

Nov. 28, 1933.

P. SPORN ET AL

1,937,296

TRANSMISSION LINE INSULATOR SYSTEM

Filed May 5, 1931

4 Sheets-Sheet 1

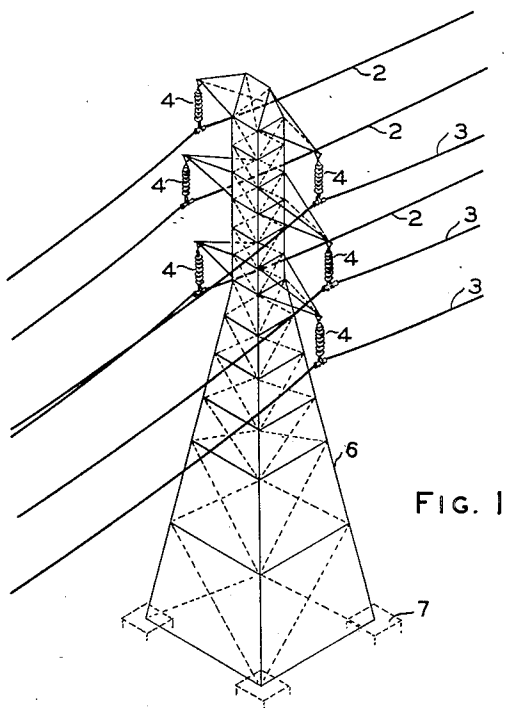


FIG. 1

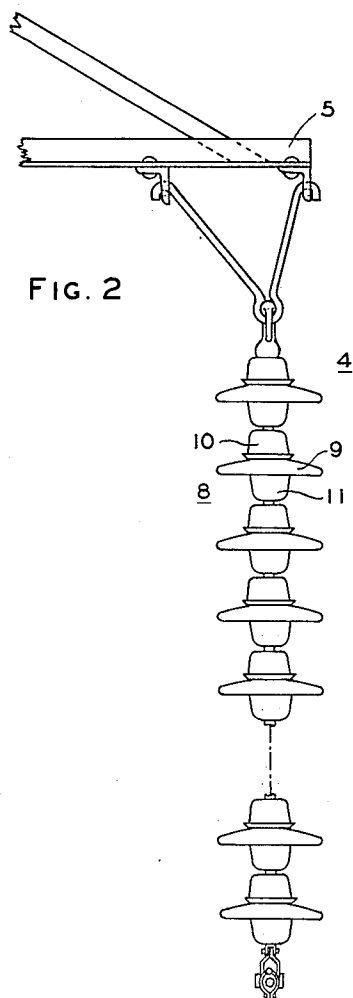


FIG. 2

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4 Sheets-Sheet 2

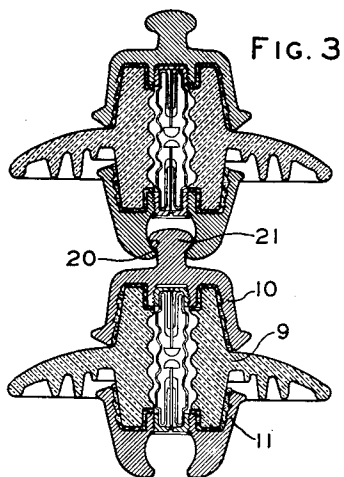


FIG. 3

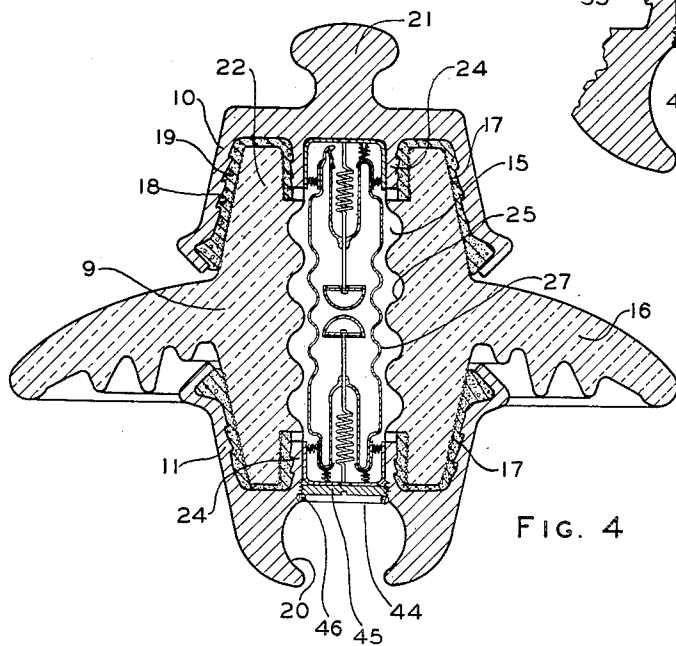


FIG. 4

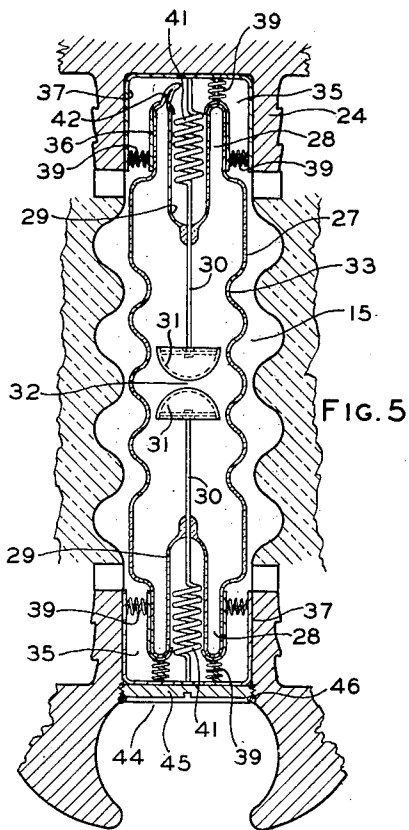


FIG. 5

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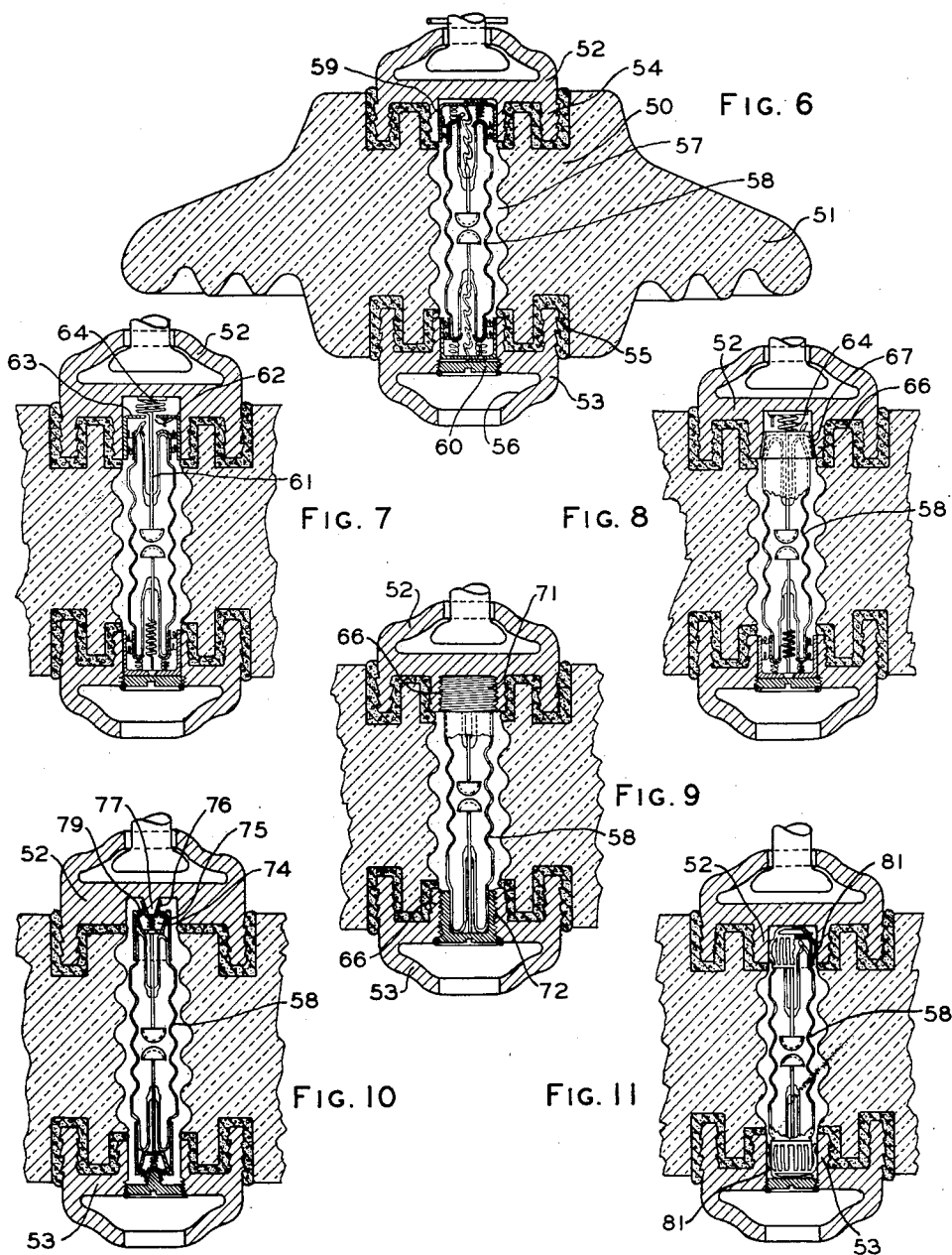
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4 Sheets-Sheet 4

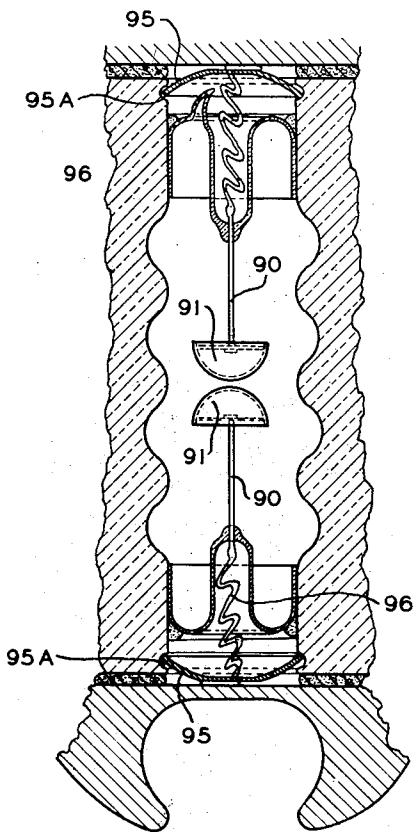
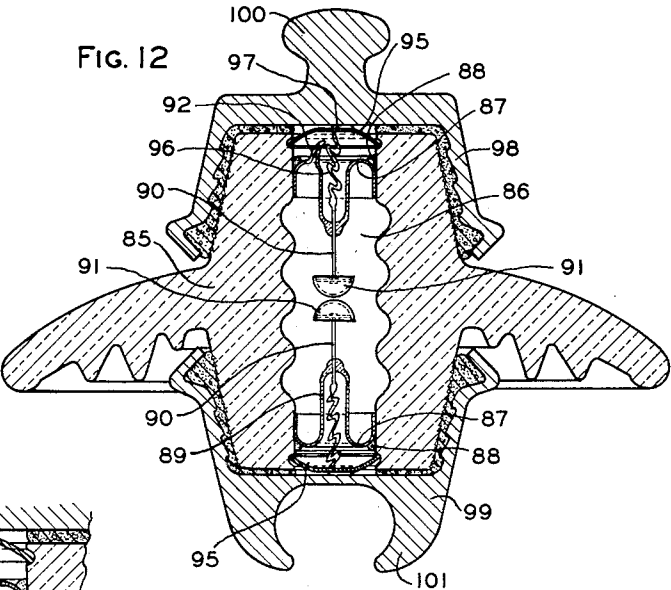
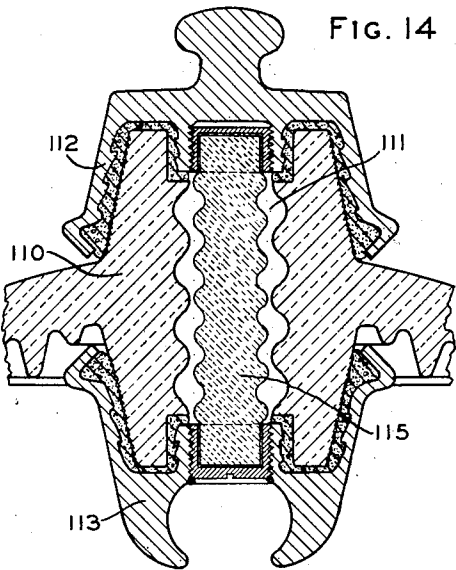


FIG. 13



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UNITED STATES PATENT OFFICE

1,937,296

TRANSMISSION LINE INSULATOR SYSTEM

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Application May 5, 1931. Serial No. 535,147

6 Claims. (Cl. 175—30)

This invention relates to insulator systems for high voltage power transmission lines, and it has among its objects the provision of such lines in which the line conductors are carried on insulating strings composed of suspension insulators enclosing evacuated valve chambers so arranged as to secure discharge of excessive overvoltages occurring on said lines, while preventing flow of power current along the path of the overvoltage discharges.

A more particular object of the invention is the provision of suspension insulators capable of mechanically carrying the strain imposed thereon in such insulator strings, and enclosing in the interior, evacuated valve chambers arranged to permit free discharge of overvoltages between the metallic connector caps on the insulators, while preventing discharges at voltages lower than the fraction of the total operating voltage normally applied to said insulators.

The foregoing and other objects of the invention will be best understood from the following description of exemplifications of the invention, reference being had to the accompanying drawings wherein

Fig. 1 is a diagrammatic view of a portion of a high voltage power transmission line;

Fig. 2 is a detail side view of the under portion of a tower arm with an insulator string suspended thereon, carrying a high voltage power conductor embodying the invention;

Fig. 3 is a cross-sectional view of two engaged suspension insulators of the string shown in Fig. 2;

Fig. 4 is an enlarged cross-sectional view of one of the suspension insulators of Fig. 3;

Fig. 5 is a still more enlarged cross-sectional view of the central portion of the insulator shown in Fig. 4, illustrating the mounting of the valve device in the interior chamber of the suspension insulator;

Figs. 6 to 11 are cross-sectional views similar to Fig. 4, of suspension insulators embodying modified forms of the invention;

Fig. 12 is a vertical sectional view of a suspension insulator embodying another modification of the invention;

Fig. 13 is an enlarged detail sectional view of the central portion of the insulator shown in Fig. 12; and

Fig. 14 is a vertical sectional view of a suspension insulator having mounted in its interior chamber a special valve resistor member.

The provision of continuous service to the customer has for some time been the most important

problem confronting the art of transmission of electric power. Many industries depend at present upon transmission line service. They cannot properly function or cannot use the service unless they have (a) a continuous uninterrupted supply of voltage on the lines furnishing them with power, and (b) a supply voltage that is not only continuous, but that is entirely free from disturbances, i. e., a voltage supply that is free from dips and other irregularities.

Records of operation of modern well-designed transmission lines indicate that seventy-five per cent of the outages are directly attributable to lightning. The dips and irregularities in the voltage supply are caused by the short circuits that take place in the system when, after a lightning flashover of the transmission line supporting structure and more particularly, the insulating members insulating the transmission line from its supporting structure, a power arc follows either between the phases or to the ground. In order to secure continuity of service, transmission systems are provided with elaborate equipment so as to clear such short circuits and sectionalize the same by means of oil circuit breakers actuated by proper relays. However, even in the cases where cutting out short-circuited lines causes no direct interruption to the service of a consumer, owing to the availability of duplicate supply lines, short circuits nevertheless cause a grave disturbance in the voltage of the system and may bring the voltage down to practically zero for periods as low as one-fifth of a second to periods as high as three or four seconds.

The duration of most of the lightning disturbances is comparatively short. The lightning disturbance, which is fundamentally an impulse discharge of the condenser formed by clouds and the earth, reaches its crest in a time varying from perhaps one-fourth to five or ten microseconds, and then dies down very rapidly. The total time of the impulse discharge, i. e., the time taken for it to discharge to almost zero, is of the order of thirty or forty microseconds in a great many types of discharges, and not much higher than 200 or 300 microseconds in very slow or long-tail impulse waves. In terms of sixty cycle frequency generally used on alternating currents in the United States, a time of 300 microseconds represents less than 1/25 of one alternation. Within that period the lightning discharge or impulse discharge has its birth so to speak, reaches its maturity, and entirely disappears.

According to the invention, the maintenance of service continuity of modern power systems is

greatly increased by suspending the transmission line conductors on insulator strings formed of special suspension insulators so arranged that the insulator strings distributed along the line cause lightning disturbances or similar excess overvoltages to quickly discharge through evacuated valve discharge vessels embodied in the suspension insulators, the valve action of these devices being such as to prevent power current from flowing in the path of the overvoltage discharge through the insulator string. By the use of such special insulator string the lightning current or impulse will quickly become discharged without disturbing the power frequency voltage, thus eliminating damage and destruction of equipment and what is even more important, interruption and disturbance to the service that heretofore invariably followed a severe lightning discharge.

In order to explain the invention more in detail it will be described in connection with the exemplifications shown in the drawings. Referring to Fig. 1, a portion of a high power transmission line 1 is shown having line conductors of two three-phase circuits 2 and 3 carried by insulator strings 4 suspended on metallic arms 5 of a supporting tower 6 that is secured in a proper foundation 7 within the ground. Such string 4 is shown in detail in Fig. 2 and is composed of a plurality of suspension insulators 8 as shown in Figs. 3 to 5, made of a skirt-shaped insulating body 9 strong enough to withstand the strain of carrying the heavy power line conductors, and two metallic cap members 10, 11 on the top and bottom of said skirt-shaped member arranged so as to permit mechanical engagement with the cap members of adjacent suspension insulators to form a continuous, mechanically strong insulator string.

The insulating skirt member 9 is not made in the form of a solid body as in suspension insulators heretofore used, but has in its interior a vertically extending tubular chamber 15. The exterior of the skirt member 9 has integrally formed thereon a downwardly protruding skirt 16 shaped so as to give a high resistance leakage path over the exterior surface of the insulating member and secure high flashover voltage between the upper and lower cap members 10, 11 of the insulator.

These cap members may have frustoconical shape and are arranged to fit over similarly shaped upper and lower end portions of the insulator member 9, similarly to the standard method of mounting caps on ordinary suspension insulators of this type. As seen in the drawings, the outer end surfaces 17 of the insulator member 9 are suitably roughened and the inner surfaces of the cap members 10 and 11 are grooved at 18 and the caps are firmly united to the adjacent surfaces of the insulating member by a filling of cement 19 so that the caps with the insulating member 9 form a single mechanically strong unit. The bottom cap has formed on its lower end a socket 20 and the top cap has formed on its upper end a head 21 arranged to fit into such socket 20, so that the head 21 of one suspension insulator may be brought into engagement with the socket 20 of the adjacent higher insulator to form a flexible, mechanical connection by means of which the lower insulator is suspended and carried by the higher insulator. The wall thickness of the portions 22 of the insulating member 9 clamped to the caps is so proportioned that notwithstanding the central vertical chamber 15, the insulator member will have sufficient

mechanical strength to withstand the strain imposed upon it when mounted in the insulator string and carrying the heavy line conductor. The details of construction of the socket 20 and the head 21 may be the same as followed in the head and socket constructions of ordinary suspension insulators.

The cap members 10, 11 are also shown provided with reentrant tubular flanges 24 embracing the ends of the wall members 22 of the insulating member 9 from the interior and constituting the upper and lower enclosing walls for the hollow chamber 15 within the insulator. The wall of this chamber is provided with transverse corrugations 25 so as to increase the surface resistance of the chamber wall in the direction between the upper and lower cap members and preclude direct discharges between said cap members along said wall. Inside the hollow chamber 15 there is mounted an evacuated discharge valve 27 designed to discharge voltages above a predetermined starting value, and prevent discharge if the voltage applied to said valve is below a predetermined sealing value. The construction of the discharge valve 27 in itself is not a part of the present invention, having been devised by A. W. Hull of Schenectady, New York, a number of such valves being employed in various uses at present.

Such discharge valves comprise an evacuated, hermetically closed vessel, of glass for instance, arranged preferably in tubular form as shown in the drawings and having at the opposite ends 28 reentrant stems 29 carrying lead-in conductors 30 upon which are mounted electrodes 31. These electrodes are in the form of hemispheres closely spaced from each other so as to provide a small gap 32 therebetween. The tubular wall of the vessel has transverse corrugations 33 so as to secure a high leakage path between the parts of opposite potential in the tube and prevent flash-over or discharges across the vessel surfaces.

A discharge valve 27 such as illustrated in Fig. 3, using hemispherical electrodes of seven-eighths inch diameter with a gap length of one-sixteenth of an inch, enclosed in a glass shell having an overall length of approximately six inches and an outside diameter of approximately one and one-half inches, shows in operation the following properties:

The gap breaks down at a maximum voltage of approximately 45 kv (crest value) and permits passage of heavy discharge current for a very short while without damage to the tube. When the voltage across the gap drops down the discharge stops and is sealed off at a voltage not less than approximately 15 kv. Depending upon the variability of the gap, this sealing or breaking-off voltage may be considerably higher, but it was found that under all conditions of operation the gap would stop the discharge when the voltage dropped down below the sealing value of approximately 15 kv. Furthermore, the gap is very fast in starting the discharge as well as breaking off the discharge, so that when a current 60 cycle power line operating with a voltage below 15 kv (crest value) is connected across the valve, a lightning disturbance having a voltage over 55 kv will produce an instantaneous break-down of the gap and discharge the overvoltage while preventing flow of power current in the wake of the overvoltage discharge through the tube. Such vacuum valves are thus able to discharge lightning discharges imposed on the

line without permitting the flow of dynamic or power current through the discharge path.

In accordance with the invention the suspension insulators 9 of the insulator strings are provided with such vacuum discharge valves and the number of suspension insulators in the string is so apportioned that under normal operating conditions the fraction of the normal line voltage applied to the individual insulators is below the sealing value of the valves within the respective insulators; and that in case of disturbances, such as lightning, causing dangerous excess voltages on the line, the fraction of the total voltage applied to the individual insulators is such as to cause break-down of the gap and discharge the overvoltage while preventing the power current from flowing through the gap. Thus, in the case of a three-phase power line with 132 kv between the phases and 76.3 kv between the line and the ground, corresponding to a crest voltage of 108 kv, a suspension string with ten insulators provided with valves as described above will secure the necessary protection of the system to avoid most of the usually occurring lightning disturbances. Such an arrangement insures discharge of overvoltages in excess of 550 kv, this being a good safety limit for a line operating at 108 kv. The insulator string valves stop current flow and seal off the discharge when the voltage drops to about 150 kv, thus leaving a safe margin against flow of dynamic current following the overvoltage discharge. In this way, lightning disturbances will be discharged over the insulator strings, but dynamic power flow prevented, thus eliminating the outages which constituted heretofore one of the greatest difficulties in modern power distribution systems.

As shown in Fig. 5, the vacuum valve 27 is held at its ends in special holders 35 composed of an inner shell 36 clamped around the vessel end and a concentric outer shell 37 fitting against the cap extension 24, a set of springs 39 between the shells serving to secure resilient support of the glass valve 27 in the two holders 35. Flexible connectors 41, resilient if desired, effect connection between the lead-in wires 30 and the outer holder shells 37 so that a good conducting connection is obtained between the electrodes 31 and the insulator caps 10, 11, respectively. The holders 35 are so arranged as to protect the tip 42 left on the tube after sealing it off from the vacuum system during the evacuation process. By securing resilient support of the evacuated valve vessel within the suspension insulator, breakage or damage of the valve vessel is eliminated and the suspension insulator provided with the valve may be handled with not much greater degree of care than ordinary suspension insulators.

In order to permit ready replacement of a valve tube 27 without disturbing the mechanical structure of the suspension insulator and also to permit the ready original mounting of the valve tube in place, the lower cap 11 of the insulator has an opening 44 of sufficient size to permit the withdrawal of the tube with its holders from the insulator chamber 15 past the socket 20. The arrangement of the socket 20 on the lower cap member is of great advantage because it prevents moisture and rain or snow from getting into the opening 44 and thence into the chamber 15 where it might leave a conducting deposit on the tube surface or on the chamber walls, affecting its insulation, the socket structure serving thus as a protection for the opening 44. A screw cover

45 is provided for enclosing the opening 44 in the insulator chamber 15, the cover being threaded through the edges so as to fit into a co-operating threaded portion of the flange member 24 of the cap. After the valve tube 27 is put in place within the chamber the cap is screwed in place and the chamber sealed against entrance of moisture by inserting a layer of wax or similar substance in the groove 46 formed around the periphery of the cover 45.

A variety of other forms of suspension insulators provided with internal evacuated valves, is shown in Figs. 6 to 13. In the arrangement shown in Fig. 6, the insulator member 50 has a heavy central portion with a surrounding skirt 51, and cap members 52, 53 are secured to the top and bottom sides of the insulator member 50 by cementing extensions or legs 54 of the caps 52, 53 within the recesses 55 formed in the insulator body. Such method of constructing ordinary suspension insulators is described in, for instance, Johnston Patent No. 1,329,770. The caps are provided with suitable socket structures 56 for joining consecutive suspension insulators to each other, which may likewise be as shown in said Johnston patent.

In the center of the insulating member 50 there is provided a vertical chamber 57 having its walls corrugated to secure high surface resistance, and within the chamber is mounted a valve 58 like the valve 33 of Figs. 3 to 5. The valve is held in place by resilient holders 59 and is inserted into the chamber through a cap-covered opening 60 also like in the arrangements shown in Figs. 3 to 5. This type of insulator in which the caps are anchored on both sides of the insulator disk by means of legs or extensions embedded in recesses of the insulator disk is particularly adapted for use in conjunction with the evacuated valve chambers, because the body portions of such insulators as used heretofore in ordinary suspension insulator strings are of large enough diameter to permit the provision of the hollow chamber for housing the evacuated vessel.

The arrangement shown in Fig. 7 is similar to that of Fig. 6, but it has a somewhat different arrangement for making electrical connections between the gap electrodes and the cap members. As shown in Fig. 7, the terminal lead 61 of the upper gap electrode is arranged so as to extend through an opening 62 in the center of the upper valve tube holder 63, the lead carrying at its end a helical spring 64 which contacts with the cap wall and cushions the valve tube as well as establishes electrical connection with the upper cap member 52.

In the arrangement of Fig. 8, there is shown a different support for the upper end of the valve tube 58. The tube itself has its upper end shaped in frustoconical form adapted to fit into a corresponding opening within the extension 66 of the upper cap member 52, a layer of resilient material 67 such as rubber being interposed between the adjacent surfaces. Contact is made with the cap 52 by contact springs 64 as in Fig. 7.

In the arrangement of Fig. 9, the valve tube 58 has its ends provided with threaded bases 71, 72, fitting into suitable threaded openings in the extensions 66 of the caps 52, 53. A cushioning material such as rubber is placed intermediate the bases 71, 72, and the glass tube, so as to protect the same during transportation and mounting.

The arrangement of Fig. 10 differs from that

of Fig. 6 by the provision of conically shaped tube holders 74 comprising an outer shell member 75 seated on the valve end and an inner shell member 76 adapted to fit over a conical projection 77 on the cap members 52, 53, springs 79 holding the shell members 75, 76 together and serving to cushion the valve tube 58 and establish electrical contact between the tube electrodes and the cap members. The valve tube is thus properly centered against the upper and lower caps of the insulators.

In the arrangement shown in Fig. 11, the valve tube 58 is held in place by means of two base members 81 mounted on the ends of the tube. The base members have their sides slotted and shaped to form a series of springs exerting pressure outwards against the walls of the cap members 52, 53 surrounding the same.

In the arrangement described above the insulator member 9 is preferably made of porcelain which has proved both from the mechanical standpoint as well as the electrical standpoint, an excellent material for suspension insulators. However, there are at present also manufactured glass suspension insulators comparable in performance both electrically and mechanically, with the porcelain insulators. A feature of the invention is the construction of vacuum-valve suspension insulators by the utilization of glass such as used in suspension insulators as the material of the insulating body, and arranging it so that the glass itself forms a hermetically closed, highly evacuated chamber for holding the valve electrodes. Such a suspension insulator is illustrated in Figs. 12 and 13.

As seen in Fig. 12, the suspension insulator comprises a skirt-shaped insulating member 85 similar to the insulating member 9 of the arrangement shown in Fig. 3, but is made of glass that is mechanically and electrically comparable with porcelain, and has in addition, the property of vacuum-tightness that porcelain does not have. In the center of the insulating member is provided a substantially cylindrical vertical chamber 86 with transversely corrugated walls to secure high leakage resistance. The upper and lower openings of the cylindrical chamber 86 are sealed up by closure members 87 of glass, the periphery of the closure members being fused or united with the adjacent walls of the insulator by a filler 88 of glass or some other suitable way, so as to make the chamber 86 vacuum-tight, like the evacuated vessel 27 in the arrangement shown in Figs. 3 to 5. The closure members 87 have reentrant stems 89 carrying sealed-in lead wires 90 upon which are mounted hemispherical electrodes 91 forming a gap like in the vacuum vessel 27. Prior to completion, the chamber 86 is exhausted by an exhaust connection joined to the upper closure member at 92, the junction being sealed up after evacuation so as to leave the vessel evacuated and vacuum-tight. The vacuum condition and the spacing of the electrodes 91 are the same as in the vacuum valve 27 shown in Figs. 3 to 5, so that the gap between the electrodes 91 forms a discharge valve having the same discharge characteristics as the separate valves described above.

To protect the glass closures 87 against injury, metallic spring disks 95 are mounted within grooves 95a over the upper and lower openings of the central insulator member, the disks being electrically connected to the electrode lead-in wires 90 by flexible connectors 96 which have their ends soldered or otherwise joined to the

disks at 97. Metallic caps 98, 99 provided with heads 100 and 101 respectively, are cemented over the upper and lower ends of the insulating member 85, similarly to the mounting of the caps 10 and 11 on the insulating member 9 of the arrangement shown in Figs. 3 to 5, so that the complete structure looks very much like an ordinary suspension insulator and may be assembled in a string to carry the transmission line in the usual way. The caps 98, 99 are electrically connected to the upper and lower gap electrodes 91, respectively, through electrical contact with the outwardly bent portions of the spring disks 95.

By reason of the provision of an evacuated valve in the interior, the improved suspension insulators shown in Figs. 12 and 13 will, when used in the way described hereinabove in connection with the insulator shown in Figs. 3 to 5, protect the transmission line and prevent lightning disturbances from interfering with the operation and voltage regulation of the transmission system.

Because of the small heat capacity of the electrodes and the entire structure of the vacuum valves used in the novel suspension insulator arrangement described above, it is possible to maintain discharges through such valves only for a very short instance of time. As pointed out before, lightning discharges are only of very short duration, lasting usually about thirty or forty microseconds and only very rarely, lasting up to 300 microseconds. The suspension insulator vacuum valves as described above will readily discharge such short duration discharges without damage to the valve structure, and without affecting its operativeness.

Transmission lines are, however, subjected not only to lightning overvoltages of very high value, but also to switching surges which are of much lower value than the lightning discharges but last much longer than the same. If insulators with vacuum valves as described above are subjected to discharges from such switching surges lasting an appreciable time, they are often damaged and the valve action detrimentally affected. The overvoltages produced by switching surges are usually not more than three or four times the crest value of the operating voltage of the line and only in rare cases reach as much as five times the crest value of the normal operating voltage. Such surge voltages do not present any danger to the transmission lines and the station apparatus is, as a rule sufficiently insulated to withstand the switching surges without harm to the apparatus. According to the invention, the insulator string with the vacuum-valve suspension insulators are so arranged as to prevent overvoltage discharge by switching surges through the valve chambers. We desire it to be understood that the term "voltage of switching surges" as used herein is intended to designate voltages up to about five times the crest value of the normal line operating voltages.

In accordance with the invention, surge voltage discharges through the suspension insulator vacuum valves of the insulator strings may be prevented in a variety of different ways. According to one arrangement, the number of valve units in the insulator string is so chosen that the total starting voltage for the discharge through the vacuum valve chambers of the string is higher than the switching surge voltage of the line. Thus, in the example referred to before, of a 132 kv, three-phase line with a crest voltage of 108 kv between the phases and ground, insula-

tor strings composed of ten suspension insulator units with vacuum valve chambers having a starting voltage of 55 kv and a sealing voltage of 15 kv, will give protection against lightning overvoltages above about 550 kv, will seal against power flow at voltages below about 150 kv, and will prevent switching surge discharges below about 550 kv. Such line, provided with strings of ten vacuum valve suspension insulators, will therefore not be subject to troubles due to valve discharges on account of switching surges, and will provide full protection against lightning discharges.

According to another arrangement, instead of using ten vacuum-valve suspension insulators of the type described above, the insulator strings for such a 132 kv, three-phase line, are made up of seven vacuum-valve suspension insulators having connected in series therewith one or two suspension insulator units enclosing ordinary discharge gaps operating at atmospheric pressure and so adjusted that the total break-down voltage of the string is about 550 kv. With such arrangement, lightning disturbances having overvoltages higher than 550 kv will break-down the series gaps in the additional suspension insulators and pass through the valve chambers of the seven suspension insulators of the string. There will be no substantial power current discharge through the valve chambers of the insulators following the lightning discharge, because the sealing voltage of the seven units is about 105 kv, almost equal to the crest value of the line voltage. However, in order to secure a greater margin of safety with such arrangement, it is preferred to use in the particular instance referred to, at least eight vacuum-valve suspension insulator units so that the sealing voltage of the units shall be definitely higher than the crest value of the normal operating voltage. With eight units, the sealing voltage will be 120 kv against the crest value of the operating value of a 132 kv, three-phase line, of 108 kv.

In the arrangement last described the suspension insulators which provide the atmospheric series gap for the vacuum-valve suspension insulator units are either in the form of external ring electrodes carried by the suspension insulators, or in the form of gaps mounted in the chamber in the interior of the insulator, similarly to the arrangement shown in Figs. 3 to 5, but without the vacuum vessel, so that the gap operates under atmospheric pressure.

Instead of using series gap units operating under atmospheric pressure, the vacuum-valve suspension insulator may be combined with suspension insulator units which house special valve resistor materials of such character that in combination with the vacuum valve insulators, there is obtained protection against the discharge of switching surge voltages through the valve chambers without impairing the freedom of the discharge of lightning overvoltages. There are known at present several types of valve resistor materials in the art, chiefly used in the construction of lightning arresters. Such materials were described in papers delivered at the mid-winter convention of the American Institute of Electrical Engineers in New York on January 27-31, 1930, one paper by K. B. McEachron entitled "Thyrite, a new material for lightning arresters"; and another paper by J. Slepian, R. Lanberg and C. E. Krause entitled "Developments of new autovalve arrester". These papers have been

published in the transactions of the American Institute of Electrical Engineers for 1930.

Each of these papers describes a special porous resistor material which has the properties of presenting a high resistance to the flow of current up to a certain value, so that it in effect prevents substantial current flow up to said value, but for voltages above said predetermined value, which may be designated as the sealing value, the resistance of the material rapidly decreases and permits relatively free discharge of the current. Thus, for instance, the material described in the paper by McEachron has the property that for each time the voltage is doubled the current increases 12.6 times, this material being termed by McEachron as "Thyrite". The present invention does not relate to the structure of these materials, which will hereinafter be designated as "valve resistor materials", but makes use of the same in securing improved operation of the insulator strings described hereinabove.

According to the invention, one or several suspension insulators of a string composed of vacuum-valve suspension insulators has enclosed in its interior a block of valve resistor material and the blocks are so dimensioned that the assembled string will prevent discharges of overvoltages below the upper value of switching surge voltages, but will permit free discharge of lightning disturbances higher than the surge voltage limit, while preventing dynamic power flow in the path of the lightning discharge.

A suspension insulator with such valve resistor unit is shown in Fig. 14. The insulator comprises an insulating member 110 of porcelain or glass like that of Fig. 4, having in its interior a hollow chamber 111 with transversely corrugated walls to secure a high surface leakage resistance. The insulator is provided with a top cap 112 and a bottom cap 113 having a head and socket and enclosing the chamber 111 on the top and bottom, like in the insulator of Fig. 4. Within the chamber is mounted a block 115 of valve resistor material of the kind described in the papers of McEachron and Slepian et al., referred to above. The blocks are so designed, and the number of insulators with such valve resistor blocks in series with the string of vacuum-valve suspension insulators is so chosen and correlated, that the additional resistance of the valve resistor blocks will prevent switching surges from breaking down the vacuum valve chambers, but will permit relatively unimpeded discharge of lightning overvoltages higher than the switching surge voltages. In the case dealt with before, i. e., 132 kv, three-phase line, a string of eight vacuum-valve suspension insulators such as shown in Fig. 4, with two or three serially arranged valve resistor suspension insulators such as shown in Fig. 14, may be arranged so as to prevent discharges of switching surge voltages below 550 kv and to secure discharges of lightning overvoltages above 550 kv, while preventing dynamic power from flowing through the valve chambers.

In accordance with the invention, the discharge of switching surges and undesirable overloading of the vacuum valves of the suspension insulators may also be obtained by the utilization of the ground resistance of the supporting towers of the transmission line, and the correlation of the ground resistance with the vacuum-valve suspension insulator units constituting the string. The protection of the line will in general be the better, the less the number of vacuum-

valve suspension insulators used in the string. By connecting in series with such valves, limiting resistors, it is possible to prevent the passage of switching surges through the valves by a smaller number of vacuum valve units than would be necessary without the resistance connected in series. The supporting towers upon which the transmission lines are carried, although mounted on the ground, do not constitute a complete short-circuit with the ground, but have a very definite ground resistance for discharges through the tower. This ground resistance differs, depending on the geology of the right of way, and varies between values as low as two to three ohms, and values as high as 100 ohms, and in some cases, as in rocky country, reaches even as much as 500 ohms.

According to the invention, the number of vacuum valve units in the individual insulator strings is chosen in correlation with the resistance of the individual transmission line towers so that the resistance of the tower acting in series with the valves shall be sufficient to prevent switching surges from breaking down the vacuum valve in the suspension insulator, while permitting break-down under lightning discharges and sealing off against dynamic power discharges. Thus, for instance, in the case of a 132 kv three-phase line, eight vacuum-valve suspension insulators will be sufficient for stretches of the line going over rocky country, having a tower resistance of about 50 ohms, while stretches of the line having wet ground with a tower resistance of two to three ohms will have insulator strings composed of eight vacuum-valve suspension insulators, as shown in Fig. 4, and one or two valve-resistor suspension insulators as shown in Fig. 14, so as to obtain by the combination of the elements, security against switching surge discharges through the valves, while retaining protection against lightning and dynamic power flow.

Many modifications of the invention will suggest themselves to those skilled in the art, and it is accordingly desired that the appended claims be given a broad construction commensurate with the scope of the invention within the art.

What is claimed is:

1. A suspension insulator for insulator strings carrying high-voltage, high-power transmission lines comprising a central insulating member of a tight and mechanically strong material capable of carrying the transmission line, a pair of metallic connectors secured to the top and the bottom, respectively, of said member, said connectors having on their exterior sides complementary junction elements for flexible connection to complementary junction elements of adjacent insulators for forming a suspension string, an insulating skirt extending between said connectors integrally from around said member and protruding downwardly to increase the insulating effect of the exterior surface of the insulator, said insulating member having in its interior a highly-evacuated, hermetically-closed valve chamber and a pair of spaced electrodes insulatingly supported in said chamber connected, respectively, to the top and bottom connectors of said member, said chamber being sufficiently evacuated and said electrodes being sufficiently spaced to prevent flow of current following an over-voltage discharge when the voltage between the electrodes is less than a predetermined sealing voltage that is higher than the fraction of the total operating voltage applied to said insulator

in normal operation, and to pass freely discharges between said electrodes upon application of a voltage higher than said sealing voltage to said insulator.

2. A suspension insulator for insulator strings carrying high-voltage, high-power transmission lines comprising a tubular strain insulator member having in its interior a vertical tubular chamber and surrounded on its exterior by a downwardly protruding insulating skirt integrally extending from said member to increase the insulating effect of the exterior surface of said member, the interior wall surface of said chamber having transverse corrugations increasing the insulating effect of the interior wall surface, a metallic cap secured to the top of said member and constituting a permanent enclosure over the upper end of said chamber, a metallic cap secured to the bottom of said member and enclosing the lower opening of said chamber, connector means on said caps providing mechanical connections to adjacent suspension insulators to form therewith a suspension string, a valve device in said chamber comprising an evacuated, hermetically-sealed tubular vessel, a pair of spaced electrodes in said vessel, and lead-in conductors extending from the upper and lower ends of said vessel to said electrodes connecting the same to the upper and lower caps, respectively, said tubular vessel having transverse corrugations in its walls to secure high surface resistance between the upper and lower ends thereof, the lower cap having an opening for inserting said valve device into said chamber, and a removable cover for said opening for completely enclosing said valve in said chamber, and means for resiliently supporting the ends of said tubular vessel within said tubular chamber.

3. A suspension insulator for insulator strings carrying high-voltage, high-power transmission lines comprising a tubular strain insulator member of hermetically-tight material having in its interior a vertical tubular chamber and surrounded on its exterior by a downwardly protruding insulating skirt integrally extending from said member to increase the insulating effect of the exterior surface of said member, the interior wall surface of said chamber having transverse corrugations increasing the insulating effect of the interior wall surface, closure members sealed to the upper and lower ends of said chamber to provide a hermetically-sealed enclosure, said enclosure being evacuated, a metallic cap secured to the top of said member and enclosing the upper end of said chamber over the upper closure member, a metallic cap secured to the bottom of said member and enclosing the lower opening of said chamber over the lower closure member, connector means on said caps providing mechanical connections to adjacent suspension insulators to form therewith a suspension string, a pair of spaced electrodes in said enclosure, and lead-in conductors sealed through said closure members connecting said electrodes to the upper and lower cap members, respectively, said electrodes being sufficiently spaced and said enclosure being sufficiently evacuated to prevent passage of current following an over-voltage discharge on applying to said electrodes a voltage lower than a predetermined sealing voltage that is higher than the fraction of the total operating voltage applied to said insulator in normal operation, and to pass freely discharges between said electrodes upon applica-

tion of a voltage higher than the sealing voltage to said insulator.

4. A suspension insulator for insulator strings carrying high voltage transmission lines comprising a tubular strain insulator member having in its interior a vertical tubular chamber and surrounded on its exterior by a downwardly protruding insulating skirt integrally extending from said member to increase the insulating effect of the exterior insulating surface and preserve on it dry portions, a pair of metallic connectors secured to the opposite ends of said member and enclosing the opposite ends of said chamber, said metallic connectors having on their exterior sides complementary elements adapted to flexibly engage complementary elements of adjacent insulators to form therewith a suspension string for carrying the line, a valve device in said chamber comprising an evacuated hermetically-tight tubular vessel, a pair of spaced electrodes insulatingly held in said vessel, and leads for said electrodes extending through the upper and lower ends of said vessel, holder means on the interior sides of said connectors for holding said vessel suspended at its upper and lower ends and for establishing conducting connection between the leads and the respective connecting members, one of said connectors constituting a permanent enclosure around one end of said chamber, the other of said connectors having an opening for inserting said valve in its position within said chamber and a removable cover for enclosing said opening.

5. A suspension insulator for insulator strings carrying high voltage transmission lines comprising a tubular strain insulator member having in its interior a vertical tubular chamber and surrounded on its exterior by a downwardly protruding insulating skirt integrally extending from said member to increase the insulating effect of the exterior insulating surface and preserve on it dry portions, a metallic cap secured to the top of said member and constituting a permanent enclosure over the upper end of said chamber, a second metallic cap secured to the bottom of said member and constituting an enclosure over the lower end of said chamber, said caps having on their exterior sides complementary connecting elements adapted to flexibly

engage complementary elements of adjacent insulators to form therewith a suspension string for carrying the line, a valve device in said chamber comprising an evacuated hermetically-tight tubular vessel, a pair of spaced electrodes insulatingly held in said vessel, and leads for said electrodes extending through the upper and lower ends of said vessel, holder means on the interior sides of said caps for holding said vessel suspended at its upper and lower ends and for establishing conducting connection between the leads and the respective connecting members, said lower cap having an opening for inserting said valve in its position within said chamber and a removable cover for enclosing said opening.

6. A suspension insulator for insulator strings carrying high voltage transmission lines comprising a tubular strain insulator member having in its interior a vertical tubular chamber and surrounded on its exterior by a downwardly protruding insulating skirt integrally extending from said member to increase the insulating effect of the exterior insulating surface and preserve on it dry portions, a metallic cap secured to the top of said member and constituting a permanent enclosure over the upper end of said chamber, a second metallic cap secured to the bottom of said member and constituting an enclosure over the lower end of said chamber, said caps having on their exterior sides complementary connecting elements adapted to flexibly engage complementary elements of adjacent insulators to form therewith a suspension string for carrying the line, a valve device in said chamber comprising an evacuated hermetically-tight tubular vessel, a pair of spaced electrodes insulatingly held in said vessel, and leads for said electrodes extending through the upper and lower ends of said vessel, said lower cap having an opening for inserting said valve in its position within said chamber and a removable cover for enclosing said opening, said removable cover and the upper cap having on their interior sides sockets for holding the lower and upper ends of said valve and making connection with the lower and upper leads thereof.

PHILIP SPORN.
EDWIN LEONARD PETERSON.

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