March 10, 1970 C. W. BELL 3,500,009

HIGH VOLTAGE CIRCUIT BREAKER WITH MEANS FOR PREINSERTING RESISTORS DURING CLOSING

Filed Feb. 24, 1967 2 Sheets-Sheet 1

Fig. 1.

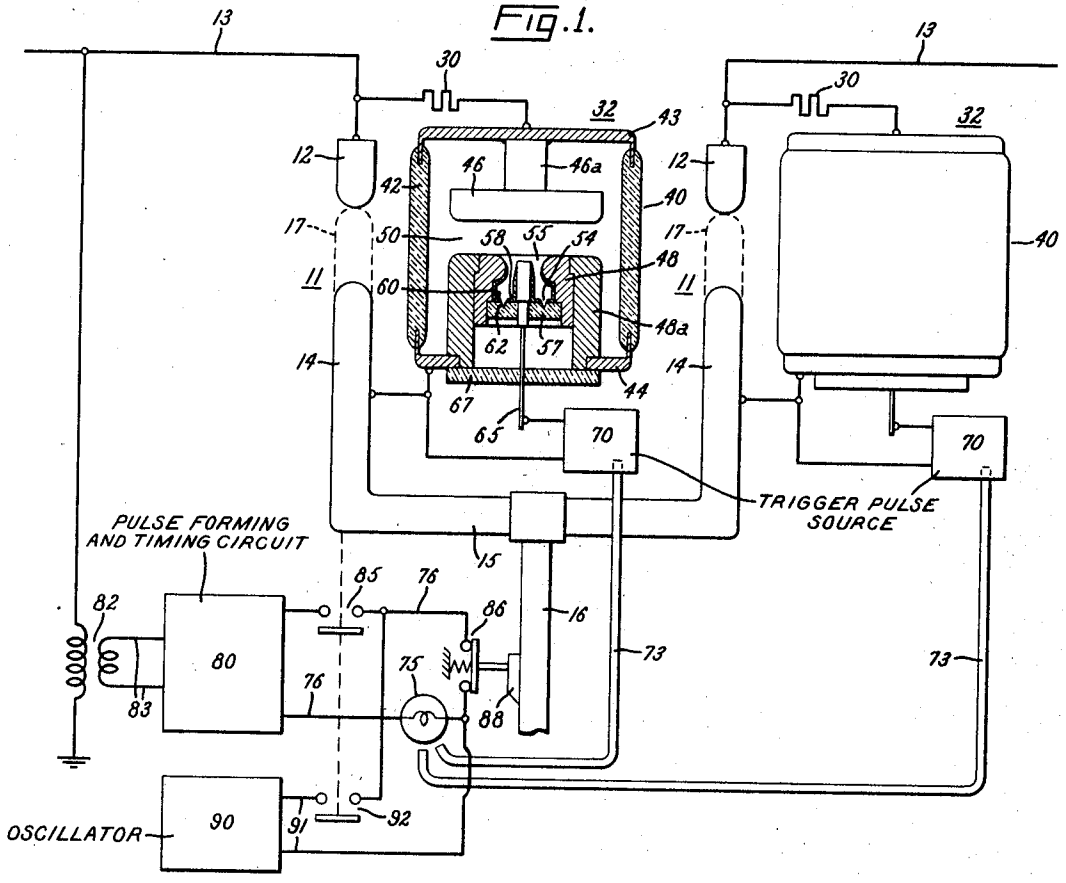
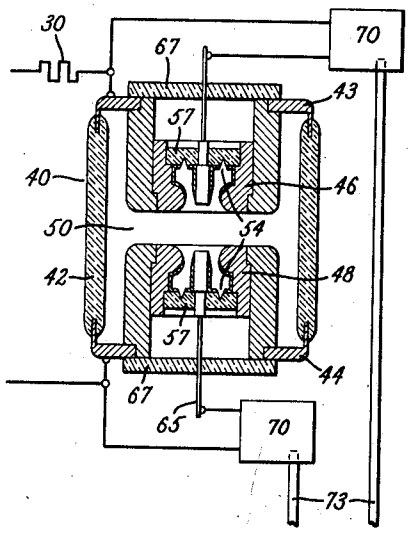


Fig. 1a.



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Filed Feb. 24, 1967 2 Sheets-Sheet 2

Fig. 2.

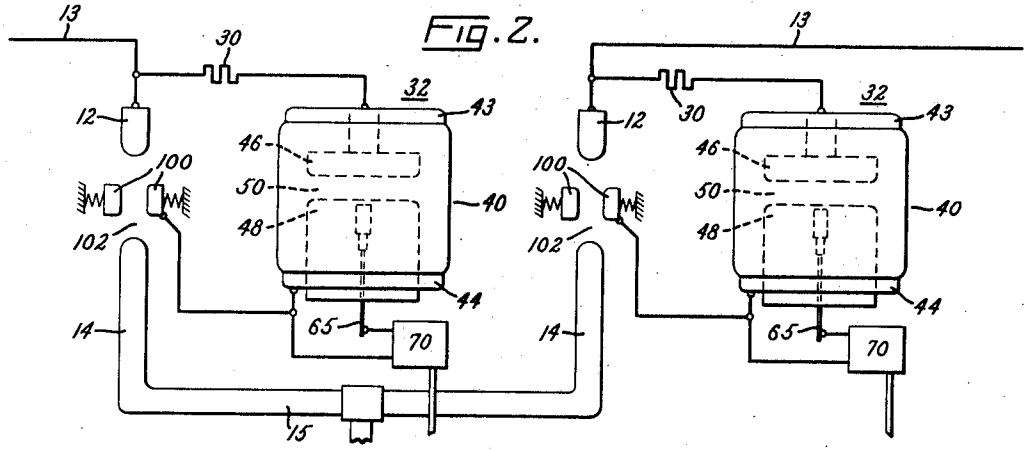


Fig. 3.

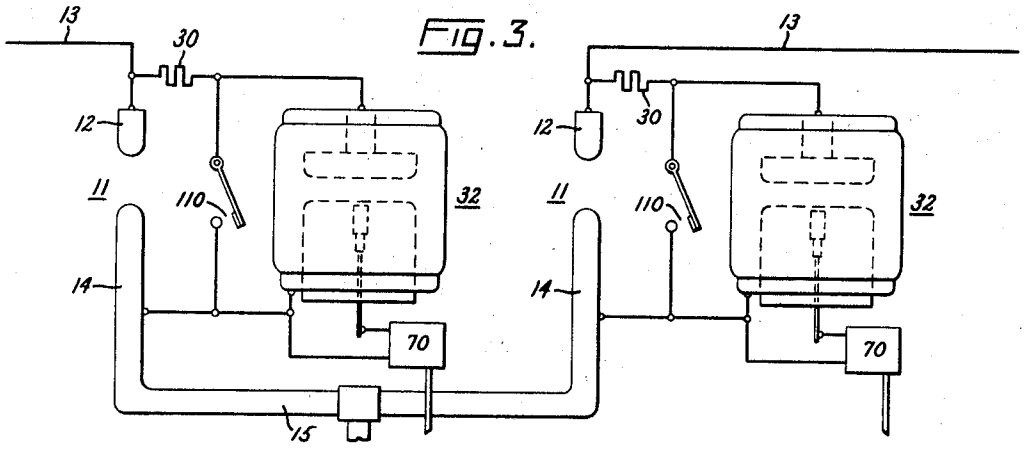
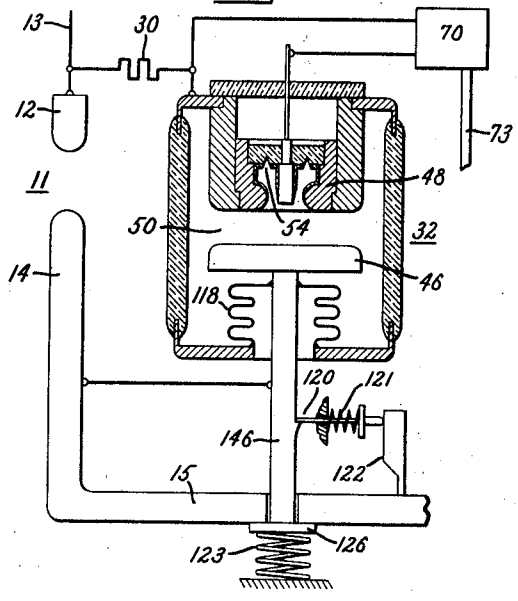


Fig. 4.



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3,500,009

HIGH VOLTAGE CIRCUIT BREAKER WITH MEANS FOR PREINSERTING RESISTORS DURING CLOSING

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Int. Cl. H01h 33/00
U.S. Cl. 200—144 15 Claims

ABSTRACT OF THE DISCLOSURE

A high voltage circuit breaker comprising a plurality of sets of separable contacts electrically connected in series. Paralleling each set of contacts is the series combination of a voltage-controlling resistor and a triggered gap device. During circuit-breaker closing, the resistors are preinserted in parallel with the contacts by simultaneously triggering the gap devices into a conductive state, thus simultaneously preinserting all the resistors.

BACKGROUND OF THE INVENTION

This invention relates to a high voltage electric circuit breaker and, more particularly, relates to a high voltage circuit breaker in which the circuit through the breaker is completed at a precisely-controlled instant during a circuit breaker-closing operation.

For limiting the magnitude of the voltage surge developed by a high voltage circuit breaker upon closing, it has been proposed that the circuit breaker be provided with resistors that can be inserted into the power circuit just prior to closing-engagement of the main contacts. Typically, these resistors are connected in parallel with the main contacts and in series with suitably controlled resistor switches that are caused to close and thereby insert the resistors at an appropriate instant preceding engagement of the main contacts.

Where there are a plurality of series-connected resistor switches in a very high voltage circuit, it is important that all of the resistor switches be closed substantially simultaneously. Otherwise, the inter-contact gap of the last resistor switch to close may be so long that it does not immediately break down in response to the high voltage developed thereacross when the other resistor switches close. This high voltage could cause a damaging arc-over across insulation exposed to such voltage.

SUMMARY

Accordingly, an object of my invention is to provide switching means capable of preinserting the resistors at a precisely-controlled instant, thus enabling substantially simultaneous preinsertion of all the series-connected resistors.

The magnitude of the voltage surge developed by circuit-breaker closing can be further controlled by controlling the instant on the voltage wave at which the resistors are preinserted. For example, in the AIEE paper by Skeats et al. appearing in the AIEE Transactions, volume 68, Part II, 1949, pages 1058–1067, it is pointed out that a voltage surge of minimum amplitude is developed if closing occurs at or near voltage zero. Accordingly, another object of my invention is to provide means capable of preinserting the resistors at a desired instant on the voltage wave.

A more general object of the invention is to provide improved means for closing the power circuit at a preselected precisely-controlled instant on the voltage wave.

In carrying out my invention in one form, I provide a high voltage circuit breaker comprising a plurality of sets of separable contacts electrically connected in series.

Paralleling each set of contacts is the series combination of a voltage-controlling resistor and a triggered gap device. Each triggered gap device comprises spaced-apart main electrodes defining a gap in series with its associated resistor and triggering means for causing an arc-over of said gap when a triggering signal is supplied to the triggering means. Means operable during a circuit-breaker closing operation is provided for supplying to the triggering means of said gaps triggering signals which cause arc-overs to be initiated substantially simultaneously in all of said gaps before said sets of contacts engage.

BRIEF DESCRIPTION OF DRAWINGS

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 illustration of a circuit breaker embodying one particular form of my invention.

FIG. 1*a* schematically illustrates a modified form of the invention.

FIG. 2 is a schematic illustration of another modified form of the invention.

FIG. 3 illustrates still another modification of the invention.

FIG. 4 illustrates still another modification of the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to FIG. 1, there is shown schematically a high voltage electric circuit breaker comprising two pairs **11** of main contacts electrically connected in series in a high voltage A.C. circuit **13**. Each pair of main contacts comprises a stationary contact **12** and a movable contact **14** movable in a vertical direction into and out of engagement with the stationary contact. The movable contacts are electrically and mechanically connected together by a conductive bridging member **15**, to which an insulating operating rod **16** is fixed.

The circuit breaker of FIG. 1 is shown in its solid-line open position with its main contacts **14** separated from their respective stationary contacts **12**. When the operating rod **16** is driven in an upward direction by suitable operating means (not shown), the bridging member **15** together with movable contacts **14** are driven upwardly until the movable contacts **14** engage the stationary contact **12**, thereby closing the circuit breaker. The dotted lines **17** indicate the position of the movable contacts when the circuit breaker is closed. The bridging member **15** mechanically couples the movable contacts together, thereby assuring that the two movable contacts **14** will move together in unison during a closing operation and will engage their respective stationary contacts **12** at approximately the same time.

Circuit-breaker opening is performed by driving movable contacts **14** downwardly from their dotted line position **17** into their solid line position shown. Opening force is transmitted through operating rod **16**, and the mechanical coupling provided by bridging member **15** assures that movable contacts **14** will separate from their respective stationary contacts substantially simultaneously.

For a more detailed example of a high voltage circuit breaker that performs in the general manner described up to this point, reference may be had to U.S. Patent 2,911,546—Oppel, assigned to the assignee of the present invention.

For limiting the magnitude of the voltage surge developed by the circuit breaker upon closing, the circuit breaker is provided with low ohmic resistors **30** that can be inserted into the power circuit during a closing operation just prior to engagement of the main contacts. Such insertion of the resistors is referred to herein as "pre-

insertion." When these resistors **30** are inserted into the power circuit, each is connected in parallel with a set **11** of the main contacts **12, 14.**

For inserting the resistors **30** in the power circuit at the desired instant, I provide a triggered vacuum gap **32** in series with each resistor and in parallel with the associated set of main contacts. These triggered vacuum gaps can be identical and therefore only one is shown in detail, the other being shown in outline form. Each is preferably constructed as shown and claimed in application Ser. No. 580,998—Lafferty, filed Sept. 21, 1966, now Patent No. 3,465,192 and assigned to the assignee of the present invention. Accordingly, it comprises a sealed envelope **40** that is evacuated to a pressure of 10^{-4} mm. of mercury or lower. The envelope **40** comprises a tubular casing **42** of a suitable insulating material and a pair of metallic end caps **43** and **44** joined in vacuum-tight relationship to the respective opposite ends of the insulating casing **42** by suitable seals.

Located within the evacuated envelope **40** is a pair of main electrodes **46** and **48** that are spaced apart to define a primary gap **50** therebetween. The upper electrode **46** is supported on upper end cap **43** by means of a conductive supporting rod **46***a*, whereas the lower electrode **48** is supported on lower end cap **44** by a tubular conductive supporting rod **48***a*.

The primary gap **50** between electrodes **46, 48** has a high enough dielectric strength to normally maintain the parallel circuit through resistor **30** open. It is to be understood that the circuit breaker of FIG. 1 has a low enough voltage rating to permit a single gap to be relied upon to withstand the voltages developed across the shunted main contacts **12, 14** without a breakdown. For higher voltage circuits, an appropriate number of these gap devices are connected in series in the shunt circuit.

For causing the main gap to break down when a triggering pulse is supplied to the triggered vacuum gap, there is provided a trigger gap **54** located within a centrally disposed recess **55** in the lower electrode **48.** This trigger gap comprises an annular ceramic disk **57** located within recess **55** and two thin layers **58** and **60** of metal bonded to the upper surface of ceramic disk **57** in radially spaced apart relationship. These two layers of metal constitute the electrodes of the trigger gap. They are separated by a circular groove **62** of V cross-section that extends circumferentially of the ceramic disk and has its walls defined by the ceramic material itself. One of the trigger electrodes **60** is electrically connected to the main electrode **48.** The other trigger electrode **58** is normally electrically isolated from the main electrode **48.** These layers **58** and **60** are preferably formed of a metal such as titanium charged with a large quantity of hydrogen.

As is well known, the lines of field distribution at the interface between a metal and a ceramic body in intimate contact are highly favorable to a breakdown at such interface. Accordingly, a relatively low voltage appearing across the trigger gap can initiate a discharge from one of the interfaces across the trigger gap. This discharge immediately evolves hydrogen from the trigger electrodes ionizing it and forcing electron-ion plasma into the main gap **50** to initiate an arc across the main gap.

For applying voltage across the trigger gap, a conductive lead **65** is provided extending through a central passageway in ceramic disk **57.** At its upper end this lead **65** is suitably electrically connected to trigger electrode **58.** At its lower end the lead **65** projects through a ceramic plate **67** that is hermetically sealed to the lead and to the lower end cap **44,** thereby sealing the lower end of the envelope.

The electrode **48** is shaped to provide a nozzle surrounding the upper end of lead **65.** This nozzle has a restricted throat located between the trigger gap **54** and main gap **50** through which ionized plasma is projected from the trigger gap into the main gap to initiate the main arc. The restricted nature of this throat prevents the main arc from finding its way onto the parts of the trigger gap, thereby protecting these parts from the main arc.

For applying a triggering pulse to trigger gap **54** at a predetermined instant, a trigger pulse source **70** is connected across the gap **54** between lead **65** and end cap **44.** This trigger pulse source can be of a conventional design and its details are therefore not shown. In a preferred form of the invention, this trigger pulse source **70** is a normally-off source that is turned on by a light signal transmitted thereto through a fibre optics light pipe **73.** For turning on source **70** in response to reception of the light signal, a light-activated SCR can be used in the manner shown, for example, in FIG. 11.4*a*, p. 211 of the General Electric SCR Manual, 3rd edition, 1964.

For developing a light signal to turn on the trigger pulse source **70,** a suitable lamp **75** is provided. This lamp **75,** which is connected in an energizing circuit **76,** is normally off. But when the energizing circuit **76** is completed, a voltage pulse is applied across the lamp to produce a light pulse of steeply rising luminous intensity. The light pulse travels through the light pipe **73** to turn on the light-activated trigger pulse source **70.**

Each trigger pulse source **70** is provided with a light pipe **73** through which the light pulse from the lamp **75** is transmitted. Since the two trigger pulse source **70** derive their turn-on signal from a common light source **75,** it will be apparent that the light pulses arrive at each trigger pulse source simultaneously. Both trigger pulse sources **70** turn on at an extremely high speed in response to the reception of the light pulse. Thus, the trigger pulse sources **70** deliver their voltage pulses to their respective trigger gaps substantially simultaneously.

In response to the application of the trigger pulses thereacross, the trigger gaps **54** immediately sparkover and immediately produce an arc-over of their associated primary gaps **50.** The total time between establishment of the light pulse and arc-over of the primary gaps **50** is in the neighborhood of 15–20 microseconds. This time may vary by several microseconds from one triggered vacuum gap to another, resulting in one gap firing several microseconds after the other, but this time variance is so slight as to be of little consequence.

In a preferred form of the invention, I develop the light pulse at such an instant that the triggered vacuum gap **32** fires near a voltage zero in the voltage between the power circuit **13** at the source side of the circuit breaker and ground. This is accomplished by applying a voltage pulse to the lamp **75** just prior to or shortly after such voltage-zero point. This timing of the voltage pulse can be accomplished by conventional means such as shown for example in U.S. Patent 2,825,824—Perolini, where a circuit is disclosed for developing an output pulse at a desired instant on the voltage wave. Since the details of the pulse-forming-and-timing circuit are not a part of my invention, I have shown the circuit in block form at **80.** A suitable potential transformer **82** connected between line **13** and ground at the source side of the breaker supplies input information on line voltage to the pulse-forming-and-timing circuit **80** through an input circuit **83.**

To prevent the pulse-forming circuit **80** from supplying an output pulse to the lamp **75** until a predetermined point in the closing operation, a normally-open control switch **85** is provided. This control switch **85** is suitably coupled to the movable contacts **14** of the circuit breaker. When the contacts **14** of the circuit breaker are moved through a desired point in the closing stroke, control switch **85** is closed. Thereafter, the next pulse developed by the pulse-forming-and-timing circuit **80** is supplied to the lamp **75** to turn on trigger pulse source **70** to cause arc over of the triggered vacuum gap **32.** When the circuit breaker reaches its fully closed position, a suitable *b* switch **86** opens to prevent further voltage pulses from being applied to lamp **75** so long as the circuit breaker

remains closed. This *b* switch **86** is schematically shown as being controlled by a suitable cam **88** on the circuit breaker operating rod **16**.

It is known that the magnitude of the voltage surge developed by circuit-breaker closing can be substantially reduced if closing is approximately synchronized with voltage zero, but such synchronized closing has not generally been attempted, because mechanically-controlled circuit breakers can rarely be closed with the precision needed to consistently effect closing at voltage zero. In a mechanically-controlled circuit breaker minor variations in starting characteristics, in speed, and prestrike gap length can introduce unpredictable variations in the point of circuit completion which defeat consistent closing at the desired voltage zero point. My circuit breaker with its triggered vacuum gaps, however, can be controlled with much more precision than a mechanically-controlled circuit breaker. As pointed out hereinabove, variations in the total time between application of the light signal and firing of the triggered vacuum gaps are only on the order of microseconds, and this is so small that firing can be consistently produced across all the triggered vacuum gaps within a few degress of the desired instant adjacent voltage zero. This instant can be made close enough to voltage zero to achieve a substantial reduction of the magnitude of the voltage surge produced by closing.

Since all the triggered vacuum gaps fire substantially simultaneously, there is a materially reduced likelihood that a damaging voltage will be built up across the insulation paralleling the last gap to fire. Before the voltage across the last gap to fire can build up to a damaging level, this gap fires, thereby preventing further voltage buildup.

Although my invention lends itself exceptionally well to a circuit breaker in which closing is synchronized with a particular point in the voltage wave, it is to be understood that the invention also has application to circuit breakers in which no effort is made to time closing with respect to a point in the voltage wave. In such a circuit breaker the potential transformer **82** can be omitted and the voltage pulse delivered to the lamp **75** when the control switch **85** is closed without regard to power circuit voltage. Such a control will produce substantially simultaneous firing of the triggered vacuum gaps **32** and will thus protect the insulation paralleling the last gap to fire, as described in the preceding paragraph.

A triggered vacuum gap, once fired, will continue to conduct until the current across the main gap reaches substantially zero at which point it will normally clear, i.e., will recover its dielectric strength to prevent further conduction. To prevent either of the triggered vacuum gaps **32** from clearing prior to the point at which the main contacts **12, 14** engage, I supply repetitive voltage pulses to the trigger gap **54** once the main gap **50** begins conducting. These repetitive pulses prevent the main gap **50**, once fired, from clearing until the contacts **12, 14** engage.

For supplying these repetitive pulses following initial firing of the triggered vacuum gap, a suitable oscillator **90** is provided which is capable of delivering repetitive voltage pulses at the desired frequency across its output terminals **91**. The output terminals **91** of the oscillator are arranged for connection across the lamp **75**. An auxiliary control switch **92** connects the oscillator across lamp **75** shortly after control switch **85** is closed, thus supplying the pulses from the oscillator to the lamp. The lamp responds to each voltage pulse by supplying a light pulse to the trigger pulse sources **70**, causing each source **70** to supply a pulse to its respective trigger gap as desired. When the main contacts reach their engaged position, the *b* switch **86** opens to isolate the lamp **75** from the oscillator, thereby terminating pulsing of the trigger gap.

I can eliminate the need for oscillator **90** by using instead of a triggered vacuum gap, a triggered low pressure gas gap, such as shown in U.S. Patent 3,248,603—Howell et al., assigned to the assignee of the present invention. The triggered low pressure gas gap can be constructed in the same manner as the triggered vacuum gap shown at **32** except that instead of being highly evacuated, it contains gas at a pressure in the micron range, e.g., nitrogen at a pressure of 100 microns. Such a gap will not normally clear at a current zero following arcing. Thus, once fired, it will continue conducting until the main contacts **12, 14** engage. Contact-engagement removes voltage from across the main gap and permits it to clear. Since there is no need for repetitive pulses with such a gap, the oscillator **90** can be omitted when such a gap is used. As pointed out in the aforesaid Howell patent, the gas pressure in the gap is sufficiently low that the mean free path of gas particles within the container **40** is greater than the inter-electrode distance.

Although I have shown in FIG. 1 only one trigger gap (**54**) in each triggered vacuum gap device **32**, it is usually desirable for A-C applications to provide two trigger gaps, one adjacent each main electrode. To facilitate firing of the main gap in response to sparkover of the trigger gap, the location of the trigger gap should be adjacent the cathode of the main gap. By having two trigger gaps, one adjacent each main electrode, and by sparking-over these two trigger gaps each time it is desired to fire the main gap, assurance is had that a trigger gap will spark-over adjacent the cathode irrespective of which main electrode is the cathode.

FIG. 1*a* schematically illustrate a triggered vacuum gap device with two trigger gaps **54**, one adjacent each main electrode. Each trigger gap **54** is connected across a separate trigger pulse source **70**. The trigger pulse sources **70** are normally-off sources that are activated simultaneously by light pulse signals delivered through light pipes **73** from a common light source such as **75** in FIG. 1.

For reducing the amount of voltage that the triggered vacuum gap will be required to withstand when the circuit breaker is open, the embodiment of FIG. 2 can be utilized. Here, at each break of the circuit breaker, an intermediate contact **100** is provided between the two main contacts **12** and **14**. An isolating gap **102** is present between the intermediate contact **100** and the movable contact **14** when the circuit breaker is in its fully-open position of FIG. 2. When the circuit breaker is in its fully open position of FIG. 2, isolating gap **102** is in series with the main gap **50** of the triggered vacuum gap. Accordingly, the voltage present between the main contacts **12** and **14** is distributed between isolating gap **102** and vacuum gap **50**, thus relieving vacuum gap **50** of a portion of the total voltage.

During a closing operation, the movable contact **14** is driven in an upward direction, first engaging intermediate contact **100** and then engaging the stationary contact **12**. Firing of the triggered vacuum gap is delayed until after the movable contact has engaged the intermediate contact **100**. The firing means employed in FIG. 2 can be substantially the same as that used in FIG. 1 and therefore has not been shown in the drawing.

Although not shown, it is to be understood that suitable capacitors or other impedances can be connected across the gaps of the circuit breaker to achieve a desired distribution of voltage between the gaps when the circuit breaker is open.

In certain circuit breakers it is necessary to use the resistors **30** during a circuit-breaker opening operation as well as during a closing operation. During an opening operation, as is known, resistors **30** can facilitate interruption by limiting the rate of rise of the recovery voltage transient. In the circuit breakers of FIGS. 1 and 2 the resistors **30** are disconnected during an opening operation and are not relied upon to effect the desired reduction in the recovery voltage rate during opening. In

the embodiment of FIG. 3, however, the resistors are available for this purpose during an opening operation. Here, each of the main breaks **11** is shunted by a resistor switch **110** in parallel with the main break. These resistor switches **110** are arranged to close at about the same time as the main breaks **11**. Upon closing, the resistor switches **110** connect the resistors **30** in parallel with the main breaks. During a circuit breaker opening operation, the resistor switches **110** remain closed until a predetermined period has elapsed after the main breaks are opened. During this period, the resistors **30** shunt the main breaks and limit the rate of rise of recovery voltage in the desired manner. When the interruption has been completed at the main breaks, the resistor switches **110** open to interrupt the flow of residual current through resistors **30**.

The resistor switches **110** have been shown schematically in FIG. 3 in order to facilitate an understanding of the invention. For a more detailed showing of how such resistor switches are constructed and controlled, reference may be had to the aforementioned U.S. Patent 2,911,546—Oppel.

In the embodiment of FIG. 3, the triggered vacuum gaps **32** are simultaneously fired during closing in essentially the same manner as described with respect to FIGS. 1 and 2. Such firing preinserts the resistors **30** in the same manner as described with respect to FIGS. 1 and 2.

FIG. 4 illustrates another embodiment which is capable of making the resistors **30** available during an opening operation. FIG. 4 shows a portion of the circuit breaker in its fully-open position. In FIG. 4, the triggered vacuum gap **32**, instead of having fixed electrodes, has relatively movable main electrodes **46**, **48** which are moved into engagement following arc-over of the main gap **50**. A more detailed disclosure of a triggered vacuum gap of this type is contained in application S. N. 438,005—Lee, filed Mar. 8, 1965, now Patent No. 3,319,121 and assigned to the assignee of the present invention.

Referring more specifically to FIG. 4, electrode **48** is a stationary electrode and **46** is a vertically movable electrode. The movable electrode **46** is mounted on the upper end of a contact rod **146** that extends freely through the lower end plate **44** and freely through an opening in bridging member **15**. A suitable metallic bellows **118** provides a seal about contact rod **46** to maintain the vacuum inside the gap device **32**. When the circuit breaker is open, the movable electrode **46** is held in its illustrated position by a hold-open latch schematically shown at **120**.

Closing of the circuit breaker and triggering of the gap device during closing are effected in the same manner as described in connection with FIG. 1. But in FIG. 4, after the gap device is triggered into conduction, its electrodes **46**, **48**, instead of remaining stationary, are driven into engagement. In this connection, the hold-open latch **120** is tripped at a suitable point in the circuit-breaker closing stroke, whereupon a closing spring **123** drives electrode **46** upward into engagement with stationary electrode **48**.

For tripping latch **120** at the desired point in the circuit breaker closing stroke, a tripping spring **121** and a cam **122** fixed to bridging member **15** are provided. When the bridging member **15** reaches a certain point in its upward closing travel, cam **122** permits spring **121** to release, or trip, latch **121**. This tripping permits closing spring **123** to quickly drive the movable electrode **46** of the gap into engagement with stationary electrode **48**. This engagement effectively maintains the resistor **30** in parallel with the main contacts when the circuit breaker is closed and during the initial portion of an opening operation.

During circuit-breaker opening, the bridging member **15**, after moving through a predetermined downward travel, engages a shoulder **126** on movable contact rod **146**, thereby opening the triggered vacuum interrupter **32** at a desired point in the opening stroke after the main contacts have parted. Prior to such opening of interrupter **32**, the resistor **30** remained connected in parallel with the main break **11** to perform its intended function. Opening of interrupter **32** interrupts the current through resistor **30**.

Although I have shown only single phase circuit breakers, it is to be understood that the invention is equally applicable to polyphase circuit breakers. In such circuit breakers, an assembly identical to any one of those shown in the drawings is connected in each phase of the circuit. A light source **75** common to the assemblies of all the phases can be used for turning on the trigger pulse sources **70** for all the triggered gap devices simultaneously, thereby arcing-over all the triggered gap devices **32** substantially simultaneously. In another form of the invention, the triggered gap devices in each phase can be controlled separately from those in the other phases. For example, the triggered gap devices in each phase can be fired in synchronism with a predetermined instant on the voltage wave associated with that particular phase.

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

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

1. A high voltage circuit breaker comprising:

(a) a plurality of sets of separable contacts electrically connected in series,

(b) the contacts of each set being separated when the circuit breaker is open and being relatively movable to an engaged position during a circuit-breaker-closing operation,

(c) a voltage controlling resistor associated with each set of contacts,

(d) switching means for connecting the resistor associated with each set of contacts in parallel with the associated set of contacts at a predetermined time during a circuit-breaker-closing operation,

(e) said switching means comprising a pluraliy of triggered gap devices, each device comprising a pair of primary electrodes defining a main gap therebetween in series with the associated resistor and triggering means for causing an arc-over of said main gap when a triggering signal is supplied to said triggering means, said triggering means comprising a trigger gap within said triggered gap device near said main gap but not exposed to the full voltage present across said main gap, said trigger gap sparking over in response to receipt of said triggering signal to cause arc-over of the associated main gap,

(f) and means operable during a circuit-breaker-closing operation for supplying to the triggering means of said gap devices triggering signals which spark-over the trigger gaps in all of said gap devices and cause arc-overs to be initiated substantially simultaneously in all of said main gaps before said sets of contacts engage.

2. The high voltage circuit breaker of claim **1** in which said triggered gap device is a triggered vacuum gap device wherein the normal pressure between said electrodes is less than 10^{-4} mm. of mercury.

3. The high voltage circuit breaker of claim **1** in which said triggered gap device is a low pressure gas device in which the mean free path of gas particles in said device exceeds the gap distance between said primary electrodes.

4. A polyphase high voltage circuit breaker comprising:

(a) a plurality of assemblies for connection in the respective phases of a polyphase circuit, each assembly being constructed as defined in claim **1**, and

(b) means for causing the triggered main gaps in the assemblies in the respective phases to arc-over substantially simultaneously.

5. The circuit breaker of claim **1** in combination with

means for consistently causing said triggering means to produce arc-over of said main gaps near voltage zero in voltage present on said breaker during said circuit-breaker closing operation.

6. A high voltage circuit breaker comprising:

(a) a plurality of sets of separable contacts electrically connected in series,

(b) the contacts of each set being separated when the circuit breaker is open and being relatively movable to an engaged position during a circuit-breaker-closing operation,

(c) a voltage controlling resistor associated with each set of contacts,

(d) switching means for connecting the resistor associated with each set of contacts in parallel with the associated set of contacts at a predetermined time during a circuit-breaker-closing operation,

(e) said switching means comprising a plurality of triggered gap devices, each device comprising a pair of primary electrodes defining a gap therebetween in series with the associated resistor and triggering means for causing an arc-over of said gap when a triggering signal is supplied to said triggering means,

(f) and means operable during a circuit-breaker-closing operation for supplying to the triggering means of said gap devices triggering signals which cause arc-overs to be initiated substantially simultaneously in all of said gaps before said sets of contacts engage,

(g) an intermediate electrode being provided for each pair of said separable contacts, said intermediate electrode being located between said separable contacts when the separable contacts are in their fully open position so that a first circuit-breaker gap is then present between said intermediate electrode and one of said contacts and a second circuit-breaker gap is then present between said intermediate electrode and the other of said contacts and the total voltage prevailing between said separable contacts is divided between said two circuit-breaker gaps, and means connecting one of the electrodes of said triggered gap device to said intermediate electrode to connect said gap device in parallel with said first circuit-breaker gap.

7. A high voltage circuit breaker comprising:

(a) a plurality of sets of separable contacts electrically connected in series,

(b) the contacts of each set being separated when the circuit breaker is open and being relatively movable to an engaged position during a circuit-breaker-closing operation,

(c) a voltage controlling resistor associated with each set of contacts,

(d) switching means for connecting the resistor associated with each set of contacts in parallel with the associated set of contacts at a predetermined time during a circuit-breaker-closing operation,

(e) said switching means comprising a plurality of triggered gap devices, each device comprising a pair of primary electrodes defining a gap therebetween in series with the associated resistor and triggering means for causing an arc-over of said gap when a triggering signal is supplied to said triggering means,

(f) and means operable during a circuit-breaker-closing operation for supplying to the triggering means of said gap devices triggering signals which cause arc-overs to be initiated substantially simultaneously in all of said gaps before said sets of contacts engage,

(g) a resistor switch associated with each set of contacts and operable when closed to connect said resistor in parallel with said set of contacts, said resistor switch being connected in series with said resistor and in parallel with said triggered gap device, and means for maintaining said resistor switch closed during the initial portion of a circuit-breaker opening operation so that said resistor is available to control the rate of rise of the recovery voltage transient at a current zero during an opening operation, and means for opening said resistor switch following said initial portion of the circuit-breaker opening operation to interrupt the current through said resistor.

8. The circuit breaker of claim 1 in which:

(a) the electrodes of said gap device are relatively movable into and out of a position of engagement, and

(b) means is provided for moving said electrodes into engagement immediately after arc-over of said main gap during a circuit-breaker closing operation.

9. The circuit breaker of claim 8 in combination with means for maintaining said electrodes in engagement during the initial portion of a circuit breaker opening operation so that said resistor is available to control the rate of rise of the recovery voltage transient at a current zero during an opening operation, and means for separating said electrodes during a subsequent part of said opening operation to interrupt the current through said resistor.

10. The circuit breaker of claim 1 in which said means for supplying triggering signals comprises normally-inactive trigger pulse sources respectively connected to the triggering means of said gap devices and means for activating said pulse sources substantially simultaneously.

11. The circuit breaker of claim 11 in which:

(a) said trigger pulse sources are each activated in response to the reception of a predetermined light signal, and

(b) said means for activating said pulse sources comprises a light source common to all of said light-activatable trigger pulse sources for developing and transmitting light energy that simultaneously reaches said pulse sources in the form of light signals simultaneously activating said pulse sources.

12. A high voltage circuit closer for closing an alternating-current circuit at a preselected point on the voltage wave of the alternating voltage present on said circuit, comprising:

(a) a pair of separable contacts which are separated when the circuit closer is open and are relatively movable to an engaged position during a closing operation of the circuit closer,

(b) a shunt circuit including switching means for electrically connecting the shunt circuit in parallel with said contacts when said switching means is closed,

(c) said switching means comprising a triggered gap device comprising a pair of primary electrodes defining a main gap therebetween in series with said shunt circuit and triggering means for causing an arc-over of said main gap when a triggering signal is applied to said triggering means, said triggering means comprising a trigger gap within said triggered gap device near said main gap but not exposed to the full voltage present across said main gap, said trigger gap sparking over in response to receipt of said triggering signal to cause arc-over of the associated main gap,

(d) and trigger control means sensitive to said voltage and operable during a closing operation of said circuit closer for supplying to said triggering means a triggering signal which causes said main gap to arc-over at a preselected point on said voltage wave before said contacts engage.

13. The high voltage circuit closer of claim 12 in combination with means for disabling said trigger control means until one of said contacts has moved through a portion of its closing travel into a predetermined position relative to the other contact during a closing operation of said circuit closer and for thereafter allowing said trigger control means to operate.

14. The high voltage circuit closer of claim 12 in which said triggered gap device is a triggered vacuum gap de-

vice wherein the normal pressure between said electrodes is less than 10^{-4} mm. of mercury.

15. A high voltage circuit closer for closing an alternating-current circuit at a preselected point on the voltage wave of the alternating voltage present on said circuit, comprising:

(a) a plurality of sets of separable contacts electrically connected in series,

(b) the contacts of each set being separated when the circuit closer is open and being relatively movable to an engaged position during a closing operation of said circuit closer,

(c) shunt circuits respectively associated with said sets of contacts and including switching means for electrically connecting the shunt circuits in parallel with their respective sets of contacts when said switching means is closed,

(d) said switching means comprising a plurality of series-connected triggered gap devices, each comprising a pair of primary electrodes defining a main gap therebetween in series with its associated shunt circuit and triggering means for causing an arc-over of said main gap when a triggering signal is applied to said triggering means, said triggering means comprising a trigger gap within said triggered gap device near said main gap but not exposed to the full voltage present across said main gap, said trigger gap sparking over in response to receipt of said triggering signal to cause arc-over of the associated main gap,

(e) and trigger control means sensitive to said voltage and operable during a closing operation of said circuit closer for supplying to the triggering means of said gap devices triggering signals which spark-over the trigger gaps in all of said gap devices and cause arc-overs to be initiated substantially simultaneously in all of said main gaps before said sets of contacts engage and at a preselected point on said voltage wave.

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