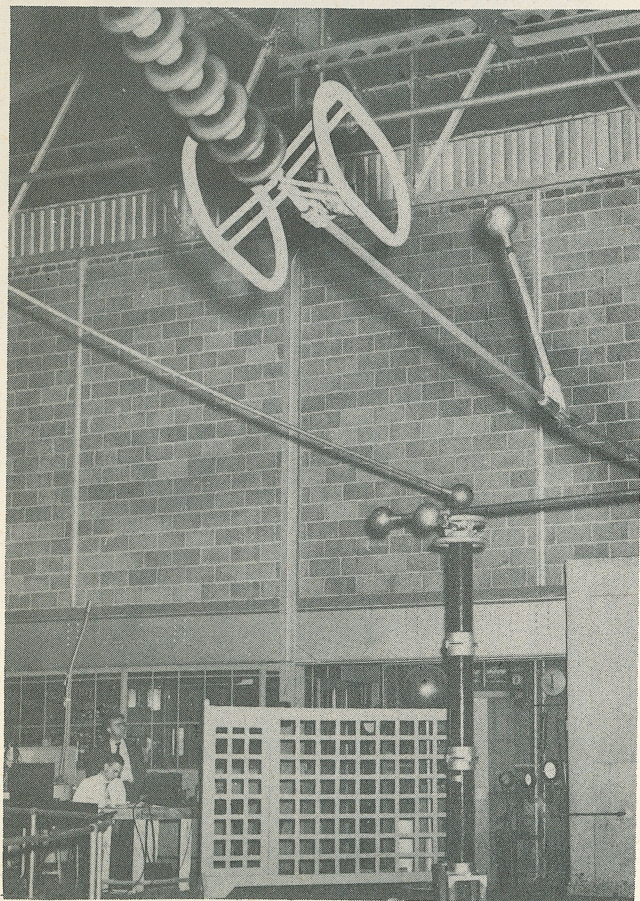


Figure 4.

Radio Influence Test Arrangement for a Conductor. Radio Influence Voltage is measured by the EEL-NEMA-RMA Recommended Circuit.

an arrangement for tests on conductors with associated hardware. Figure 5 shows typical conductor radio influence curves. Note that under wet conditions with water drops on the surface of the conductor the radio influence voltage increases by a factor of 50 or more. From these data a choice of conductor size may be made based on experience with lower voltage transmission.

If the control ring tube diameter is about the same as that of the conductor for single conductor line, or of the equivalent conductor for bundle conductor lines, then the change in radio influence of the control ring from dry to wet conditions will be similar to that of the conductor.

There is little change in radio influence of suspension insulator strings from clean, dry to clean, wet conditions. For dirty, wet conditions resistance grading of the insulator string may predominate and overstress may occur at high resistance areas at the pinhole or near the cap on any insulator. This localized air breakdown causes a marked increase in radio influence, but for the usual high voltage line, this increase is less than the normally expected increase for dry to wet conductor.

Since the limitation of wet conductor radio influence apparently governs for most high voltage lines the use of insulator control rings may not be necessary for some applications above 230 kv. A 287 kv line is now under construction with no control rings. Field data from this line compared with laboratory radio tests on the components will serve as an additional guide to future design at higher voltages.

Control rings similar to those described may be applied to other insulators. Dead end strings, air break switches and bus insulators may be shielded readily with simple ring designs.

Summary

Based on laboratory tests, test line trials and service experience, control rings have been developed to reduce voltage stress of insulators and line hardware for extra high voltage lines.

A wide range in style of rings is available. Choice may be determined by degree of shielding, convenience in handling and economic factors.

Laboratory radio influence tests provide a simple means for evaluating relative voltage stress.

Tests far beyond present applications at 330 kv and 380 kv indicate no upper limit to the use of standard suspension insulators and conventional suspension clamps with properly designed control rings.