

March 14, 1967

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3,309,575

TRIGGERED SPARK GAP TYPE OF SURGE ARRESTOR

Filed Oct. 19, 1965

3 Sheets-Sheet 1

FIG. 1.

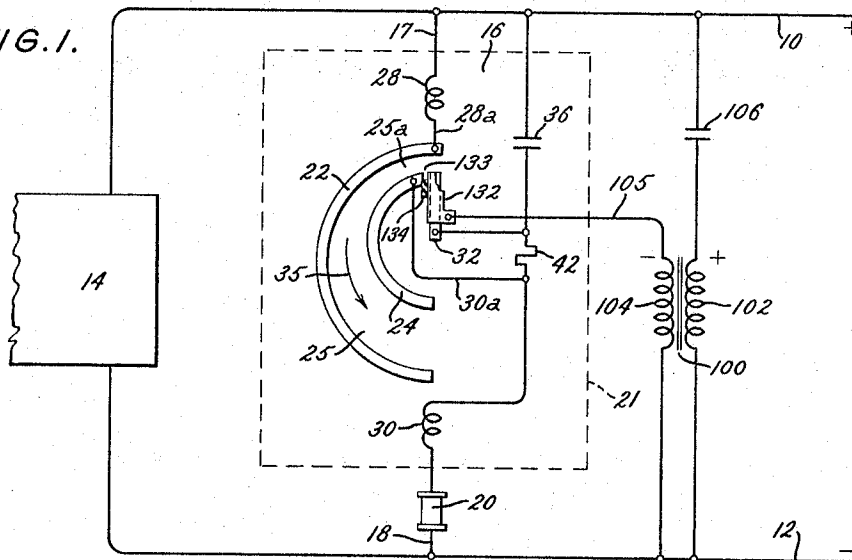


FIG. 2.

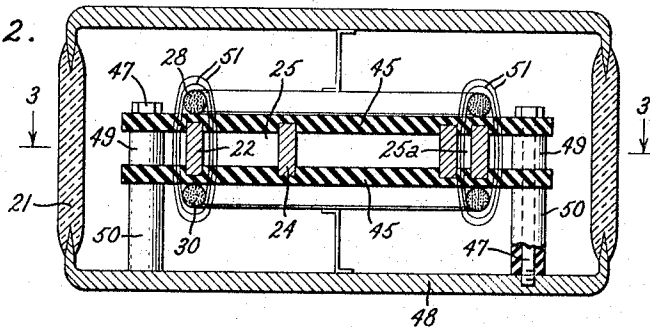


FIG. 3.

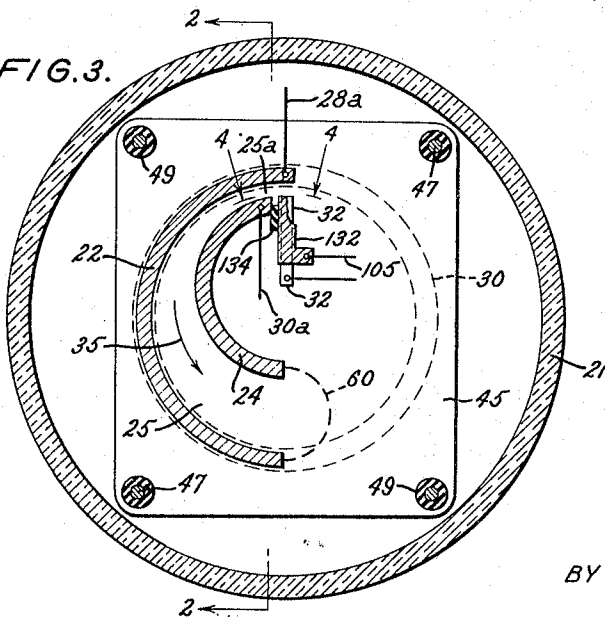
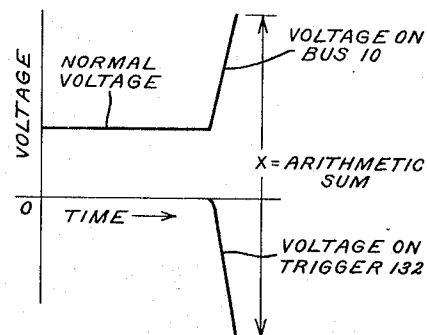


FIG. 4a.



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FIG. 5.

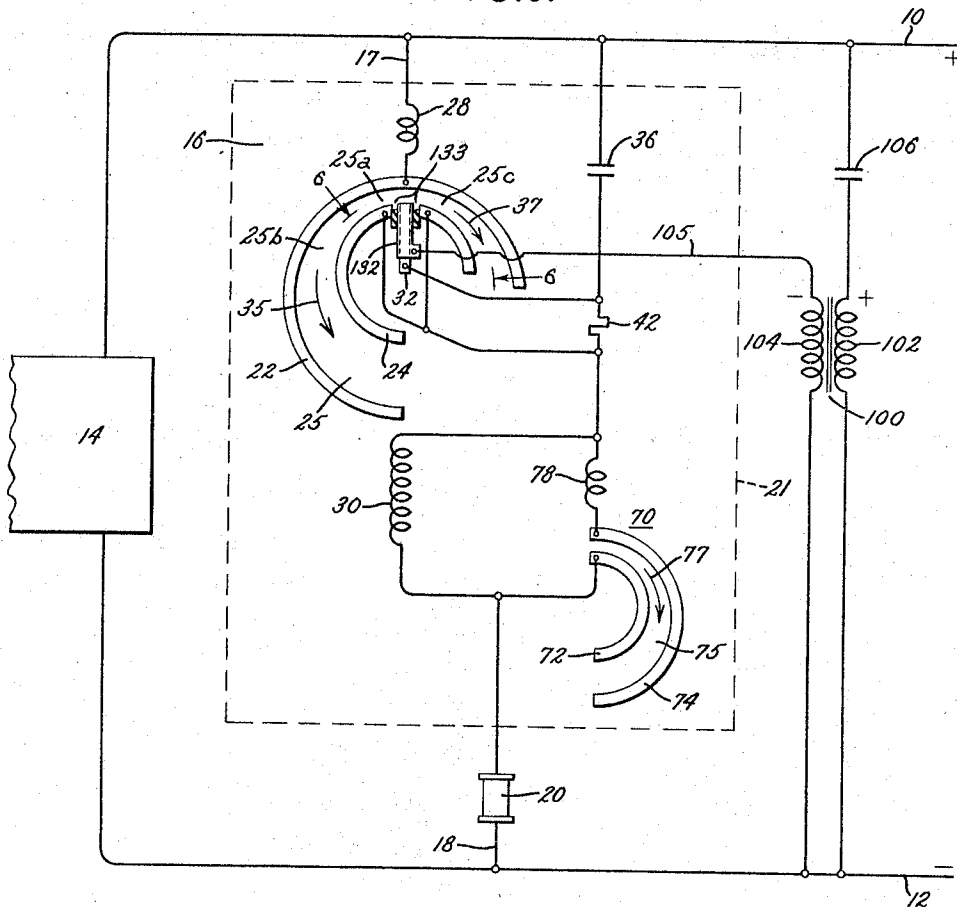


FIG. 6.

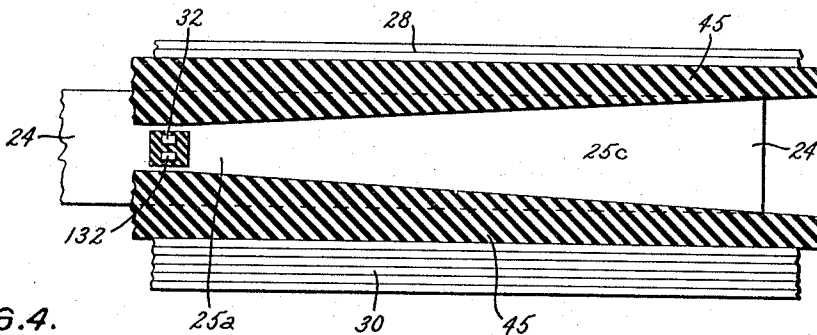
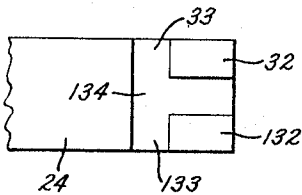


FIG.4.



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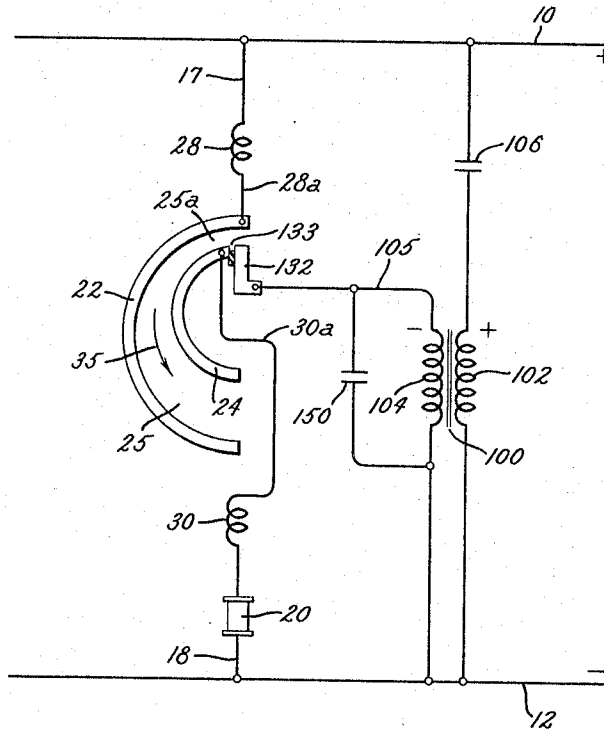
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FIG. 7.



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3,309,575 TRIGGERED SPARK GAP TYPE OF SURGE ARRESTOR

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Filed Oct. 19, 1965, Ser. No. 505,122

9 Claims. (Cl. 317-61.5)

This application is a continuation-in-part of application S.N. 417,704, now abandoned, filed December 11, 1964, and assigned to the assignee of the present application.

This invention relates to a triggered spark gap type of surge arrester for protecting a D.-C. power system against the effects of voltage surges and, more particularly, relates to improved triggering means for causing sparkover of the surge arrester in response to both low frequency and high frequency voltage surges. The invention also relates to an improved triggering circuit for causing spark-over of the arrester in response to low frequency voltage surges.

A triggered spark gap type of surge arrester typically comprises a pair of spaced-apart main electrodes defining a spark gap therebetween and triggering means for initiating sparkover of the gap when the triggering means is energized with a predetermined minimum voltage. The triggering means typically comprises a trigger electrode located adjacent one of the main electrodes but insulated therefrom to provide a trigger gap between the trigger electrode and said one main electrode. When a sufficient voltage appears across the trigger gap, a spark is developed thereacross, and this releases charged particles which are projected into the main gap to initiate a sparkover of the main gap.

In many circuit applications, the triggering means must be capable of initiating a sparkover in response to both low frequency voltage surges and high frequency voltage surges. For example, in certain circuit applications, the gap, in order to provide the desired protection must sparkover in response to both lightning surges, which are high frequency surges, and switching surges, which are of a relatively low frequency compared to lightning surges.

A very effective triggering means for responding to relatively low frequency surges, such as switching surges, comprises a transformer having a primary winding connected for energization by the switching surge and a secondary winding connected in circuit with the trigger electrode. When the primary winding is energized by the switching surge, the transformer applies through its secondary winding to the trigger electrode a voltage pulse that is more effective than the switching surge itself would be in producing gap breakdown.

While effective for initiating gap breakdown in response to relatively low frequency surges, such as switching surges, such a triggering means is vulnerable to being damaged by high frequency surges, such as lightning surges. Unless the transformer insulation is of exceptional thickness, this insulation will be damaged by the high frequency surge.

Accordingly, an object of the present invention is to provide triggering means capable of initiating gap breakdown in response to both low and high frequency voltage surges, but which is not vulnerable to damage from the high frequency surges.

Another object is to provide triggering means that operates at exceptionally high speed to initiate sparkover of the main gap in response to voltage surges of relatively low amplitude on the protected circuit.

In carrying out our invention in one form, we provide a surge arrester that comprises a pair of spaced-apart main electrodes that are connected across the opposite polarity conductors of the D.-C. circuit that is to be protected.

Each of the main electrodes comprises an arc-initiation portion and an arc-running portion adjacent the arc-initiation portion. High-frequency-responsive triggering means is provided for causing an arc to be established between the arc-initiation portions of said main electrodes when the high-frequency-responsive triggering means is energized by a voltage surge on the D.-C. circuit of a predetermined minimum magnitude having a high rate of change. This high-frequency-responsive triggering means comprises a first trigger electrode located adjacent the arc-initiation portion of one of the main electrodes and insulated therefrom. Low-frequency-responsive triggering means is also provided for causing an arc to be established between the arc-initiation portions of the main electrodes when the low-frequency-responsive triggering means is energized by a voltage surge on the D.-C. circuit of a predetermined minimum magnitude having a relatively low rate of change. This low-frequency-responsive triggering means comprises a transformer and a second trigger electrode in circuit with the transformer and electrically insulated from the first trigger electrode. This second trigger electrode is located adjacent the arc-initiation portion of said one main electrode and is insulated therefrom. The establishment of an arc between the main electrodes completes a bypass circuit between the opposite polarity conductors of the D.-C. system around the transformer and protects the transformer from the high rate-of-change voltage surge. Means is provided for developing when an arc is established between the main electrodes an increasing arc voltage for driving the arcing current toward zero. This latter means comprises magnetic means for propelling the arc along the arc-running portions of the main electrodes.

For a better understanding of the invention, reference may be had to the following description taken in conjunction with the accompanying drawings; wherein:

FIG. 1 is a schematic view of a surge arrester embodying one form of our invention connected to protect a D.-C. power circuit.

FIG. 2 is a cross-sectional view through an arrester of the type schematically depicted in FIG. 1. FIG. 2 is taken along the line 2-2 of FIG. 3.

FIG. 3 is a cross-sectional view along the line 3-3 of FIG. 2.

FIG. 4 is a sectional view taken along the line 4-4 of FIG. 3.

FIG. 4a is a graphical representation of certain voltage relationships.

FIG. 5 is a schematic view showing a modified form of our invention.

FIG. 6 is a sectional view along the line 6-6 of FIG. 5.

FIG. 7 is a schematic view of a modified form of the invention.

Referring now to FIG. 1, there is shown a D.-C. circuit comprising a positive bus 10, a negative bus 12, and semi-conductor rectifier equipment 14 connected to the buses for supplying D.-C. power thereto. As stated hereinabove, voltage surges, either of a high frequency as might be produced by lightning or a relatively low frequency as might be produced by switching, may appear on buses 10, 12, and these surges could damage the semi-conductor equipment 14 unless suitable protection is provided.

For protecting the equipment 14 from such voltage surges, a surge arrester, schematically shown at 16 is provided. This surge arrester has one terminal 17 connected to the positive bus 10 and its opposite terminal 18 connected to the negative bus 12, preferably through a resistor 20. The resistor 20 is a non-linear resistor, preferably made of a material having a negative resistance-current characteristic, such as the material sold by

General Electric Company under the trademark Thyrite.

The illustrated arrestor 16 is, in many respects, identical to the arrestor shown and claimed in our application S.N. 298,942, filed July 31, 1963, and will therefore be described in the present application only to the extent believed necessary to convey an understanding of the present invention. This arrestor 16 comprises a sealed envelope 21 containing an arc-extinguishing gas, preferably one consisting essentially of hydrogen. Disposed within the envelope is a pair of spaced-apart main electrodes 22 and 24 defining a gap 25 therebetween across which arcs are adapted to be established. The electrodes are preferably of a generally semi-circular configuration with one electrode 22 disposed about the other electrode 24. The centers of curvature of the two main electrodes are offset with respect to each other so that the gap 25 is relatively short in length at one end of the electrodes and gradually increases in length as the other end is approached via circumferential path extending along the length of the electrodes. The portion 25a of the gap where the electrodes are closest together is referred to hereinafter as the arc-initiation region, and the remainder of the electrodes in the arc-initiation region 25a are referred to as arc-initiation portions, and the other electrode portions are referred to as arc-running portions.

Connected in series with the electrodes 22 and 24 are two arc-propelling coils 28 and 30, one between the terminal 17 and electrode 22 and the other between the terminal 18 and electrode 24. The coils are used to create a magnetic field for propelling the arc established between the main electrodes 22 and 24, as will soon be explained.

For initiating an arc between the main electrodes 22 and 24, a first trigger electrode 132 is provided adjacent the arc-initiation region of the main electrode 24. This trigger electrode 132 is separated from the main electrode 24 by means of a strip of high dielectric constant insulating material 134, preferably of barium titanate. When a voltage pulse of a predetermined minimum amplitude is applied between the trigger electrode 132 and main electrode 24, the electric field near the edge of the insulating material 134 is intensified due to the high dielectric constant of the insulating material and a spark will jump across the trigger gap 133 between the trigger electrode and the main electrode 24. The positive ions produced by the spark distort the electric field between the two main electrodes 22 and 24, reducing the breakdown voltage between the main electrodes 22 and 24 to a value below the applied voltage between the main electrodes. This results in an arc being established between the two main electrodes 22 and 24 in their arc-initiation region. The current that flows through the arc also flows through the arc-propelling coils 28 and 30, and this produces a magnetic field that drives the arc in the direction of the arrow 35 of FIG. 1, as will soon appear more clearly.

For applying a voltage pulse to the trigger electrode 132 when a surge voltage appears across the buses 10, 12, an iron core pulse transformer 100 is provided. This pulse transformer 100 has a primary winding 102 and a secondary winding 104. The primary winding is connected across the buses 10, 12 and in series with a capacitor 106 located electrically between the primary winding and one of the buses 10. The secondary winding 104 has one terminal which is connected to the negative bus 12 and an opposite terminal which is connected through a conductor 105 to the trigger electrode 132. The trigger gap 133 is, in effect, connected across the secondary winding 104.

In a preferred form of the invention, the secondary winding 104 is arranged in such a manner that when the primary winding 102 is energized by a voltage surge of a predetermined polarity on the bus 10, an output voltage pulse of an opposite polarity appears on secondary conductor 105 and the trigger electrode 132. This opposite

polarity relationship is indicated by the plus and minus signs applied to adjacent terminals of the two transformer windings 102 and 104.

For several reasons, the presence of transformer 100 renders the above-described triggering means more effective in producing a sparkover of the main gap in response to a voltage surge on bus 10. One of these reasons is that the transformer 100 is a step-up transformer that develops a higher voltage across its secondary winding than the voltage which is applied to its primary winding. Hence, the voltage applied to the trigger gap 133 through the secondary winding 104 is higher than the surge voltage itself that appears on bus 10. This higher voltage is, of course, more capable of producing a trigger gap sparkover and a resulting main gap sparkover.

A second reason is that the transformer 100 assists in producing a main gap sparkover in the opposite polarity relationship between its output and input signals. In this connection, note that when the negative polarity pulse is initially applied to trigger electrode 132 in response to a positive pulse on bus 10, the main electrode 24 is at the potential of negative bus 12, since there is no current flowing between main electrode 24 and the negative bus 12. When a breakdown of the trigger gap 133 occurs in response to this negative pulse, the potential of the main electrode 24 quickly falls to substantially the same value as the negative potential of the trigger electrode (since the impedance of circuit elements 30 and 20 located between the main electrode 24 and the negative bus 12 allows the main electrode 24 to become negative with respect to bus 12 for a brief period). During this brief period, the other main electrode 22 is at a high positive potential, substantially equal to the instantaneous potential of bus 10 with the positive surge thereon, since this electrode 22 is connected directly to the bus 10 and no significant current is yet flowing through the coil 28. The resultant voltage appearing between the electrodes 22 and 24 across the main gap 25 is equal to the arithmetic sum of these two instantaneous voltages, and hence a very high voltage immediately appears across the main gap 25, and this accelerates sparkover of the main gap following breakdown of the trigger gap. This arithmetic sum is illustrated at X in FIG. 4a, where the voltages on the various components are depicted just prior to sparkover of the trigger gap.

Had the transformer 100 not reversed the polarity of its output signal relative to its input signal, the voltage appearing across the main gap immediately following breakdown of the trigger gap would merely equal the arithmetic difference of the instantaneous voltages for the two main electrodes 22 and 24. Since this difference voltage is much less than the previously-described arithmetic sum, it would be less capable of sparking over the main gap than the net voltage resulting when the negative polarity pulse is used for triggering. While it is true that oscillations in the voltage of the lower main electrode 24 occur shortly after trigger gap breakdown and these oscillations would result in a much higher voltage subsequently appearing across the main gap, the above-described opposite polarity triggering arrangement does not need to wait for such oscillations and can effect an extremely high speed sparkover of the main gap.

The purpose of capacitor 106 connected in series with primary winding 102 is to prevent steady-state D.C. current from flowing through the primary winding, thus preventing the core of the transformer 100 from being saturated by the flux that would be generated by such current. By preventing such saturation, a smaller core may be used for the transformer 100.

The above-described triggering means, which includes transformer 100, if used as the sole triggering means, has a disadvantage of being relatively vulnerable to damage by high frequency voltage surges appearing on the bus 10. Such high frequency voltage surges could reach very high values across the primary winding 102 before de-

veloping a significant pulse across the secondary winding 104 in view of the time lag inherently present in the transformer's operation.

Unless the transformer was built with very special and expensive insulation, this high frequency surge across the primary winding could damage the transformer insulation before a sufficient secondary pulse developed to initiate breakdown of the main gap.

To protect the transformer 100 from being damaged by these high frequency voltage surges, we provide a second triggering means that comprises a second trigger electrode 32. The second trigger electrode 32 is located adjacent the first trigger electrode 132 and the main electrode 24 but is insulated from both of these latter two electrodes by the insulation 134 best shown in FIG. 4. A pulse applied to this second trigger electrode 32 initiates sparkover of the trigger gap 33 between the trigger electrode 32 and the main electrode 24 in the same manner as described hereinabove with respect to pulses applied to the first trigger electrode 132. Sparkover of this trigger gap 33 results in charged particles being projected into the main gap 25 to initiate a sparkover of the main gap 25 in the same manner as hereinabove described with respect to sparkovers initiated from the first trigger electrode 132.

For applying surge voltages to the second trigger electrode 32 when they appear across the buses 10, 12, the second trigger electrode 32 is connected to the bus 10 through a small capacitor 36. Under normal or steady-state conditions, the trigger electrode 32 will be essentially isolated from the bus 10 by the capacitor 36. But when surge voltage appears on the bus 10, the capacitor presents a low impedance, and most of the surge voltage will appear across the trigger gap 33 between the trigger electrode 32 and the main electrode 24.

The magnitude of the voltage appearing across the capacitor 36 varies inversely with respect to $f \times C$, where f is the frequency of the surge and C is the capacitance of capacitor 36. For cost reasons, it is desirable to use a capacitor 36 of low capacitance. The capacitance of capacitor 36 is preferably made so low that it is only for relatively high frequency surges that no substantial voltage appears across capacitor 36. Under these high frequency surge conditions, since no substantial surge voltage appears across capacitor 36, substantially all the surge voltage appears across the trigger gap 33 and can spark over the trigger gap to initiate breakdown of the main gap. A low frequency surge voltage on the bus 10 causes a much higher percentage of the surge voltage to appear across the capacitor 36 and hence a much lower percentage across the trigger gap. The capacitor 36 is preferably made so small that low frequency surge voltages do not develop enough voltage across the trigger gap to cause it to spark over unless these low frequency surge voltages reach very high magnitudes beyond the voltage level that it is desired to protect against.

For triggering the main gap in response to low frequency surges, the first triggering means including the transformer 100 is relied upon. This triggering means, as explained above, can initiate gap breakdown in response to low frequency surge voltages of any desired low magnitude. High frequency voltage surges acting through the second trigger electrode 32 can produce a sparkover of the trigger gap 38 and the main gap 25 in a sufficiently short time to prevent the high frequency voltage surge from building up an excessively high voltage across the primary winding 102 of the transformer 100. When the main gap 25 sparks over, it establishes a low impedance circuit through the gap 25 that shunts the transformer 100 to limit and quickly reduce the voltage developed thereacross, thus protecting the transformer from damage through overvoltage.

It will be noted that a resistor 42 is connected between the second trigger electrode 32 and the main electrode 24. This resistor 42 has a very low resistance in comparison to the leakage resistance of capacitor 36.

The purpose of this resistor 42 is to maintain the trigger electrode 32 and the main electrode 24 at substantially the same potential under normal or steady-state conditions, i.e., conditions when no surge voltage is present between the buses 10 and 12. Under these conditions, there is a high resistance current path present across the buses 10, 12 that comprises the series combination of the leakage resistance of capacitor 36, the parallel combination of resistor 42 and the leakage resistance of the trigger gap 33, and the resistance of elements 30 and 20. The resistance of elements 42, 30 and 20 is very low in comparison to the leakage resistance of the capacitor 36. Hence, almost all the steady-state voltage appears across the capacitor 36, and substantially none of this voltage appears across the resistor 42 and, hence, across the trigger gap 33 in parallel with the resistor 42. Isolating the trigger gap from the steady-state voltage is desirable in preventing degradation of the trigger gap and possible false sparkovers.

Referring to FIG. 2, it will be noted that the main electrodes 22 and 24 are mounted between two insulating plates 45 that act as side walls for the arcing gap 25 between the electrodes. These plates 45 are substantially imperforate in the region of the arcing gap 25 and extend generally parallel to the longitudinal axis of any arc between the electrodes 22 and 24. These insulating plates 45 are made of a material that emits very little gas when exposed to an arc, for example, aluminum silicate. The plates 45 are clamped against opposite edges of the electrodes 22 and 24 by suitable fastening means such as the insulating bolts 47 located at spaced apart locations around the outer periphery of plate 45. These bolts 47 extend through aligned openings in the insulating plates 45 and are threaded into an end cap 48 of the envelope 21. Surrounding each bolt 47 between the plates 45 is a spacer 49 of insulating material that limits the clamping pressure applied by the bolts 47. Also surrounding each bolt is a sleeve 50 that supports the insulating plates 45 relative to the end cap 48.

The coils 28 and 30 for creating the arc-propelling magnetic field are mounted on the outer sides of the insulating plates 45. Each of these coils is preferably of a circular configuration as viewed in FIG. 3, and half of the circumference of each coil is disposed approximately in alignment with the semicircular outer electrode 22. The coils are connected in the circuit in such a manner that when current flows through the arrestor, it flows through each of the coils in the same angular direction. Thus, a magnetic field 51 surrounding the two coils 28 and 30 and having the general configuration depicted in FIG. 2 is developed. At all points along the length of the outer electrode 22, this magnetic field 51 extends across the arcing gap 25 in a direction generally perpendicular to the longitudinal axis of any arc between the electrodes 22 and 24. As is known, a magnetic field applied transverse to an arc will coax with the local magnetic field around the arc to drive the arc in a direction transverse to the longitudinal axis of the arc and transverse to the direction of the applied magnetic field. The polarity of the applied magnetic field is selected so that the arc-propelling force is in the direction of arrow 35 in FIGS. 1 and 3. Thus, when an arc is established at the arc-initiating region 25a, it is driven along the electrodes 22 and 24 in the direction of arrow 35 to the opposite end of the electrode.

The motion of the arc in the direction of arrow 35 of FIG. 3 progressively lengthens the arc due to the progressively increasing length of the arcing gap 25. This progressive lengthening of the arc produces a progressive increase in the arc voltage, which progressively reduces the arcing current. When the arc voltage exceeds the voltage applied by the system to the main gap, the arcing current will rapidly approach zero. If the energy of the voltage surge that initiated the arc has then been dissipated in the arrestor, the arc will be extinguished and no

further breakdown of the gap 25 will occur, thus enabling the system to be restored to normal operation. It will be apparent that the highest arc voltage is developed when the arc reaches the end of the electrodes 22, 24 and is bowed outwardly in its central region, as is shown at 60 in FIG. 3. When in this position, the arc has its maximum length.

If the voltage surge is a high energy surge, only a portion of the surge energy will have been dissipated by the time the arc reaches its position 60 of FIG. 3. The remaining surge energy will produce another abrupt voltage rise that will cause the main gap to spark over in the arc-initiation region 25a, thus establishing another arc between the main electrodes in the arc-initiation region 25a. The first arc may or may not have been completely extinguished at the instant that the second arc is established, but upon establishment of the second arc, the first arc vanishes. The second arc, like its predecessor, is driven in the direction of arrow 35 into position 60 thereby increasing the arc voltage and driving the arc current rapidly towards zero. Just before or as soon as the current reaches zero, the surge voltage resulting from the remaining surge energy initiates a third arc in the arc-initiation region 25a. The second arc vanishes, and the third arc is handled in the same manner as its predecessor. This sequence of events is repeated over and over again until the surge energy is finally completely dissipated. When this complete dissipation occurs, the maximum arc voltage developed when the arc is at position 60 is insufficient to cause a breakdown at the arc-initiation region 25a, and hence the gap acts thereafter to prevent further current flow.

If the type of high frequency voltage surge that the arrester is to protect the circuit against is a lightning surge and particularly the type of lightning surge that results from a lightning stroke to the system 10, 12 at a point near the arrester, then it is most desirable that the arrester be constructed generally as shown in our application S.N. 397,215 filed September 17, 1964, now Patent No. 3,287,588. Such an arrester is illustrated in FIG. 5.

The current through an arrester that accompanies a lightning surge comprises two parts: (1) a lightning discharge current, which is the current of the lightning surge, and (2) a follow current, which is the current of the system that flows through the arrester following passage of the lightning discharge current. The magnitude of the lightning discharge current is largely independent of the impedance of the arrester and therefore may reach very high values. If an arc carrying a very high current were forced from the arc-initiating region 25a in the direction of arrow 35, as described in connection with FIGS. 1-4, an excessively high arc voltage would be developed. In this respect, the discharge path between the electrodes 22 and 24 at the left hand side of the arc-initiating region in FIG. 5 is the same as that of the arrester of FIGS. 1-4 and therefore has a relatively high impedance. For low current arcs such as switching surge arcs, this high impedance is desirable because it enables the arc voltage to be built up quickly to force the switching surge current toward zero. The flow of switching surge current through this relatively high impedance path does not develop excessive voltages across the arrester because the switching surge current is relatively low and is limited by the relatively high impedance of the arrester. But lightning discharge currents will usually be much higher and will have a magnitude that is essentially independent of the arrester impedance. Accordingly, if this high lightning discharge current was discharged through the high impedance path at the left hand side 25b of the arrester, excessive voltages would be developed across the arrester that could damage the rectifier equipment 14.

To prevent the development of such excess voltages, we exclude high lightning discharge current arcs from the left hand region 25b of the arrester and instead propel these arcs from the arc-initiation region 25a into a region

25c at the right of the arc-initiation region. For reasons which will soon be explained, the right hand region 25c of the arrester has a relatively low impedance. Hence, the passage of the high lightning discharge currents through this path does not generate excessive voltages across the arrester.

The reason that the right hand portion 25c of the arrester has a relatively low impedance compared to that of the left hand portion 25b is that the spacing between the insulating side walls 45 in this region is relatively large compared to the spacing in the region 25b. This relatively large spacing of the side walls 45 permits any arc burning in this region 25c to increase its cross section and to become diffused, which in turn permits it to burn with a much lower arc voltage. In effect, this region 25c of relatively large side wall spacing presents a low impedance path for any lightning discharge current arc which is propelled into it.

For propelling a high current lightning arc in the direction of arrow 37 (FIG. 5) from the arc-initiation region 25a into the low impedance region 25c, we disable the lower coil 30 by shorting it out (in a manner soon to be described) and permit the magnetic field from the upper coil 28 to propel the lightning discharge current arc. The field from this upper coil 28 has a polarity such as to drive arcs in the direction of arrow 37, and accordingly the lightning discharge current arc will be driven in the direction of arrow 37. The coil 28 has only a small percentage of the number of turns of coil 30 and normally its arc-propelling ability is completely defeated by the opposing magnetic field of the coil 30. But when the coil 30 is disabled, the magnetic field from the upper coil is capable of forcing an arc established at the arc-initiation region toward the right. Even though the coil 28 has only a few turns, it can provide a high enough magnetic field to effectively propel the lightning current arc because the lightning current that traverses the coil during this interval is very high. It is most desirable that this coil 28 have a minimum number of turns since this limits its impedance to a sufficiently low value to prevent excessive voltages from being developed thereacross by the lightning current.

For disabling the other coil 30 during the period when lightning discharge current is flowing through the arrester, we provide a coil-shortening gap 70 that is connected in parallel with the coil 30. Since both the magnitude and rate of change of lightning discharge current are very high and since the coil 30 has a relatively large number of turns, the voltage developed across the coil 30 by the lightning current quickly rises toward a high value. This sharply rising voltage is used to spark over the coil shorting gap 70, and thereafter the lightning current flows through the coil shorting gap 70. The coil shorting gap 70 is designed to present a low impedance to the lightning current, and thus the voltages developed thereacross by the lightning current are limited to a relatively low value.

This coil-shortening gap 70 comprises spaced-apart electrodes 72 and 74 defining a gap 75 therebetween and an arc-propelling coil 78 for propelling an arc across gap 75 in the direction of arrow 77. The gap 70 is constructed in the same manner as a similarly designated gap in our aforesaid application Serial No. 397,215 and will, therefore, not be described in detail in the present application.

When the lightning discharge current has fallen to a predetermined value indicative of substantially complete dissipation of the energy of the lightning surge, the arc in the coil-shortening gap 70 will be extinguished. The follow current that flows thereafter follows a path through the coil 30 rather than the gap 70. This is the case because the coil 30 presents a very low impedance to the follow current in view of the low rate of change of the follow current. Since this impedance to follow current through the coil 30 is much lower than that through the coil shorting gap 70, essentially all of the follow cur-

rent flows through the coil 30 after passage of the lightning discharge current.

As soon as the coil 30 is traversed by follow current, it develops its previously-described magnetic field for driving the arc in the main gap in the direction of arrow 35. The arc in the main gap is then carrying follow current. This arc is forced by the magnetic field of the lower coil 30 into the left hand region 25b of gap 25 where the spacing between the insulating plates is small. This results in the development of a higher arc voltage and higher effective impedance, which drives the current through the arrestor to zero and prevents reestablishment of the arc, all in the same manner as described hereinabove with respect to FIGS. 1-4. Typically, the arc carrying power follow current after the passage of the lightning discharge current can be extinguished even before it has reached the position 60 of FIG. 3 on its first movement through the arc-running region 25b.

The arrestor of FIG. 5 utilizes substantially the same two triggering means as the arrestor of FIGS. 1-4, and corresponding parts of these triggering means have been assigned identical reference numerals. Lightning surges, which are high frequency surges, will initiate arc-over of the arrestor by triggering it through the trigger means 32, 36. Switching surges, which are relatively low frequency surges, will initiate arc-over of the arrestor by triggering it through the triggering means 132, 100.

When the main gap is sparked over by a voltage pulse applied through the triggering means 32, 36 in response to the high frequency lightning surge, the arc that is initially formed is driven into the low impedance region 25c of the arrestor to the right of the arc-initiation region. After the lightning current is dissipated, the arc carrying follow current is driven into the relatively high impedance region 25b of the arrestor to build up a high arc voltage that extinguishes the arc.

When the main gap is sparked over by a voltage pulse applied through the triggering means 100, 132 in response to a relatively low frequency surge such as a switching surge, the arc that is initially formed is driven to the left into the relatively high impedance region 25b to quickly build up arc voltage for extinguishing the arc, as described hereinabove.

FIG. 7 illustrates a slightly modified form of triggering means for causing spark-over of the surge arrestor in response to a low frequency voltage surge. In many respects, the embodiment of FIG. 5 corresponds to that of FIG. 1, and, hence, corresponding parts of these embodiments have been assigned corresponding reference characters. The basic structural difference between these two embodiments is that in FIG. 5 a capacitor 150 has been connected across the secondary winding 104 of the pulse transformer 100.

This capacitor 150 serves a number of important functions. One is that it prevents the iron core of the pulse transformer 100 from becoming saturated by the cumulative build-up of residual magnetism therein as a result of repeated unidirectional voltage pulse appearing across buses 10, 12 over a prolonged period. Without the capacitor 150, the application of these repeated unidirectional voltage pulses to the primary winding 102 has a tendency to cumulatively build-up residual magnetism in the iron core. As this cumulative build-up continues and the saturation point is approached, the transformer 100 loses its ability to produce an output pulse of the desired wave shape and amplitude. The capacitor 150 prevents this condition from developing inasmuch as it cooperates with the secondary winding 104 to form an oscillatory circuit. This oscillatory circuit produces an oscillatory output voltage on the trigger electrode 132 in response to a unidirectional voltage pulse being applied to primary winding 102 and, furthermore, produces this oscillatory voltage irrespective of whether the trigger gap 133 sparks over. The oscillatory current flowing through the secondary winding 104 as a result of the oscillatory

voltage developed by the circuit 104, 150 produces a counter magnetizing force which drives any residual magnetism in the core back to approximately zero. Thus, the core of the transformer is, in effect, reset by the oscillatory current and is thus prevented from accumulating sufficient residual magnetism to impair operation of the pulse transformer.

Another function of the capacitor 150 is to extend the period that the main electrode 24 remains near the peak pulse voltage of the trigger electrode 132 following spark over of the trigger gap 133. This extension results from the added energy stored in the capacitor 150, which decreases the rate at which the voltage of the main electrode 24 falls following trigger gap spark over. By extending this period, a voltage substantially equal to X in FIG. 4a is maintained for an extended period, thus increasing the chances for a main gap spark-over in response to a trigger gap spark-over.

Another function of capacitor 150 is to increase the current and energy supplied to the trigger gap 133 upon its sparkover, thereby releasing more charged particles to accelerate spark-over of the main gap 25a.

In typical embodiments of our invention, the capacitor 150 has a capacitance of 0.001 to 0.01 microfarad; the capacitor 106 has a capacitance of 1 microfarad; and the pulse transformer has a ratio of between 1.5 and 3 to 1. The larger the ratio of the transformer, the smaller the value of capacitance used for capacitor 150.

In its broader aspects, our invention contemplates use of the low-frequency triggering circuits of FIGS. 1 and 7 either in combination with a high-frequency triggering circuit, as shown in FIG. 1, or without the high-frequency triggering circuit.

While we have shown and described particular embodiments of our invention, it will be obvious to those skilled in the art that various changes and modifications may be made without departing from our invention in its broader aspects and we, therefore, intend in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of our invention.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. In a D.-C. circuit comprising a pair of conductors of opposite polarity, a surge arrestor comprising:

- (a) a pair of spaced apart main electrodes,
- (b) means adapted to electrically connect said main electrodes across said conductors,
- (c) each of said main electrodes comprising an arc-initiation portion and an arc-running portion adjacent said arc-initiation portion,
- (d) high-frequency-responsive triggering means comprising a first trigger electrode located adjacent the arc-initiation portion of one of said main electrodes for causing an arc to be established between the arc-initiation portions of said main electrodes when said high-frequency-responsive triggering means is energized by a voltage surge on said D.-C. circuit of a predetermined minimum magnitude having a high rate of change,
- (e) low-frequency-responsive triggering means for causing an arc to be established between the arc-initiation portions of said main electrodes when said low-frequency-responsive triggering means is energized by a voltage surge on said D.-C. circuit of a predetermined minimum magnitude having a relatively low rate of change, said low-frequency-responsive triggering means comprising a transformer and a second trigger electrode in circuit with said transformer and electrically insulated from said first trigger electrode, said second trigger electrode being located adjacent the arc-initiation portion of said one main electrode and insulated therefrom,
- (f) the establishment of an arc between said main electrodes completing a by-pass circuit between said D.-C. conductors around said transformer that pro-

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fects said transformer from said high rate of change voltage surges,

- (g) and means operable when an arc is established between said main electrodes for developing an increasing arc voltage for driving the arc current toward zero, comprising means for propelling said arc along the arc-running portions of the main electrodes.

2. The combination of claim 1 in which said transformer is a step-up transformer for increasing the magnitude of the voltage pulse applied to said trigger electrode as compared to the magnitude of the voltage surge on said D.-C. circuit.

3. The combination of claim 1 in which:

- (a) said transformer comprises a primary winding and a secondary winding,
(b) means is provided for connecting said primary winding for energization by voltage surges on said D.-C. circuit,
(c) means is provided for connecting said secondary winding in circuit with said second trigger electrode,
(d) the polarity of said secondary winding with respect to said primary winding is such that when the primary winding is energized by voltage surge on said D.-C. circuit, a voltage pulse of opposite polarity to said voltage surge appears across said secondary winding and is applied to said second trigger electrode, and
(e) means is provided for causing substantially the arithmetic sum of the voltages of said voltage pulse and said voltage surge to be applied between said main electrodes immediately following sparkover between said second trigger and said one main electrode.

4. The combination of claim 1 in which:

- (a) said transformer comprises a primary winding and a secondary winding,
(b) means is provided for connecting said primary winding for energization by voltage surges on said D.-C. circuit,
(c) means is provided for connecting said secondary winding in circuit with said second trigger electrode, and
(d) the polarity of said secondary winding with respect to said primary winding is such that when the primary winding is energized by voltage surge on said D.-C. circuit, a voltage pulse of opposite polarity to said voltage surge appears across said secondary winding and is applied to said second trigger electrode.

5. The combination of claim 1 in which said high-frequency-responsive triggering means comprises a capacitor connected between said first trigger electrode and the other of said main electrodes, said capacitor being so small that low rate-of-change voltage surges that cause operation of said low-frequency-responsive triggering means normally do not cause operation of said high-frequency-responsive triggering means.

6. In a D.-C. circuit comprising a pair of conductors of opposite polarity, a surge arrestor comprising:

- (a) a pair of spaced-apart main electrodes,
(b) means adapted to electrically connect said main electrodes across said conductors,
(c) each of said main electrodes comprising an arc-initiation portion and an arc-running portion adjacent said arc-initiation portion,
(d) triggering means comprising a trigger electrode

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located adjacent one of said main electrodes and insulated therefrom for causing an arc to be established between the arc-initiation portion of said main electrodes when said triggering means is energized by a voltage surge on said D.-C. circuit of a predetermined minimum magnitude,

(e) said triggering means further comprising:

- (i) a transformer having primary and secondary windings,
(ii) means for connecting said primary winding for energization by voltage surges on said D.-C. circuit,
(iii) means for connecting said secondary winding in circuit with said trigger electrode,
(f) the polarity of said second winding with respect to said primary winding being such that when the primary winding is energized by a voltage surge on said D.-C. circuit, a voltage pulse of opposite polarity to said voltage surge appears across said secondary winding and is applied to said trigger electrode, and
(g) means for causing substantially the arithmetic sum of the voltages of said voltage pulse and said voltage surge to be applied between said main electrodes immediately following sparkover between said trigger electrode and said one main electrode.

7. The apparatus of claim 1 in which:

- (a) said main electrodes having auxiliary portions located on the opposite side of said arc-initiation portion from said arc-running portions,
(b) means is provided defining a region of relatively low impedance to arcing current flowing between said auxiliary portions in comparison to the impedance to arcing current flowing between said arc-running portions,
(c) means is provided for driving arcs initiated by said high-frequency-responsive triggering means into said region of relatively low impedance, and
(d) means is provided for driving arcs initiated by said low-frequency-responsive triggering means along said arc-running portions without entry of said latter arcs into said region of relatively low impedance.

8. The apparatus of claim 6 in combination with a capacitor connected across said secondary winding for substantially increasing the current and energy supplied to the trigger gap upon its sparkover as compared to that available from said transformer without said capacitor.

9. The apparatus of claim 6 in which:

- (a) said transformer comprises an iron core, and
(b) oscillation-producing means is provided for causing the voltage appearing across said secondary winding when said primary winding is energized by a unidirectional voltage surge to be an oscillatory voltage capable of preventing a cumulative build-up in residual magnetism in said iron core as a result of repeated unidirectional voltage surges being applied to said primary winding,
(c) said oscillation-producing means comprising a capacitor connected across said secondary winding.

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