Nov. 1, 1938. L. R. LUDWIG ET AL 2,135,085

LIGHTNING ARRESTER

Filed July 7, 1937 3 Sheets-Sheet 1

Fig. 1.

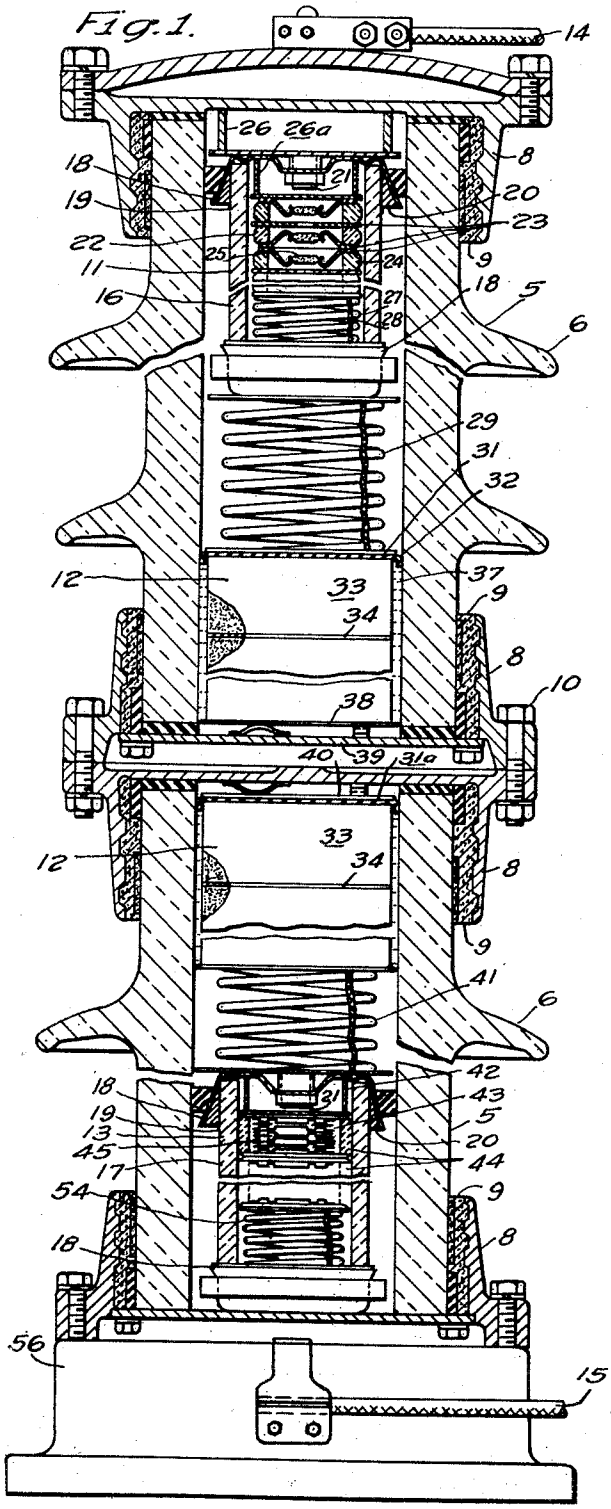
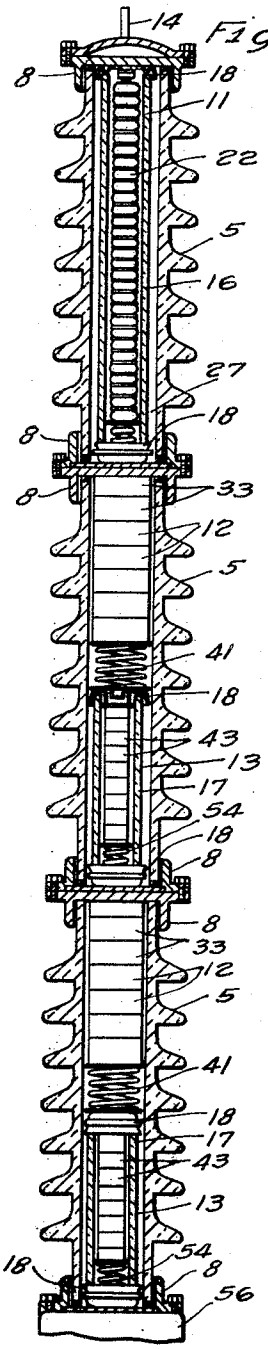


Fig. 2.



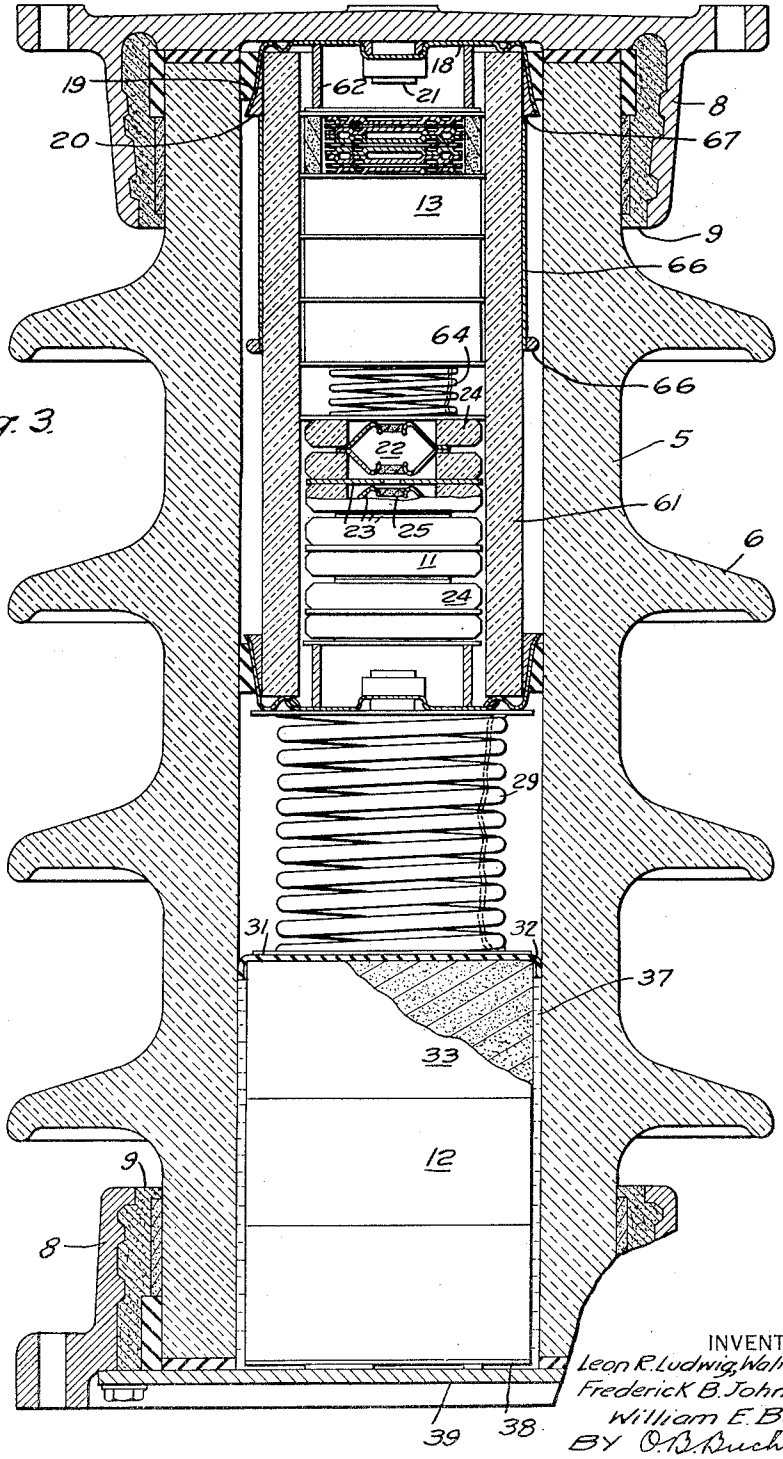
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LIGHTNING ARRESTER

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Fig. 3.



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LIGHTNING ARRESTER

Filed July 7, 1937 3 Sheets-Sheet 3

Fig. 4.

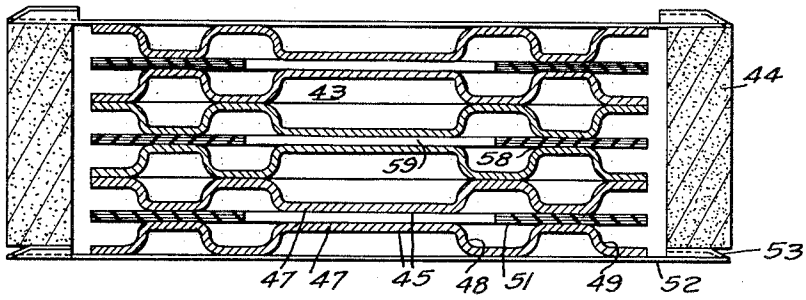
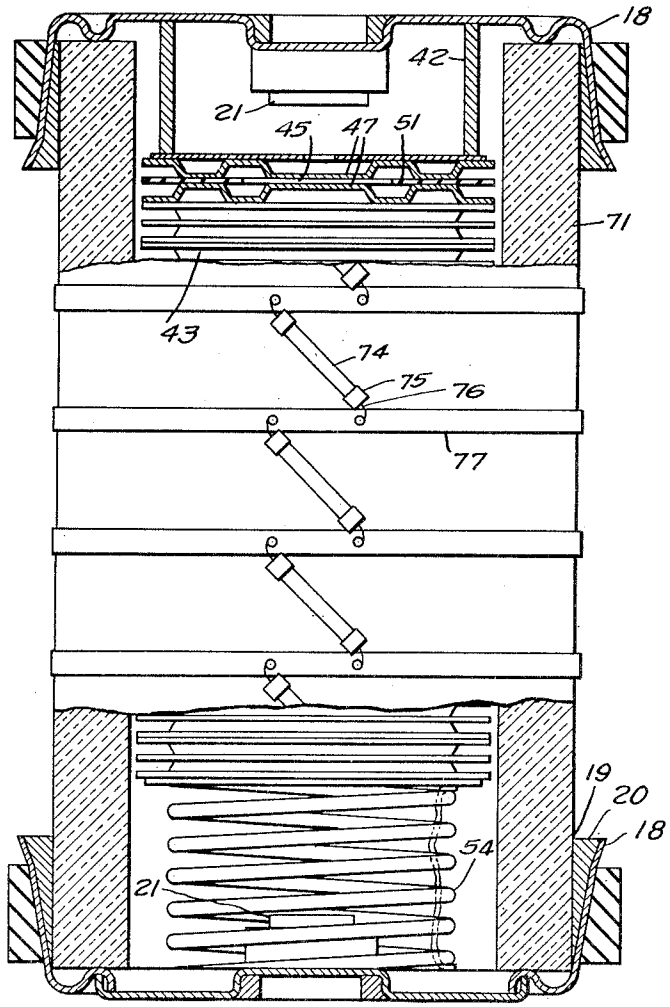


Fig. 5.



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UNITED STATES PATENT OFFICE

2,135,085

LIGHTNING ARRESTER

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Application July 7, 1937, Serial No. 152,416

18 Claims. (Cl. 175—30)

Our invention relates to excess-voltage protective devices of the type commonly known as lightning arresters, and it has particular relation to arresters having the very best over-all performance, so as to be adapted for locations where the highest degree of protection is desired.

It is an object of our invention to provide a lightning arrester having an improved performance in every way. In general, the things required of a lightning arrester are that it should have a low surge breakdown-voltage, a low impulse-ratio approaching unity, a low protective ratio, and a high current-rating. The surge breakdown voltage is the voltage at which the arrester breaks down, and changes from substantially an insulator to a current-conductor, when subjected to a surge of voltage rising at a standard rate as defined in the A. I. E. E. standards, or it may be specified at any other rate of rise: it is usually expressed as the ratio of this voltage to the crest value of the rated voltage of the arrester. The impulse-ratio is the ratio between the surge breakdown-voltage and the 60-cycle breakdown-voltage, or the breakdown voltage at the normal line-frequency of the arrester. The protective ratio of an arrester is the ratio of the discharge-voltage to the crest of the rated voltage of the arrester, the discharge-voltage being the voltage which appears across the arrester while it is discharging, this voltage being usually defined as the voltage obtaining when the discharge-current is 1500 amperes. The current-rating of the arrester is the amount of current which it can discharge without failure.

Heretofore, the best surge breakdown ratio obtained on lightning arresters has been of the order of 2.8 to 3.0. In accordance with our invention, this ratio is reduced to a value which is not greater than 2.5, thus limiting the excess voltage to which the insulation of the protected apparatus is subjected during surges, the protected apparatus being either a transmission-line conductor, with its suspension insulators, or electrical machinery such as a transformer or a dynamo-electric machine.

In all lightning arresters, a low impulse-ratio is desired so that the 60-cycle breakdown-voltage will be as high as possible without making the surge breakdown-voltage any higher than it has to be. It is desired to have a high 60-cycle breakdown-voltage so that the arrester will not break down and discharge currents unnecessarily during minor voltage-surges resulting from switching operations and the like. The 60-cycle breakdown ratio, or the voltage at which the arrester breaks down, under 60-cycle conditions, divided by the rated voltage of the arrester, used to vary heretofore in the range of 1.5 to 2.0 in the best arresters. By our present invention, we have secured a 60-cycle breakdown-ratio which lies in the range of 1.75 to 2.0.

A high current-rating has become recognized as a requisite of any arrester which is designed for the fullest and best protective value. Heretofore arresters of a type having a reasonably low protective ratio at the maximum discharge-rate have been incapable of successfully withstanding more than about 30,000 or 50,000 amperes with only a limited number of discharges permissible. Our arrester is rated at 100,000 amperes. We have successfully tested it and run it without failure up to about 90,000 amperes, without reaching the limit of its safe current-carrying capacity. This discharge-capacity is high enough for all traveling-line surges and for almost all direct strokes of lightning.

In addition to the foregoing it is obviously necessary for lightning arresters to have a certain permanence in their characteristics or performance, that is, they should not change in their various properties such as breakdown-voltage, cutoff value, etc. By our invention we have very materially improved the consistency of the lightning-arrester operation, and we have done this by improving both the valve-type elements and the gap-elements of the arrester.

The valve-type part of the arrester is the part which permits the flow of heavy discharge-currents without producing a low-voltage arc. In other words, it has the property of conducting heavy-current, excess-voltage discharges at a discharge-voltage which is in excess, but only a small multiple, of the normal line-voltage of the arrester. As a necessary implication of its valve-type action, this part of the arrester must strongly limit the current-flow, or shut it off or nearly off, when the discharge-voltage falls to a value approximating the normal line-voltage, so that this valve-type part of the arrester will carry only a small current (as compared with its lightning-discharge rate) when it is subjected to the normal line-voltage.

In a preferred form of embodiment of our invention we utilize a waterglass-bonded porous block of molded granulated silicon carbide, which is molded by heavy hydraulic pressure and then baked at a moderate temperature, instead of utilizing the old ceramic-bonded porous block of granulated silicon carbide which is molded and then burned or fired at a rather high tempera-

ture. The old ceramic block had the advantage of a definite cutoff-point, or points, in the decreasing voltage-wave, at which there was a sharp decrease in the discharge-current, so that the leakage current at the normal line-voltage was very small, usually much less than one ampere, but it had a limited surge-current capacity, because of local heating and current-concentration, which would destroy it, and it also had the misfortune to be inconsistent in its operation, tending to gradually increase the over-all breakdown voltage of the arrester with time, because of a variation in the seal-off action of the ceramic blocks, which caused these blocks to take an increasingly large proportion of the total surge-voltage, as time went on, when surges were applied to the arrester, thus causing the series gaps (which are connected in series with the valve-type elements) to break down at a later point in the excess-voltage surge.

On the other hand, our waterglass-bonded block has no sharply defined cutoff-point, but reduces the current to a value having a crest of the order of 20 to 30 amperes when the full normal rated voltage of the entire arrester is impressed across the porous blocks which constitute the valve-type part of the arrester. The result of this construction is that the surge-voltage, when it is in the process of building up on the line, will appear practically entirely across the series gap-devices, until these gap-devices break down, at which time the gap-voltage will reduce to a very small value, necessary to maintain an open arc, and practically all of the surge-voltage will appear across the porous blocks. Our waterglass-bonded porous blocks have the very great advantage, also, of being able to discharge currents which must be at least of the order of 100,000 amperes, without increasing the size over that of the ceramic blocks which could safely carry no more than 30,000 to 50,000 amperes.

In addition to the foregoing, it has been necessary for us to introduce special design-features because of the large value of the power-follow current which the water-glass-bonded blocks permit to flow, until the first current-zero, after the cessation of the excess-voltage discharge, which usually takes something like 40 microseconds, or $\frac{1}{400}$th of a line-frequency cycle; because this large power-follow current has imposed a much heavier duty on the current-interrupting characteristics of the series gap-devices than was the case of the old arrester utilizing the ceramic porous blocks.

As a result of the foregoing, we have rather extensively redesigned our gap structure and in effect it has been segregated into two parts, one part, which we call our quench-gap, for interrupting or nearly interrupting the large power-follow current of the valve-type element, and the other part, which we call our switch-gap, for switching off the quench gap from the normal line voltage. The result of the foregoing changes and developments is an arrester of outstanding performance and of many characteristic features of design which are new in the lightning-arrester art.

With the foregoing and other objects in view, our invention consists in the parts, structures, combinations, elements and methods hereinafter described and claimed and illustrated in the accompanying drawings wherein

Figure 1 is a longitudinal sectional view of a lightning arrester of a moderately high voltage-rating, embodying our invention in a preferred form of embodiment;

Fig. 2 is a similar view, on a smaller scale, showing an embodiment of our invention in an arrester of still higher voltage-rating;

Fig. 3 is a similar view of an embodiment of our invention in an arrester of one of the lower ratings;

Fig. 4 is an enlarged, double-size, vertical sectional view of our novel quench-gap element; and

Fig. 5 is a vertical-sectional view of a modification of the entire hermetically enclosed quench-gap assembly.

In all forms of embodiment, our arrester is housed in a porcelain weather-casing **5** which is provided with a plurality of water-shedding skirts or petticoats **6**. The weather-casing **5** may be either in one part, as in Fig. 3, or in two parts, as in Fig. 1, or in three or more parts, as in Fig. 2. In each case it consists of a skirted porcelain tube which is closed at both ends by metallic end-castings **8** which are firmly cemented onto the ends of the casing **5**, by joints **9** which are more or less weatherproof but which it is impracticable to make absolutely hermetically tight.

In the form of our invention which is shown in Fig. 1, there are two weather-casings **5**, which are bolted together at **10**. The upper casing **5** contains the sealed switch-gap element **11** and about half of the porous blocks which constitute the valve-type part **12** of the arrester. The lower casing **5** contains the rest of the porous blocks or valve-type part **12** and the sealed quench-gap element **13**. The switch-gap element **11** is disposed in the top of the upper weather-casing **5**, at the point nearest to the high-voltage terminal or line-connection **14** at the top of the arrester, whereas the quench-gap element **13** is disposed at the bottom of the lower weather-casing **5**, adjacent to the base-plate or ground-connection **15**.

Each of the gap elements **11** and **13** is sealed in its own hermetically tight insulating casing, the switch-gap casing being indicated at **16** and the quench-gap casing being indicated at **17**. Each of these casings consists of a tube of wet-process porcelain which is non-porous, with a metallic cap-closure **18** at each end thereof, the caps **18** being sealed hermetically tight to the porcelain tubes of the casings **16** and **17** by a special soldered metal-to-porcelain seal which has been developed in connection with metal-tank mercury-arc rectifiers, consisting of a direct soldered connection **20** between the metal cap-closure and a metallic glaze **19** which is applied to the adjacent surface of the porcelain tube. Each of the cap-closures is provided with a pipe-plug connection **21** which is normally tightly sealed, but which can be opened for forcing heated dry air through the gap-casing in order to thoroughly dry out the parts in the process of assembly.

The switch-gap casing **16** contains a plurality of switch-gap elements **22** which, aside from their enclosure in a hermetically sealed casing, are of a conventional design such as has heretofore been employed for the series gaps of lightning arresters. These switch-gap elements are of limited-current interrupting capacity, but this defect is cured, in our design, by the addition of the quench-gap part **13**. The switch-gap elements **22** consist of electrodes **23** of brass or other non-arcing metal, separated by insulating rings **24**. The impulse ratio of these gaps is improved by the utilization of molded inserts **25** of granulated silicon carbide, as described and claimed

in an application of Frederick B. Johnson, Serial No. 50,854, filed November 21, 1935, and assigned to the Westinghouse Electric & Manufacturing Company.

The switch-gap casing 16 is spaced from the top end-casting 8 of the upper weather-casing 5 by a metal spacer-ring 26.

Within the switch-gap casing 16, the entire stack of switch-gap elements 22 is spaced from the top enclosing-cap 18 by a metal spacer-ring 26a. The stack of switch-gap elements 22 is resiliently supported by means of a coil spring 27 disposed underneath said switch-gap elements 22, and between the same and the bottom of the enclosing casing 16. The coil spring 27 is preferably provided with a flexible shunt or pigtail 28 which serves to carry the current and to protect the spring against the overheating which would result from passing heavy currents therethrough.

The entire switch-gap casing 16 is supported by a shunted coil spring 29, which rests on a stop-device 31 which includes a flexible washer 32 for making a moderately tight connection with the bore of the upper weather-casing 5, for a purpose to be subsequently described.

The utilization of a construction having the supporting spring 29 and the upper metal spacer-ring 26 provides a convenient means for adjusting the 60-cycle breakdown-voltage of the switch-gap part of our arrester, which is accomplished, in the assembly process, by subjecting the switch-gap unit or casing to breakdown tests, and substituting a suitable length of pipe for the metal spacer-ring 26. This changes the breakdown voltage, which is affected by the shape of the electrostatic field surrounding the upper end of the switch-gap casing 16, so that a convenient adjustment-method is provided by having, in stock, a number of spacer-rings 26 of different lengths, so that the best length of ring may be substituted, in accordance with the requirements of the particular shape of the electrostatic field which is present in any given arrester-structure. There is enough flexibility in the coil spring 29 so that it will compensate readily for the slight differences in lengths of the spacer-rings 26 which are available for insertion in the top of the upper weather-casing 5.

Under the spring 29 and the stop-device 31 are disposed a number of porous blocks or discs 33 which constitute about half of the valve-type part of the arrester shown in Fig. 1, the blocks 33 being separated by lead washers 34. Each of the blocks 33, as previously described, is made of granulated silicon carbide pressed and held together with a waterglass binder. The blocks are made in certain convenient heights or lengths rated at any convenient rating, such as 3 kilovolts or 5 kilovolts and enough blocks are connected in series to make up the entire kilovolt rating of the arrester, utilizing as many weather-casings 5 as may be necessary to house the entire assembly. Except for the use of a waterglass-bond and except for the manufacturing process of baking the molded discs in an oven or furnace, as distinguished from the burning or firing operation which was necessary in the old ceramic discs, the discs are similar to the ceramic discs which are described and claimed in Slepian patent 1,509,493, granted September 23, 1924. They are preferably coated, at each end, with copper or other metal, which is conveniently applied by a spraying process, to make good electrical contacts. Preferably, the sides of the porous blocks or discs 33 are protected with an insulating coating of wax or the like, and the entire stack of porous blocks or discs is preferably enclosed in a thick cementitious coating of wax which holds the stack together. After the stack is assembled in the weather-casing 5, the space between the stack of porous blocks 33 and the inner bore of the casing is filled with hot wax 37 which solidifies into a semi-solid mass which protects the blocks against movement and consequent breakage during shipment. All danger or possbility of a flowing or misplacement of the hot wax 37 during the filling operation is avoided by the use of the previously mentioned stop-device 31 which is disposed on top of the wax, (the casing being inverted when the hot wax is poured in), so as to confine the wax to its proper place around the porous blocks 33. The porous blocks 33 which are located in the upper casing 5 rest on a spring-plate 38 which in turn rests directly on the bottom base-plate 39 of the upper casing 5.

The lower casing 5 of Fig. 1 contains the rest of the porous blocks 33 which are disposed in the upper portion of said casing. Another stop-device 31a and a spring plate 40 is placed between the top of the blocks and the metallic end-casting 8, and the blocks, in turn, rest upon a shunted coil-spring 41, the bottom end of which is in operative engagement with the top of the quench-gap casing 17.

The quench-gap casing 17 has a metal spacer-ring 42 in its interior, disposed close up against the top cap-closure 18 of the casing. Under the spacer-ring 42, within the quench-gap casing 18, there are disposed a number of quench-gap units 43, each of which consists, in the form shown in Fig. 1, of a resistance-ring 44 of a suitable molded composition material, within which are nested a plurality of quench-gap elements 45. In each of the modifications of our invention, except that which is illustrated in Fig. 5, we utilize three quench-gap elements 45 for each resistance-ring 44, although it will be obvious that other numbers, more or less than three, may be utilized.

The detailed construction of one of the quench-gap elements 45 is best seen in Fig. 4, which is drawn to twice the actual size of the gap-structure. Each of the quench-gap elements consists of two electrode-plates 47 of brass or other non-arcing metal, each plate having two concentric annular depressions 48 and 49, said depressions defining portions of the two plates which are separated further than the flat, undepressed portions. Disposed between the two electrode-plates 47 of each gap-element 45 is an insulating separating washer 51 which may be built up from laminations of mica and other suitable insulating sheet-material suitably bonded together. The insulating washer 51 is disposed between the two plates, and contacts with the undepressed portions which lie between the two concentric annular depressions 48 and 49. The plates 47 are preferably of pressed sheet-metal construction, with somewhat rounded corners at the edges of the depressions 48 and 49.

A novel feature of considerable importance, from a practical standpoint, is our utilization of a spring-plate 52, which consists of a flat disc with several peripheral tabs 53 cut out of its periphery and bent up to form yieldable spring-fingers or tabs 53 which engage the end of the high-resistance ring 44. By the use of this construction, it is possible to design the gap-unit so that the stack of three quench-elements 45 is a little bit taller than the length or height of

the high-resistance ring 44; and the manufacturing tolerances, or permissible variations in the heights of the two respective elements, may be large enough for economical manufacture, because there is enough give, in the spring-tabs 53, to allow for sufficient discrepancies in the heights of the two elements, so that good electrical contact is made between the plate and both the high-resistance ring 44 and the end one of the three gap-elements 45, as shown in Fig. 4.

The bottom of the stack of quench-gap units 43, in the quench-gap casing 17 of Fig. 1, is supported by a shunted coil spring 54, which rests, in turn, on the bottom cap-closure 18 of the quench-gap casing 17. It will be understood that the spring-pressure exerted by the shunted coil-spring 54 is greater than the pressure exerted by the spring-tabs 53, so that the spring-plates 52 are pressed into firm engagement with the quench-gap elements 45.

The bottom of the quench-gap casing 17 rests directly on the bottom end-casting 8 of the lower weather-casing 5. In general, this casing is supported on a suitable base structure 56 carrying the ground-lead connection 15.

It should be understood that the lightning arrester, which is shown in Fig. 1, consists of a large number of elements in each stack, although, for convenience in illustration, only two elements of each stack are illustrated, the omission of the intermediate elements being indicated, in each case, by showing a break in the construction. Thus, for a 40-kilovolt arrester, there are 17 insulating rings 24 in the switch-gap casing 16; there are 8 porous blocks 33 of 5-kilovolt rating each, and there are 10 high-resistance rings 44 in the quench-gap casing 17.

The operation of the arrester shown in Fig. 1 is as follows: The total stack of porous blocks 33, which constitutes the valve-type part 12 of the arrester, is rated at the full rated voltage of the arrester, and each of the dual gap elements, namely, the switch-gap element 11 and the quench-gap element 13 is also individually rated at the full-line voltage of the arrester.

The switch-gap elements 22 are normally in a non-arcing condition, so that the insulating rings 24 of the switch-gap elements normally insulate the porous-block assembly 12 and the quench-gap assembly 13 from the line-voltage, the normal line-voltage appearing substantially altogether across the switch-gap assembly 11. Thus, the coil-spring 29, which is disposed in the upper weather-casing 5, underneath the switch-gap casing 16, is at a potential which is only slightly elevated above the ground potential, as compared to the total voltage impressed upon the high-voltage terminal-connection 14 of the arrester.

The switch-gap assembly 11 does not have as low an impulse-ratio as the quench-gap assembly 13, but, as the two gap-assemblies operate together to jointly make up the series-gap element which protects the porous-block assembly 12, it is not necessary for both of the gap-elements to have an extremely low impulse-ratio.

The switch-gap assembly has a breakdown voltage, on 60-cycle overvoltage, of something like 125% or 150% of the rated voltage. When this happens, as in the case of a switching-surge, the voltage, as measured across the switch-gap assembly 11, will drop to a relatively small percentage of the total line-voltage, and most of the line-voltage will then appear across the quench-gap assembly 13, which will carry a leakage current of less than a milliampere, which is the current conducted by the series of high-resistance rings 44. The quenching gaps between the quench-gap electrodes 47 will not break down at this voltage, however, so that, when normal line-voltage conditions are restored, after the assumed switching-surge, the discharge in the switch-gap elements 11 will be interrupted again.

As previously explained, the 60-cycle breakdown voltage of the switch-gap assembly 11 is adjusted to have the desired value by adjusting the length of the pipe or tubular spacer 21, which causes the top of the stack of switch-gap elements 22 to fall in the optimum position with respect to the 60-cycle electrostatic field surrounding the top end-casting 8 of the upper weather-casing 5 and the top cap-closure 18 of the switch-gap casing 16. As previously explained, also, the surge breakdown voltage of the switch-gap assembly is reduced by the utilization of the silicon-carbide inserts 25 which are carried by the switch-gap electrodes 23, so as to cause the breaking down processes of the switch gaps to be more rapid than if these inserts were not utilized, the effect of the increased rapidity being to cause the breakdown to occur at an earlier point in the rapidly rising voltage of a steep-wave-front surge.

Under surge-conditions, that is, when the excess voltage rises very rapidly, usually referred to as a steep-wave-front surge, the capacity-current which is carried by the different parts of the arrester increases enormously, being dependent upon the rate of rise of the impressed voltage, so that the capacity-effects become largely controlling, in determining the voltage-distributions among the various elements of the arrester. The physical arrangement of the parts is such that the switch-gap assembly 11 is disposed closest to the high-voltage terminal 14, while the quench-gap assembly 13 is disposed closest to the ground-connection 15, so that all of the elements which are disposed underneath the switch-gap assembly 11 will be shunted by a relatively large electrostatic capacity, representing the capacity of these parts to the ground.

The result of the foregoing is that a steep-wave-front surge will cause a relatively large charging current to flow in the aforesaid shunting capacity, so that the larger portion of the voltage-surge is impressed upon the switch-gap assembly 11 during the first few microseconds while the voltage is building up at a rapid rate. This provision, in effect, of a capacity-shunt around the quench-gap assembly 13, is important in causing the over-all surge breakdown-voltage of the arrester to be less than the arithmetical sum of the surge breakdown-voltages of the two gap-assemblies, namely, the switch-gap assembly 11 and the quench-gap assembly 13. In this way, we reduce the surge breakdown-voltage of our arrester to a value which is not greater than 2.5 times the crest value of the rated voltage of the arrester.

When the switch-gap assembly 11 breaks down, if the excess voltage on the line is then of the order of 1.75 to 2 times the rated-voltage crest, the quench-gap assembly 13 breaks down and begins to carry current by means of arcs which jump across the gap-spaces between the electrodes 47. The voltage-drop in the quench-gap assembly 13 immediately falls to a relatively small value, so that the dual gap-structure including the switch-gap part 11 and the quench-gap part 13 has now completed its office of connecting the valve-type part 12 between the line-connection 14

and the ground-connection **15**, thus impressing most of the line-voltage on the valve-type part.

The valve-type part 12, consisting of the stacks of porous blocks **33**, is now impressed with a steep-wave-front surge, which we will assume to be still rapidly rising in value. The immediate effect of switching in the porous-block assembly is to reduce the line-voltage, as the blocks begin to carry the surge-discharge current. As the surge-current increases, the voltage appearing across the porous blocks **33**, which is substantially the voltage appearing upon the line-conductor **14**, will gradually increase, but will really have a remarkably flat-topped characteristic, which means that the effective resistance of the blocks is decreasing as the discharge-current increases. Thus, when the discharge-current reaches 1500 amperes, the discharge-voltage of the porous blocks reaches a value from 2.0 to 2.2 times the rated-voltage crest, whereas, when the discharge-current reaches the really large value of 20,000 amperes, the line-voltage is held down to a value of only 3.0 times the crest value of the normal line-voltage, or rated voltage of the arrester.

A surge normally lasts only a very short while, in comparison to a half-wave of the normal line-frequency, which we are assuming to be 60-cycles, although the line-frequency can be any convenient frequency. At the termination of the surge, the line-voltage begins to fall down toward the normal value and the surge-discharge current begins to fall off. When the surge-current has been dissipated, say within 40 or 100 microseconds, more or less, the line-voltage will again reach its normal value, and the two gap-parts **11** and **13** will still be arcing, so that their voltage-drops are still low, but the valve-type part **12**, consisting of the porous blocks **33**, will have reduced the discharged current, which is now the so-called power-follow current, to a relatively small quantity, having a crest value of the order of 20 to 30 amperes.

The next function of the arrester is performed in the quench-gap assembly **13**. The quench-gaps have a high current-interrupting ability, which is secured by utilizing a large number of closely spaced gaps. When the arcing current in the quench-gaps is of the order of 20 amperes crest, the arcs in the quench-gaps become unstable, that is, they lose the property of restriking again, after a current-zero of the 60-cycle power-follow current, so that, when the 60-cycle voltage begins to rise again, on the next half-wave after the current-zero, the arcs in the quench-gaps will not reform themselves. Thus the quench-gap arcs become extinguished at the first current-zero after the surge-discharge, so that the power-follow current, which persisted in the porous blocks after the lightning-discharge, is reduced, by the quench-gaps, to a small value of less than a milliampere, which is easily interrupted by the switch-gap assembly **11**. The power-follow current of between 20 and 30 amperes crest-value is low enough, and of such short duration, that it will not cause any system-disturbances, and will not harm the arrester.

It will be noted that the shunting resistances **44** of the quench-gap assembly **13** are effective mainly in determining the 60-cycle breakdown-voltage of the quench-gaps, because, under 60-cycle conditions, the charging current due to the capacity-effect is relatively small, so that the subdivision of the total impressed voltage among the various gap-elements of the quench-gap series is determined largely, or substantially altogether, by the shunting resistance. We utilize the normal amount of capacity-unbalance which is incident to the construction of a long series of gaps, such as is utilized in the quench-gap assemblies of our arrester for medium and high voltages, to overcome the balanced-voltage effect of the shunting resistors on steep-wave-front surges.

In the lower-voltage arresters, the normal capacity-balance of the relatively short stack of quench-gaps is comparatively good, and a simple type of overshielding is sufficient to obtain very satisfactory results, as will be described later on, in connection with Fig. 3.

To summarize the structure and operation of the quench-gap assembly **13** of a medium or high voltage-rating, as shown in Fig. 1, a long series consisting of a large number of quench-gaps is adopted for the purpose of securing the necessary high current-interrupting ability. The use of a large number of gaps in series makes it difficult to obtain equal voltage-distributions across the several serially connected gaps during normal 60-cycle operation, and this necessitates the utilization of these shunting resistors **44**, without which some of the gaps would receive more than their proportionate share of the total 60-cycle voltage, thus reducing the 60-cycle voltage at which the quench-gap assembly would break down or arc over.

The values of the resistances **44** should be sufficient to draw more current than the tiny charging-currents under 60-cycle operating conditions, and on the other hand, these resistances should be high enough so that the resistance-current is less than the charging-currents under steep-wave-front surge-conditions. If the shunting resistance is more than about 5 megohms per kilovolt of rating, it becomes too high for the best equalization of the voltage-distribution during 60-cycle operation, particularly in the high-voltage ratings above 78 kilovolts. If the shunting resistance is too low, it becomes difficult to make a 60-cycle test without overheating the arrester, and there is also danger of burning up the resistance-rings **44** in case the line-gap assembly should accidentally become short-circuited. We prefer, therefore, to utilize a resistance of between 1 and 5 megohms for each kilovolt of the rating, and we have chosen an intermediate value of 2.5 megohms per kilovolt. In the particular form of embodiment of our invention shown in Fig. 1, each of the resistance rings **44**, with its enclosed triple quench-gap structure, has a rating of 4,000 volts and a resistance of 10 megohms.

The utilization of the resistance shunts **44** around the quench-gaps is also highly advantageous in securing a high degree of uniformity of action of the arrester, in spite of external conditions which cannot be controlled. The breakdown voltage of the quench-gap is largely determined by the equality or inequality of the voltage-distribution among the several gaps of the series. Without the shunting resistors, this voltage-distribution would be determined altogether by the capacity-effects. In the case of 60-cycle operation, as distinguished from steep-wave-front surges, the capacity-effects of the quench-gap electrodes themselves would be relatively insignificant, so that the voltage-distribution among the gaps would be largely determined by the electrostatic field-form resulting from external conditions, such as proximity to grounded

or live parts, fog or rain on the surface of the weather-casing 5, the shapes of the weather-casing porcelains, the positions of these casings, dirt, the presence of objects near the arrester, and other outside influences which obviously cannot be controlled.

Our use of the shunting resistances 44 around the quench-gaps makes the 60-cycle break-down voltage of the quench gaps substantially uniform and consistent, regardless of any external conditions.

Our quench-gap structure itself, as shown more in detail in Fig. 4, is novel and advantageous. That is, each one of the quench-gap devices, comprising the two electrode-plates 47 separated by an insulating washer 51 is of a novel and improved construction. The stamping of the two annular depressions 48 and 49 in the electrode-plates 47, as shown more in detail in Fig. 4, and the utilization of the insulating washer 51, placed where it is, results in a gap structure which is extremely fast in its break-down operation, which means that it will have a relatively low surge break-down-voltage, because it will break down earlier on the rapidly rising voltage-surge than would be the case if it were slower in its break-down operation.

We believe that this advantage is obtained by reason of corona which occurs at the junction-points 58 (Fig. 4) between the insulating washer 51 and the electrode-plates 47, where the material of the electrode-plates begins to bend away to form the depressions 48 and 49, particularly the inner depression 48. This corona is produced even when the normal line-voltage is applied to the quench-gap assembly, as it would be applied upon the breaking down of the switch-gap assembly, or if the switch-gap assembly were entirely omitted, which is one reason why we deem it much safer to normally insulate the quench-gap assembly from the line by utilizing the switch-gap assembly. If it were not for this corona effect, and the corrosion which would result therefrom, it would probably be quite satisfactory to omit the switch-gap assembly, as the leakage-current of less than a milliampere in the quench-gap assembly could often otherwise be easily tolerated.

The effect of the corona, as we understand it, is to cause ultra-violet emanations, as well as a certain amount of electrons and ionization, which, by virtue of the structure which we have devised, can proceed horizontally in an unobstructed straight line to the main gap-space 59 between the flat center portions of the spaced electrode-plates 47, thus causing this gap-space to be ionized, and expediting the breaking-down operation by which the space is changed from substantially a non-conducting condition to a conducting condition by means of the formation of first a glow-discharge and then an arc. Experiments which we have conducted, in which the same spacing of the plates 47 was obtained in a construction in which the insulating washer 51 was omitted, so that this corona-effect was removed to the widely spaced edges of the plates 47, so that the emanations could not directly reach the gap-space 59, resulted in a very material increase in the surge break-down voltage, thus materially increasing the impulse-ratio of the quench-gap device.

As a part of our means for securing a capacitive shunting effect around the quench-gap, in order to avoid an arithmetical addition of the surge breakdown-voltages of the switch-gap structure and the quench-gap structure, we find it quite desirable to separate these two gap structures as far as possible, in all except arresters of the smaller voltage-ratings, such as 16 kilovolts or lower. Since each of the gap-structures must be enclosed in a hermetically sealed casing in order to achieve the desirable uniformity of operation, independent of weather-conditions, dust, moisture or any other causes, this means that the switch-gaps and the quench-gaps must be assembled in separate hermetically tight insulating casings 16 and 17.

We have explained that our utilization of the shunting-resistance 44 around the quench-gaps prevents the 60-cycle break-down voltage of the quench-gaps from being reduced by fog, rain or other outside influences. As a matter of fact, when the over-all performances of the two gap-elements are considered together, the presence of wet-weather conditions actually results in a slight increase in the 60-cycle breakdown-voltage of our dual-gap construction, including both the switch-gap assembly 11 and the quench-gap assembly 13, because these wet-weather conditions tend to make the 60-cycle break-down voltage of the two gap-devices add slightly to each other, whereas normally the resistance shunting the quench-gap causes the switch-gap device to break down first, during 60-cycle operation. During surge-conditions, the wet surfaces of the weather-casings 5 do not make much difference, because the charging-currents due to the capacities are so much greater than the leakage-current resulting from the wetness of the outer insulator surfaces.

It will be perceived that we have segregated the functions of current-interruption of the power-follow current which is conducted by the porous blocks 33 after the discharge of a lightning surge, and switching or insulating the arrester from the normal line-voltage. By current-interruption we mean, not the reduction of the current to absolute or substantial zero, but the reduction of the current to a small value which is insufficient to maintain an arc, such as the 0.4 milliampere current which would be conducted by the shunting resistances 44 were it not for the operation of the switch-gap devices 11. By segregating these functions, so that the switch-gap device does not have to interrupt the power-follow current, the switch-gap device can be compactly designed in a small structure which is best adapted for the limited functions which it is called upon to perform.

In extremely high-voltage arresters, it is frequently desirable to place the composite parts in three or more weather-casings 5, as shown in Fig. 2. In such cases, it is frequently desirable to place the switch-gap part 11 in a separate weather-casing 5 by itself, which would be located at the top of the stack of weather-casings 5 which make up the complete arrester. Each of the other weather-casings 5 would preferably contain some porous-block elements 33 and some quench-gap elements 45, with the quench-gap elements always disposed at the bottom of the weather-casings 5.

In the lower-voltage arresters, such as the 15-kilovolt arrester which is shown in Fig. 3, it is desirable and economical to place both of the gap-devices 11 and 13 in a single hermetically closed casing 61, which is similar to the gap-casings 16 and 17 of the other figures, except that it contains both gap-devices.

Referring to Fig. 3, the arrester there shown comprises a single weather-casing 5, in the top of

which is disposed the hermetically closed casing 61 which is separated from the top end casting 8 of the weather-casing by means of a metallic tubular spacer 62. Within the hermetically closed inner casing 61 are disposed, first a quench-gap assembly 13 and then a switch-gap assembly 11, with the quench-gap assembly on top and with a shunted spring 64 for maintaining a firm electrical contact of the parts.

Underneath the hermetically closed inner casing 61 of Fig. 3, there are disposed a shunted coil-spring 29 and a series of porous blocks 33, as in the upper casing 5 of Fig. 1, the base structure 56 and ground-lead connector 15 being disposed underneath the bottom end-casting 8 of the weather-casing 5.

In these low-voltage arresters, the number of quench-gaps in series is not nearly as great as in the higher-voltage arresters, and hence the capacity-effect of just the electrode-plates of the series is too well-balanced to inherently produce the low surge breakdown-voltage which was obtained in the quench-gaps of the higher-voltage arresters, as described in connection with Fig. 1. In the Fig. 3 construction, we avoid this difficulty by placing the top portion of the quench-gap structure up under the overhanging part of the top end-casting 8 of the weather-casing 5, which thus encloses the top few gaps and provides a sufficient unbalanced capacity-effect to obtain very satisfactory results by way of a low surge breakdown-voltage of the quench-gap assembly.

In Fig. 3 it will be noted that the quench-gap assembly 13 is placed at the top rather than at the bottom, as in the higher-voltage arresters of Figs. 1 and 2. It will be recalled that the separation of the two gap-elements, and the disposition of the switch-gap element at the top, in Fig. 1, was for the purpose of securing, in effect, a capacitive shield shunting the quench-gap element, so that the surge breakdown-voltages of the two gap elements would not add arithmetically. The same effect is produced in Fig. 3 by the addition of a shield 66 on the outside surface of the hermetically closed gap-casing 61, at the upper end thereof, opposite to the quench-gap assembly 13, said shield 66 being electrically joined, as by soldering 67, to the soldered connection 20 between the metallic glaze 19 and the top-gap closure 18 of the gap-casing 61.

The shielded construction utilizing the shield 66, as just described, is quite effective in causing the switch-gap assembly 11 to break down first, on steep-wave-front surges, after which the quench-gap assembly 13 breaks down, so that the surge breakdown-voltage of the arrester is not equal to the sum of the breakdown-voltages of the two gap-assemblies. This shielded construction is not well adapted to voltages above 16 kilovolts because of the high voltage-gradients which would be encountered in the wall of the gap-tube 61, between the bottom end of the shield and the gap-devices within the tube.

In the quench-gap part, the shunting resistance consists of a number of resistance-elements which are connected in series, constituting, in effect, a resistance potentiometer for subdividing the overall applied voltage, and applying the subdivided voltage to the respective gaps or groups of gaps. In Figs. 1 to 4, the application of the subdivided voltages to the intermediate quench-gap elements is made by a conductive connection to the intermediate potentiometer-points, or junction-points between the serially connected resistors 44. It is not necessary, however, for these intermediate connections to be actual conductive connections, as capacitive couplings will serve substantially as well.

Fig. 5 shows a form of embodiment of our quench-gap structure utilizing such a capacitive coupling between the intermediate potentiometer-points and intermediate quench-gap electrodes. In this form of construction, the hermetically sealed quench-gap casing 71 is provided with a high-resistance potentiometer-means, disposed on the outside of the casing and electrically connected between the two cap-closures 18 of the casing.

The quench-gap elements 45 are placed inside of the casing 71 (Fig. 5), and are constructed in the same way as previously described, except that the high-resistance rings 44 and the spring-plates 52 are omitted, the gap-elements 45 being simply piled one on top of another in a long stack, to make up as many serially connected gap-elements as are necessary for the rated voltage, each gap-element consisting of two electrode-plates 47 separated by an insulating washer 51, as previously described.

The resistance potentiometer which is disposed on the outside of the insulating quench-gap casing 71 (Fig. 5) may take any one of a number of different forms, as any suitable-resistance leakage-element, connected between the two cap-closures 18, would suffice to properly distribute the voltage along the outside surface of the insulating casing 71. There is sufficient electrostatic capacity between the intermediate points of this resistance potentiometer outside of the casing 71 and the various intermediate gap-electrodes disposed inside of the casing 71 to maintain the desired voltage-distribution on the intermediate gap-electrodes during 60-cycle operation when the charging-current due to the capacity between the electrodes is not very large.

In the particular form of embodiment shown in Fig. 5, which is designed to be illustrative only, and not to be taken in a limiting sense, the externally disposed resistance potentiometer takes the form of a series of resistance-rods 74 which are connected together in a series-circuit connection. Each rod 74 is, or may be, capped with a metal cap 75 to which is soldered a small length of wire 76 which is utilized for the terminal connections of the resistance rods. The two end-wires of the entire series of serially connected rods 74 are soldered, respectively, to the soldered connections 20 between the metallic glaze 19 and the respective cap-closures 18. The intermediate terminal wires 76 of the resistance rods 74 are electrically joined together in any manner, preferably, as illustrated, by means of metal bands 77 which encircle the insulating casing 71.

Except for the externally disposed resistance potentiometer, the gap-casing 71 of Fig. 5 is constructed in the same manner as has been described in connection with the gap-casing 17 of Fig. 1, and it is designed to be mounted, in the same manner, within a weather-casing 5 which is not shown in Fig. 5.

Our present arrester is described in a paper by W. G. Roman, entitled "Characteristics of the new station-type autovalve lightning arrester", appearing in the July 1937 issue of Electrical Engineering, pages 819–822. We have been informed that this issue was published in the United States on July 3, 1937.

While we have illustrated our invention in several different forms of embodiment, it will be obvious that our invention is not limited, in its

broadest aspects, to any particular form of embodiment, and to that extent we desire these forms of embodiment to be regarded in an illustrative sense, rather than a limiting sense, and we desire that the appended claims shall be accorded the broadest interpretation consistent with their language and the prior art.

We claim as our invention:

1. An alternating-current lightning arrester comprising, in combination, a valve-type part, a quench-gap part, and a switch-gap part, all connected in series-circuit relation; the valve-type part having the property of conducting heavy-current excess-voltage discharges at a discharge-voltage which is in excess, but only a small multiple, of the normal line-voltage of the arrester, and of strongly limiting the current-flow, but still permitting a material current-flow, when the discharge-voltage falls to a value approximating the normal line-voltage; the quench-gap part having the property of becoming, in effect, a relatively low-impedance conductor permitting the aforesaid heavy discharges at a voltage-drop which is very low with respect to the normal line-voltage, and of changing to an unstable conductor which will change promptly, as at current-zero, to a high-resistance conductor capable of limiting the discharge to a low value when the line-voltage falls to a critical value, said critical value being intermediate between the normal line-voltage and the line-voltage during said heavy-current discharge; the switch-gap part having the property of becoming, in effect, a relatively low-impedance conductor permitting the aforesaid heavy discharges at a voltage-drop which is very low with respect to the normal line-voltage, and of changing to an unstable conductor which will change promptly, as at current-zero, to a substantially open-circuit condition after the quench-gap part limits the discharge to the aforesaid low value.

2. An arrester in accordance with claim 1, characterized by the combined gap-elements, including the quench-gap part and the switch-gap part, having the property of changing from a substantially open-circuit condition to the condition of a low-impedance conductor when a steep-wave-front surge on the line rises to a voltage less than three times the crest value of the normal line-voltage.

3. An alternating-current lightning arrester comprising, in combination, a valve-type part, a quench-gap part, and a switch-gap part, all connected in series-circuit relation; the valve-type part having the property of conducting heavy-current excess-voltage discharges at a discharge-voltage which is in excess, but only a small multiple, of the normal line-voltage of the arrester, and of strongly limiting the current-flow, but still permitting a material current-flow, when the discharge-voltage falls to a value approximating the normal line-voltage; the quench-gap part comprising a resistance-shunted multiple-gap part having a normal-frequency breakdown-voltage materially in excess of the normal line-voltage; the switch-gap part comprising a normally insulated series-gap part having a normal-frequency breakdown-voltage in excess of the normal line-voltage.

4. An arrester in accordance with claim 3, characterized by a mounting-structure and arrangement including a larger capacitance-effect in shunt to the quench-gap part than the capacitance-effect which is in shunt to the switch-gap part, whereby, upon the occurrence of a steep-wave-front surge, the switch-gap part gets a higher proportion of the total voltage than under normal-frequency conditions.

5. An arrester in accordance with claim 3, characterized by a mounting-structure and arrangement in which a switch-gap part is disposed closest to the high-voltage terminal of the arrester, with a valve-type part interposed between said switch-gap part and a quench-gap part.

6. An arrester in accordance with claim 3, characterized by a mounting-structure and arrangement including a housing enclosing at least said quench-gap part, and an external shield on said housing opposite to said quench-gap part.

7. The combination of a valve-type excess-voltage protective device of a type which becomes a relatively good conductor and is capable of momentarily carrying heavy current during excess-voltage surges and which limits the power-follow current to a small but appreciable amount after the cessation of the surge, and a dual gap-device in series with said valve-type protective device, said dual gap-device comprising a switch-gap device which switches the arrester onto the line at the incipience of a surge and which finally switches the arrester off of the line at the conclusion of a surge-discharge operation, and a separate gap-device which reduces the aforesaid power-follow current to a small value which can be completely interrupted by the switch-gap device.

8. The combination of a valve-type excess-voltage protective device of a type which becomes a relatively good conductor and is capable of momentarily carrying heavy current during excess-voltage surges and which limits the power-follow current to a small but appreciable amount after the cessation of the surge, and a dual gap-device in series with said valve-type protective device, said dual gap-device comprising a switch-gap device which switches the arrester onto the line at the incipience of a surge and which finally switches the arrester off of the line at the conclusion of a surge-discharge operation, and a separate gap-device which reduces the aforesaid power-follow current to a small value which can be completely interrupted by the switch-gap-device, each of said gap-devices being by itself capable of withstanding the full-line voltage of the protective device.

9. The combination of a valve-type excess-voltage protective device of a type which becomes a relatively good conductor and is capable of momentarily carrying heavy current during excess-voltage surges and which limits the power-follow current to a small but appreciable amount after the cessation of the surge, and a dual gap-device in series with said valve-type protective device, said dual gap-device comprising a switch-gap device which switches the arrester onto the line at the incipience of a surge and which finally switches the arrester off of the line at the conclusion of a surge-discharge operation, and a separate resistance-shunted gap-device, which reduces the aforesaid power-follow current to a small value which can be completely interrupted by the switch-gap device, and which normally carries but a small portion of the total line-voltage impressed on the protective device.

10. The combination of a valve-type alternating-current excess-voltage protective device of a type which becomes a relatively good conductor and is capable of momentarily carrying heavy current during excess-voltage surges and which limits the power-follow current to a small but appreciable amount after the cessation of the

surge, and a dual gap-device in series with said valve-type protective device, said dual gap-device comprising a switch-gap device which switches the arrester onto the line at the incipience of a surge and which finally switches the arrester off of the line at the conclusion of a surge-discharge operation, and a separate resistance-shunted gap-device, which reduces the aforesaid power-follow current to a small value which can be completely interrupted by the switch-gap device, and which normally carries but a small portion of the total line-voltage impressed on the protective device, each of said gap-devices being by itself capable of withstanding the full line-voltage of the protective device, and a mounting-structure and arrangement including a larger capacitance-effect in shunt to the resistance-shunted gap-device than the capacitance-effect which is in shunt to the switch-gap device, whereby the two gap-devices are prevented from adding their breakdown-voltages during surges.

11. The combination of a valve-type alternating-current excess-voltage protective device of a type which becomes a relatively good conductor and is capable of momentarily carrying heavy current during excess-voltage surges and which limits the power-follow current to a small but appreciable amount after the cessation of the surge, and a dual gap-device in series with said valve-type protective device, said dual gap-device comprising a switch-gap device which switches the arrester onto the line at the incipience of a surge and which finally switches the arrester off of the line at the conclusion of a surge-discharge operation, and a separate resistance-shunted gap-device, which reduces the aforesaid power-follow current to a small value which can be completely interrupted by the switch-gap device, and which normally carries but a small portion of the total line-voltage impressed on the protective device, each of said gap-devices being by itself capable of withstanding the full line-voltage of the protective device, and shielding means disposed in electrostatic relation to the resistance-shunted gap-device.

12. The combination of a valve-type alternating-current excess-voltage protective device of a type which becomes a relatively good conductor and is capable of momentarily carrying heavy current during excess-voltage surges and which limits the power-follow current to a small but appreciable amount after the cessation of the surge, and a dual gap-device in series with said valve-type protective device, said dual gap-device comprising a switch-gap device which switches the arrester onto the line at the incipience of a surge and which finally switches the arrester off of the line at the conclusion of a surge-discharge operation, and a separate resistance-shunted gap-device, which reduces the aforesaid power-follow current to a small value which can be completely interrupted by the switch-gap device, and which normally carries but a small portion of the total line-voltage impressed on the protective device, each of said gap-devices being by itself capable of withstanding the full line-voltage of the protective device, the two gap-devices being physically separated from each other, with the switch-gap device closer to the high-voltage terminal of the protective device.

13. An alternating-current lightning arrester comprising, in combination, a valve-type part, and a quench-gap part, connected in series-circuit relation; the valve-type part having the property of conducting heavy-current excess-voltage discharges at a discharge-voltage which is in excess, but only a small multiple, of the normal line-voltage of the arrester, and of strongly limiting the current-flow, but still permitting a material current-flow, when the discharge-voltage falls to a value approximating the normal line-voltage; the quench-gap part comprising a resistance-shunted multiple-gap part having a normal-frequency breakdown voltage materially in excess of the normal line-voltage, said resistance-shunt carrying a small current which flows through said valve-type part even after the arc is extinguished in said shunted multiple-gap part.

14. An alternating-current lightning arrester comprising, in combination, a valve-type part, and a quench-gap part, connected in series-circuit relation; the valve-type part having the property of conducting heavy-current excess-voltage discharges at a discharge-voltage which is in excess, but only a small multiple, of the normal line-voltage of the arrester, and of strongly limiting the current-flow, but still permitting a material current-flow, when the discharge-voltage falls to a value approximating the normal line-voltage; the quench-gap part comprising a resistance-shunted multiple-gap part having a normal-frequency break-down voltage materially in excess of the normal line-voltage, said resistance-shunt carrying a small current which flows through said valve-type part even after the arc is extinguished in said shunted multiple-gap part; and means for providing unbalanced capacity-effect operative, on steep-wave-front surges, to cause voltages to build up across a portion of the multiple-gap structure faster than across other portions thereof whereby said first-mentioned portion receives more than its proportionate share of the total voltage impressed across the total multiple-gap structure; the shunting resistance being of such relative value that its effect predominates over the unbalanced capacity-effect during normal line-frequency conditions so that all portions of the multiple-gap part receive more nearly their proper proportionate part of the impressed voltage so as to break down more nearly simultaneously on rising voltages of said normal line-frequency.

15. The combination of a valve-type alternating-current excess-voltage protective device of a type which becomes a relatively good conductor and is capable of momentarily carrying heavy current during excess-voltage surges and which limits the power-follow current to a small but appreciable amount after the cessation of the surge, and a gap-device in series with said valve-type protective device; said gap-device comprising a plurality of serially connected gaps and a shunting resistance-device connected in shunt relation to said plurality of serially connected gaps in such manner as to approximately properly distribute the applied voltage among said gaps so that substantially all of said gaps receive approximately their proper proportionate portion of the total voltage during line-frequency voltage-conditions, said shunting resistance-device carrying a small current which flows through said valve-type protective device even after the arc is extinguished in said plurality of serially connected gaps.

16. The combination of a valve-type alternating-current excess-voltage protective device of a type which becomes a relatively good conductor and is capable of momentarily carrying heavy

current during excess-voltage surges and which limits the power-follow current to a small but appreciable amount after the cessation of the surge, and a gap-device in series with said valve-type protective device; said gap-device comprising a plurality of serially connected gaps and a shunting resistance-device connected in shunt relation to said plurality of serially connected gaps in such a manner as to approximately properly distribute the applied voltage among said gaps so that substantially all of said gaps receive approximately their proper proportionate portion of the total voltage during line-frequency voltage-conditions; and a mounting-structure and arrangement including an unbalanced capacity-effect in shunt relation to said gap-device, said unbalanced capacity-effect being materially less than said shunted-resistance effect during line-frequency voltage-conditions, but, on steep-wave-front surges, causing the total applied voltage to be disproportionately divided among the respective gaps of said plurality of serially connected gaps.

17. A spark-gap unit for a lightning arrester, comprising a plurality of serially connected, stacked gap-elements having a larger plate at each end thereof, a high-resistance ring disposed outside of the stacked gap-elements and between the two larger plates, and spring-means associated with the structure whereby firm electrical contacts may be made notwithstanding slight discrepancies in the axial thicknesses of the stacked gap-elements and resistance ring, respectively.

18. An excess-voltage, alternating-current protective device comprising, in combination; a housing-structure comprising one or more petticoated tubular insulators having closure-means at each end thereof; and, in stacked relation within said housing-structure, a valve-type part, a switch-gap part, and a quench-gap part; the switch-gap part comprising a plurality of serially connected, stacked, insulating-gap elements and a separate hermetic switch-gap enclosure for said plurality of insulating-gap elements, said switch-gap enclosure being disposed within said housing-structure at the high-voltage end thereof; said quench-gap part comprising a plurality of serially connected quench-gap devices and a separate hermetic quench-gap enclosure for said plurality of quench-gap devices, the construction and arrangement being such that means including shunting resistance is provided for controlling the normal-frequency electrostatic stress-distribution of said quench-gap devices, said quench-gap enclosure being disposed within said housing-structure at the low-voltage end thereof.

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