May 17, 1966 T. H. LEE 3,252,050

CIRCUIT INTERRUPTING MEANS FOR A HIGH VOLTAGE DIRECT-CURRENT CIRCUIT WITH MEANS FOR REDUCING THE SEVERITY OF THE RECOVERY VOLTAGE

Filed April 7, 1964

3 Sheets-Sheet 1

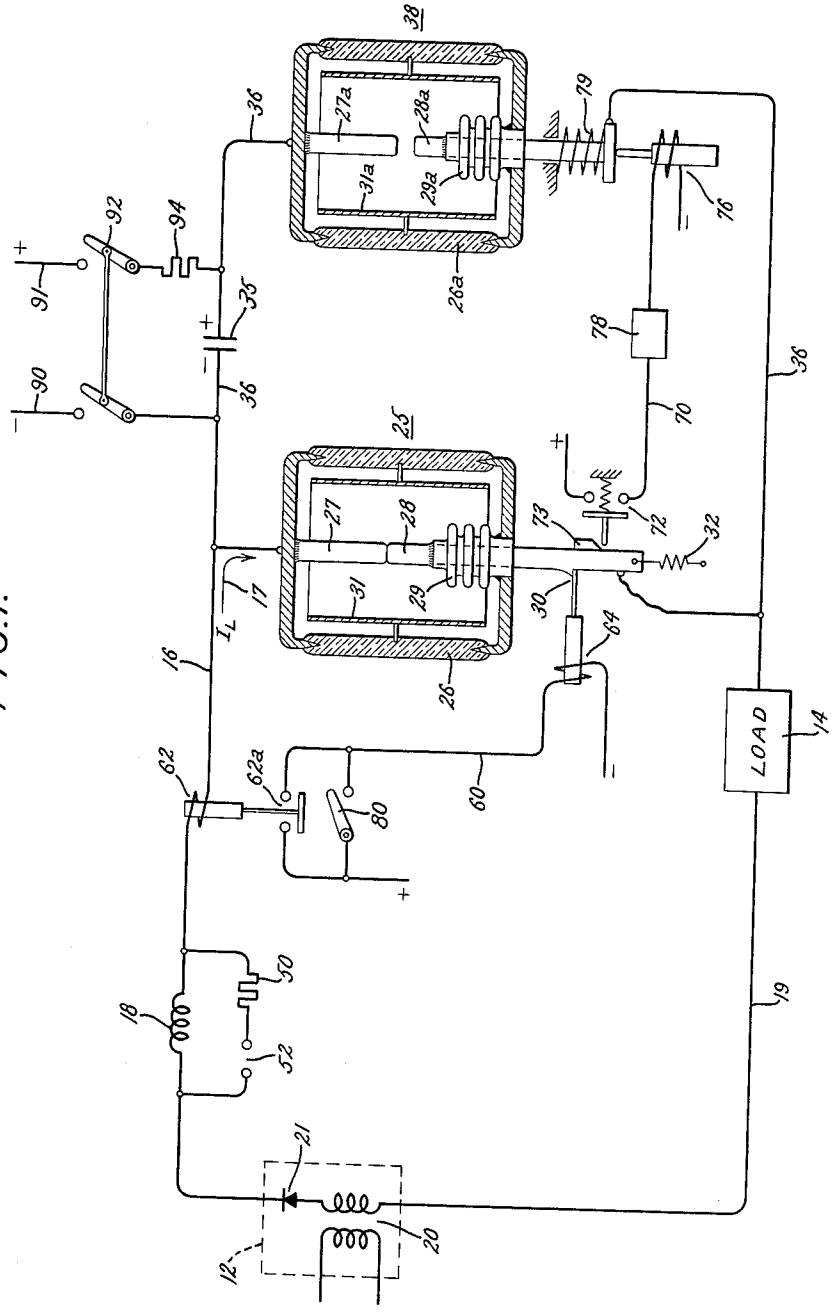



FIG. 1.

INVENTOR:
THOMAS H. LEE,

BY William Freedman
ATTORNEY

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3 Sheets-Sheet 2

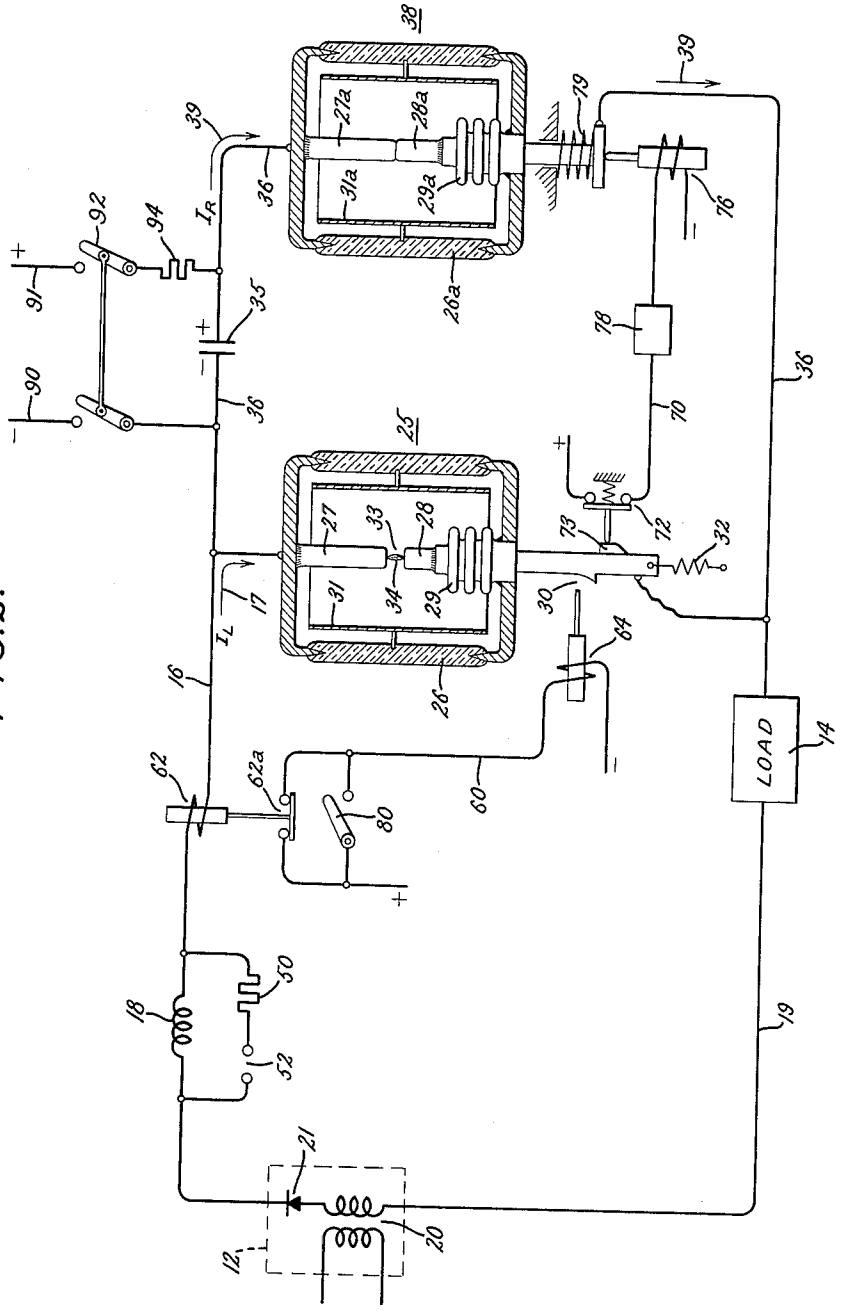



FIG. 2.

INVENTOR:
THOMAS H. LEE,
BY William Freedman
ATTORNEY

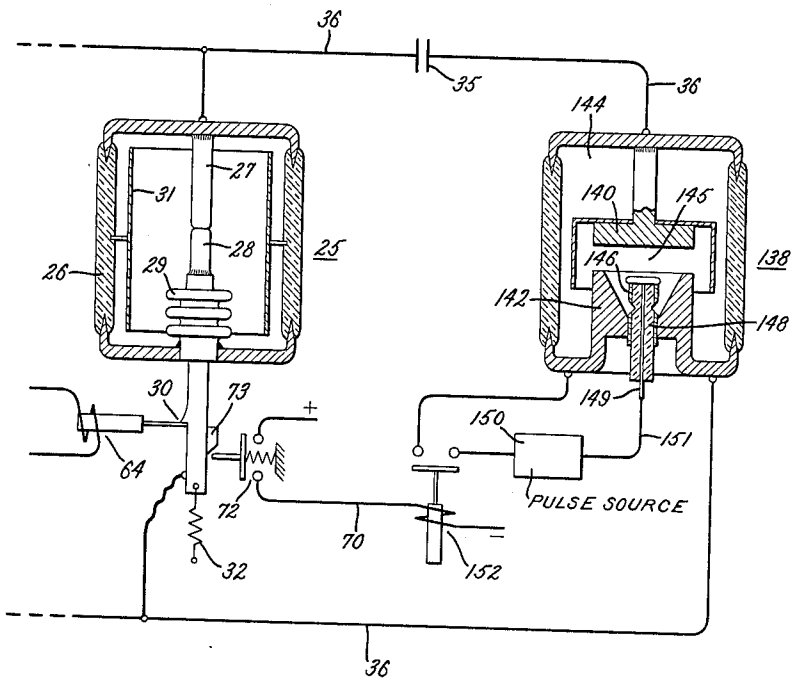
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CIRCUIT INTERRUPTING MEANS FOR A HIGH VOLTAGE DIRECT-CURRENT CIRCUIT WITH MEANS FOR REDUCING THE SEVERITY OF THE RECOVERY VOLTAGE

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3 Sheets-Sheet 3

FIG. 3.




INVENTOR:
THOMAS H. LEE,
BY William Freedman
ATTORNEY

United States Patent Office 3,252,050 Patented May 17, 1966



3,252,050

# CIRCUIT INTERRUPTING MEANS FOR A HIGH VOLTAGE DIRECT-CURRENT CIRCUIT WITH MEANS FOR REDUCING THE SEVERITY OF THE RECOVERY VOLTAGE

Thomas H. Lee, Media, Pa., assignor to General Electric Company, a corporation of New York

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5 Claims. (Cl. 317—11)

This invention relates to means for interrupting a high voltage direct-current circuit and relates, more particularly, to circuit interrupting means of the type in which a current zero is created by forcing a locally-controlled current through a circuit interrupting unit in opposition to the load or fault current.

In the particular circuit interrupting means that I am concerned with, a circuit interrupting unit, hereinafter referred to as an interrupter, is connected in series with a high voltage direct-current line that supplies current through the interrupter to a load. When the circuit is to be interrupted, the normally-closed contacts of the interrupter are separated to establish an arc across the gap developed between the contacts. Connected across this gap is a normally-open quenching circuit that inclues a pre-charged commutating capacitor. When the above-described arc is established across the interrupter gap, the capacitor is discharged through the quenching circuit and the interrupter in a direction in opposition to the load current. This discharge current is higher than the maximum load current being interrupted, and thus the resultant current through the interrupter is quickly forced to zero. By the time the current zero point is reached, the gap between the contacts has attained a substantial length. If this gap is able to withstand the recovery voltage that rapidly builds up thereacross at current zero, then circuit interruption is successfully completed.

The character of the recovery voltage is determined to a large extent by the values of capacitance, inductance and resistance then present in a circuit that extends between the terminals of the D.-C. source through the D.-C. line, the commutating capacitor, and any load remaining in the power line. This circuit is usually an oscillatory circuit that includes the series combination of the system inductance and the commutating capacitance. Oscillation between this inductance and capacitance commences as soon as the current path through the interrupter unit is interrupted, as above described, and this oscillation constitutes a major component of the recovery voltage.

An object of my invention is to reduce the frequency and peak value of the voltage developed by this oscillation, so as to improve the interrupter's chances for successfully withstanding this voltage without breaking down.

One way of attaining this object is to increase the size of the commutating capacitor, but this approach is limited because economic considerations dictate that this capacitor be as small as possible.

Accordingly, another object of my invention is to reduce the frequency and peak value of the voltage developed by this oscillation without increasing the size of the commutating capacitor or without introducing additional costly capacitance in parallel with the commutating capacitor.

In carrying out my invention in one form, I provide a



normally-open damping circuit that is connected across the usual smoothing reactor of the D.-C. system, which reactor constitutes a substantial portion of the system inductance. The damping circuit comprises the series combination of a resistor and a normally-open gap device. The gap device is caused to break down soon after the current through the interrupter is forced to zero, and this effectively closes the damping circuit, thus connecting the resistor across the smoothing reactor. The presence of this resistor materially lowers the frequency and peak value of the recovery voltage appearing across the interrupter gap when the current therethrough is forced to zero, thus materially improving the interrupter's chances for withstanding the recovery voltage.

In accordance with another feature of my invention, I use for the interrupter a vacuum-type circuit interrupter. A circuit interrupter of this particular type can recover its dielectric strength at an extremely high rate when the above-described current zero is produced. As will be explained later, this enables the commutating capacitor to be relatively small, and this in turn enables me to use a resistor in series with the gap device that has a relatively high resistance. With a relatively high resistance in this circuit, the energy dissipation requirements of the gap device can be kept low, and this permits its breakdown voltage to be maintained substantially constant despite repeated arcing experiences.

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

FIG. 1 is a schematic showing of a circuit interrupting arrangement embodying one form of my invention. The circuit interrupting arrangement is shown in its normally-closed position.

FIG. 2 is a schematic showing of the circuit interrupting arrangement of FIG. 1 shown during an interrupting operation.

FIG. 3 is a schematic showing of a circuit interrupting arrangement embodying a modified form of my invention.

Referring now to FIG. 1, there is schematically shown a high voltage D.-C. circuit comprising a source **12**, a load **14**, and a power line **16** for delivering power to the load from the source. It will be assumed that the normal load current flows in the direction indicated by the arrow **17**, returning to the source through a return conductor **19**. The source **12** is schematically depicted as comprising a transformer **20** and a rectifier **21** connected in series with the secondary winding of the transformer. Connected in the power line **16** and in series with the source **12** and the load **14** is the usual smoothing reactor **18** which acts to smooth the current output from the source.

For controlling the flow of current to the load **14**, a circuit interrupter **25** is connected in the power line **16** in series with the load **14** and the smoothing reactor **18**. In a preferred embodiment of my invention, the circuit interrupter **25** is a vacuum-type circuit interrupter. As such, it comprises a highly evacuated envelope **26** partially of insulating material, and a pair of relatively movable contacts **27** and **28** disposed within the evacuated envelope **26**. The upper contact **27** is a stationary contact, and the lower contact **28** is a movable contact that projects through the lower end of the envelope **26**. A suitable bellows **29** sealed at its respective opposite ends to the lower contact **28** and the envelope **26** permits the

lower contacts to move vertically without impairing the vacuum inside the evacuated envelope **26**. The lower contact **28** is releasably held in its closed position of FIG. 1 by a suitable latch **30** and is biased in a downward or opening direction by a suitable opening spring **32**. When the latch **30** is released, the spring **32** drives the movable contact **28** downwardly to produce a gap **33** between the contacts, as shown in FIG. 2. This contact-separation establishes an arc **34** across the gap that is quickly extinguished and prevented from reigniting, thus interrupting the circuit, all in a manner soon to be explained in greater detail. For condensing the metallic vapors generated by the arc and for protecting the insulation of the envelope **26** from these vapors, a suitable metallic shield **31** of tubular configuration is provided inside the envelope. In view of their role in initiating the arc, the latch **30** and opening spring **32** may be thought of as portions of arc-initiating means used for initiating arc **34**.

The vacuum circuit interrupter **25** can be of a suitable conventional type and is therefore shown in schematic form only. Examples of vacuum type circuit interrupters suitable for this application are shown in more detail and are claimed in U.S. Patents 2,949,520, Schneider, and 3,089,936, Smith, both assigned to the assignee of the present invention.

It is considerably more difficult to interrupt direct current than alternating current because direct current contains no naturally-occurring current zeros. With alternating currents, current zeros occur naturally, and to interrupt such currents, it is only necessary to prevent reignition of the arc after a natural current zero. But with direct current, it is necessary first to force the current to zero and then to prevent arc-reignition.

One way of forcing the current to zero is by forcing a locally-controlled current through the interrupter in opposition to the load current flowing therethrough. This is the general approach used in the illustrated interrupting arrangement, where the opposing current is derived from a commutating capacitor **35** that is precharged with the polarity shown in FIG. 1. This commutating capacitor **35** is located in an arc-quenching circuit **36** that is connected across the contacts **27, 28** of the interrupter **25**. The arc-quenching circuit **36** is normally maintained in an open position by means of a normally-open switch **38** connected in series with the commutating capacitor **35**. The illustrated normally-open switch **38** is a vacuum-type circuit interrupter similar in construction to the other interrupter **25**. Accordingly, those parts of the switch **38** that correspond to similar parts of the interrupter **25** have been assigned corresponding reference numerals with the suffix "*a*."

When the normally-open switch **38** is operated from its open position shown in FIG. 1 to a closed position shown in FIG. 2, commutating capacitor **35** discharges in the direction of arrows **39** through the quenching circuit **36**, forcing current through the interrupter **25** in a direction opposed to the normal load current therethrough. The opposing current $I_R$ can be expressed as follows:

$$I_R = Vc\sqrt{\frac{C}{L}}\sin\frac{1t}{\sqrt{L'C}}$$

where $V_c$ is the voltage across the capacitor **35** before the switch **38** is closed; C is the capacitance of capacitor **35**, and L' is the inductance in the circuit comprising quenching circuit **36** and the interrupter **25**, and *t* is the time measured from the instant that switch **38** is closed. To interrupt a current $I_L$ flowing through the interrupter **25** in the direction of arrow **17**, it is necessary that the opposing current $I_R$ be considerably higher than the maximum value of $I_L$. Accordingly, with a given size commutating capacitor **35**, the precharge voltage $V_c$ on the capacitor is made high enough to provide an opposing current $I_R$ considerably higher than the maximum value of $I_L$ that it is desired to interrupt.



In a preferred form of my invention, circuit interruption is effected by first separating the contacts **27** and **28** to draw an arc therebetween, as shown in FIG. 2. At a predetermined instant thereafter, the contacts **28***a*, **27***a* of switch **38** are driven into engagement to complete the quenching circuit **36**, as shown in FIG. 2. This forces a reverse current $I_R$ through the quenching circuit in the direction of arrows **39** and through the arc in interrupter **25** in the direction opposed to the load current $I_L$ flowing therethrough. Since $I_R$ is higher than $I_L$, the resultant current flow through the arc is quickly driven to zero, thus extinguishing the arc.

Interruption is successfully completed, however, only if the gap **33** that is then present between the contacts **27, 28** can successfully withstand the recovery voltage that is quickly built up across the gap when the current zero point is reached. A major component of this recovery voltage results from oscillation between the inductance of smoothing reactor **18** and the capacitance of commutating capacitor **35** that is set up by the sudden interruption of current through the interrupter **25**. In this respect, only a tiny percentage of the energy stored in inductance **18** is dissipated in the above-described arc **34** in the interrupter **25**. Thus, after this arc is extinguished, there is still a large amount of stored energy remaining in the inductance to produce continued current flow, which now takes place through the quenching circuit **36** containing commutating capacitor **35**. This sets up an oscillation, and such oscillation transfers energy back and forth between the inductance **18** and the capacitor **35**.

The transfer of energy from the inductance **18** to the capacitor **35** will create a component of voltage across the capacitor, and hence across the inter-contact gap **33**, that varies as a function of

$$I\sqrt{\frac{L}{C}}$$

where I is the current in the inductance **18** when the arc is extinguished and L is the inductance and C the capacitance of a circuit that extends through reactor **18**, power line **16**, quenching circuit **36**, any part of the load **14** that is still present, and the return conductor **19**. By connecting a resistor across the inductance **18** during this interval, I can very substantially reduce the peak value and frequency of this voltage. Such a resistor is shown at **50** connected in series with a gap device **52**. The series combination of resistor **50** and gap device **52** forms a damping circuit that is connected across the terminals of the smoothing reactor **18**. Under normal conditions, the gap device **52**, being non-conducting, maintains the damping circuit **50, 52** open and thus prevents current from flowing through the resistor **50**. But when the gap device **52** breaks down, the resistor **50** is connected across the smoothing reactor **18**, thus substantially reducing the peak value and frequency of the voltage appearing across the capacitor and interrupter **25** as a result of this oscillation. By reducing the peak value and frequency of this voltage that results from this oscillation, the likelihood that the system insulation and the inter-contact gap **33** will be able to successfully withstand the recovery voltage is appreciably increased. The gap device **52** is set to break down when the voltage thereacross reaches a predetermined value which corresponds to a voltage between lines **16** and **19** of 150 to 250% of normal system voltage.

In a preferred form of my invention, the resistance of resistor **50** in ohms is between

$$\tfrac{1}{2}\sqrt{\frac{L}{C}} \text{ and } 2\sqrt{\frac{L}{C}}$$

where L is the inductance of smoothing reactor **18** in henries and C is the capacitance of capacitor **35** in farads.

Other ways of reducing the frequency and peak value of the voltage resulting from the above-described oscillation are to increase the size of capacitor **35** or to connect an additional capacitor or a resistor-capacitor combination in parallel with the capacitor **35**. But for high voltage applications none of these approaches is very desirable, since they would greatly increase the cost of the interrupting arrangement in view of the large amount of expensive capacitance required. A special advantage of my interrupting arrangement is that it enables me to reduce the frequency and peak amplitude of the voltage resulting from this oscillation without necessitating either of these expensive additions to the capacitance **35**.

In addition to the component of recovery voltage represented by the above-described oscillation there is another component that develops when current ceases flowing through the interrupter **25**. This additional component results from the action of the system voltage, i.e., the voltage across source **12**, in charging the commutating capacitor **35** when current ceases flowing through interrupter **25**. This charging action takes place through the circuit **16**, **36**, **19** and tends to reverse the polarity of the commutating capacitor **35** from that shown in FIG. 1. Ultimately the capacitor **35** will be charged to the system voltage and there will then be no more current flowing from the power line **16** into the quenching circuit **36**. When this occurs, the switch **38** is suitably returned from its closed position of FIG. 2 to its open circuit position of FIG. 1. Since no current is then flowing through the quenching circuit **36**, no arcing occurs between contacts **27***a*, **28***a* when they are then separated.

During this charging of the capacitor **35** by the system voltage, the resistor **50** is effectively connected in series with the line **16** inasmuch as the gap device **52** is then conducting. The presence of this resistor introduces considerable damping into the charging circuit and thus limits the overshoot in voltage across capacitor **35** resulting from this charging action. Since this voltage across capacitor **35** corresponds to the recovery voltage appearing across interrupter **25**, it will be apparent that the resistor **50** has also lessened the severity of the voltage that this latter component imposes upon the gap **33** of the interrupter **25** and upon the system insulation.

When the capacitor **35** has been charged to line voltage as above described, there is no longer any current flow through the power line **16**. This being the case, the arc at gap device **52** is extinguished, and the resistor **50** is thus effectively removed from the power line **16**.

A vacuum-type circuit interrupter is the ideal type of interrupter for use as the main interrupter element in this general type of interrupting arrangement. In this respect, it is quiet and simple, has long contact life, and is able to interrupt consistently at the first current zero. Moreover, the contact gap required by a vacuum-type interrupter for a given voltage is exceptionally small, thus permitting shorter operating times and a simpler operating mechanism. But perhaps the greatest advantage of the vacuum-type interrupter is its extremely rapid recovery of dielectric strength following a rapid decrease of current prior to current zero (such as occurs when the reverse current drives the load current to zero, as above described). As an example of this extremely rapid recovery of dielectric strength, a single-break vacuum interrupter of the type disclosed herein has been found capable of withstanding recovery voltages up to 20 kv. at a rate of 3300 volts per microsecond following a rapid decrease of current prior to current zero (for example, a decrease at a rate of 190 amperes per microsecond).

The higher is the rate of dielectric recovery following this current zero, the higher is the permissible rate of rise of the recovery voltage and, hence, the smaller may be the capacitor **35** inasmuch as the rate of rise of the recovery voltage varies inversely with the size of the capacitor. Not only is it advantageous from the viewpoint of reducing the capacitor cost to make the capacitor as small as possible, but also it is highly advantageous from the viewpoint of providing a gap device **52** capable of consistently performing in the desired manner. In this latter respect the smaller the capacitor **35**, the higher may be the resistance of resistor **50** since the resistance has to be kept small compared to the



$$\sqrt{\frac{L}{C}}$$

where L is the inductance and C is the capacitance of circuit **16**, **36**, **19**. By using a relatively high resistance for resistor **50**, a relatively large percentage of the total energy stored in the inductance **18** that is dissipated in the damping circuit **50**, **52** is dissipated in the resistor **50** instead of in the gap device **52**. By limiting the energy dissipation in the gap device **52**, the rate at which its electrodes are consumed by arcing is held to a relatively low value and hence its breakdown voltage can be held relatively constant despite repeated arcing experiences. It will therefore be apparent that I utilize the extremely high dielectric recovery rate of a vacuum-type interrupter to reduce the energy dissipation requirements of the gap device **52**, thus preserving its dielectric breakdown properties despite repeated arcing experiences.

A problem that arises from reducing the size of the commutating capacitor **35** is that the rate of decrease of the current just prior to current zero becomes higher as the capacitor is made smaller. The higher this rate of decrease, the more difficult it is for an interrupting device to withstand the recovery voltage transient. But, as pointed out hereinabove, a vacuum-type interrupter has an exceptional ability to recover its dielectric strength despite a high rate of current decrease prior to current zero. For this additional reason, then, the use of a vacuum-type interrupter permits a relatively small commutating capacitor **35** as compared to that neeeded with other types of interrupters.

Although I have shown a single break vacuum interrupter being used as the main interrupting element **25**, it is to be understood that for high voltage applications, a number of these units must be connected in series to withstand the high voltages involved. My invention therefore comprehends an arrangement in which the main interrupter comprises a plurality of interrupting units connected in series for substantially simultaneous opening and for substantially simultaneous closing.

The control circuits for operating the two interrupters **25** and **28** in the desired sequence may be of any suitable conventional type and I have therefore shown them in a highly simplified schematic form. Referring to FIG. 1, the control circuit for the latch **30** of interrupter **25** comprises a conductor **60** extending from the positive to the negative terminals of a control voltage source through the normally-open contacts **62***a* of an overcurrent-responsive relay **62** and the coil of a tripping solenoid **64**, which controls the latch **30**. When the current in line **16** exceeds a predetermined value, the relay **62** picks up, closing its contacts **62***a* to complete an energizing circuit for the solenoid **64**. The solenoid **64** responds by tripping the latch **30** to cause opening of the interrupter **25**.

When the movable contact **28** of the interrupter **25** has reached a predetermined point in its opening stroke, it completes a control circuit **70** that causes the closing switch **38** to be operated to closed position. This control circuit **70** comprises a normally-open switch **72** which is closed by a cam on the movable contact **28** when the movable contact reaches a predetermined point in its opening stroke. This completes an energizing circuit for a closing solenoid **76**, which responds by operating the closing switch **38** to its closed position. After a predetermined period of time sufficient to enable the current in quenching circuit **36** to be brought to zero, as above described, a suitable time delay switch **78** opens the con-

trol circuit **70**, thus deenergizing solenoid **76** and permitting a spring **79** to open the closing switch **38**. Since the control circuit **70** and the cam **73** acted during the above-described sequence to produce closing of the vacuum switch **38** in response to opening of the interrupter **25**, these components **70**, **73** may be thought of as means responsive to operation of arc-initiating means **30**, **32** for closing the vacuum switch **38** upon initiation of arc **34**.

This same sequence can be initiated at will instead of in response to an in response to an overcurrent simply by manually closing a switch **80** in parallel with the normally-open contacts of the overcurrent-responsive relay **62**. This completes the trip circuit **60** to initiate the same sequence of operations as described above.

The precharging circuit for the commutating capacitor **35** may be of any suitable conventional form. It is schematically shown in the drawing as comprising a source having opposed terminals **90** and **91** and a switch **92** that can be closed to connect the commutating capacitor across the terminals **90** and **91**. Upon closing of the switch **92**, the capacitor is charged through a current limiting resistor **94** to a voltage that will be determined by the voltage of the source **90**, **91** and with the polarity shown in FIG. 1.

In the embodiments of FIGS. 1 and 2, I use a movable electrode device **38** as the circuit closing means for the quenching circuit **36**. Another way of closing this quenching circuit **36** at the desired instant is shown in FIG. 3, where a triggered vacuum gap device **138** is used instead of the switch **38** of FIGS. 1 and 2. This triggered vacuum gap device is preferably of the design disclosed and claimed in Patent No. 3,087,092, Lafferty, assigned to the assignee of the present invention. As such, it comprises a pair of spaced apart main electrodes **140** and **142** disposed in a highly evacuated chamber **144** and defining a main gap **145** therebetween. Disposed adjacent the main electrode **142** is a trigger electrode **146** defined by a hydrogen-impregnated titanium film on a ceramic supporting rod **148**. This ceramic supporting rod **148** is disposed coaxially of the main electrode **142** and is suitably sealed to the main electrode **142** about its outer periphery. A portion of the ceramic supporting rod **148** is uncoated and defines a trigger gap along this uncoated surface that electrically isolates the trigger electrode **146** from the main electrode **142** under normal conditions. A conductive connection **149** extends through the ceramic rod **148** and across its upper end surface to the trigger electrode **146**.

When an electric pulse is applied between the trigger electrode **146** and the main electrode **142**, the trigger gap breaks down and the resultant spark liberates a small quantity of hydrogen from the hydrogen-impregnated trigger electrode **146**. This hydrogen is quickly ionized and projected into the main gap **145**, thus lowering its dielectric strength and initiating a breakdown of the main gap. When the main gap **145** thus breaks down, the commutating capacitor **35** can discharge through the quenching circuit **36** in the manner described hereinabove to force the current through the main interrupting device **25** to zero.

When the current in the quenching circuit **36** finally reaches zero, as above described, a high dielectric strength is automatically reestablished across the main gap **145** of the triggered gap device, and the gap device **138** is thus restored to its original condition. Because the main gap **145** is a vacuum gap, it has a high dielectric strength capable of withstanding the transient recovery voltage appearing across it when the current through the quenching circuit **36** reaches zero.

The above described pulse across the trigger gap is derived from any suitable conventional pulse source such as schematically shown at **150** connected in a pulse circuit **149**, **151** that extends between the trigger electrode and the main electrode. This pulse source **150** is rendered operative by a suitable switching device **152** which operates to complete the pulse circuit **149**, **151** in response to completion of control circuit **70** when the movable contact **28** of the main interrupter **25** reaches a predetermined point in its opening stroke. The control circuit **70** is completed by the components **72** and **73** in the same general manner as disclosed hereinabove with respect to FIG. 1.

An advantage of using the triggered vacuum gap device of FIG. 3 instead of the switch **38** of FIGS. 1 and 2 is that the gap device can close the quenching circuit **36** at a more precisely controlled instant since there are no large moving parts to be operated as a prior condition to such circuit-closing. Another advantage is that the vacuum gap device automatically reopens the quenching circuit **36** after an interrupting operation and automatically reestablishes a high dielectric strength gap in this circuit. There is thus no need to provide any controls for returning electrodes to a separated position, as there is with the arrangement of FIGS. 1 and 2 when it is to be reset to its original condition.

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.** Means for interrupting a high voltage D.-C. circuit that comprises a smoothing reactor connected in series with a load across a source of direct current, comprising:

(a) a circuit interrupter adapted to be electrically located between said reactor and said load and comprising relatively movable contacts for connection in series wtih said reactor and said load,

(b) means for normally maintaining said contacts in engagement to enable load current to flow therethrough,

(c) arc-initiating means for separating said contacts to draw an arc therebetween,

(d) a normally-open arc-quenching circuit connected across said contacts and comprising normally-open circuit-making means and a commutating capacitor connected in series circuit relationship with each other,

(e) means for precharging said commutating capacitor,

(f) means for forcing the current through said arc to zero comprising means responsive to operation of said arc-initiating for closing said circuit-making means upon initiating of said arc to discharge said commutating capacitor through said quenching circuit and through said arc in a direction opposite to the direction of load current therethrough,

(g) and means for limiting the magnitude and frequency of the recovery voltage appearing across said circuit interrupter when the current therethrough is forced to zero comprising the series combination of a normally-open gap device and a resistor connected across said smoothing reactor, and means for causing said gap device to break down and effectively connect said resistor across said reactor immediately after the current through said interrupter reaches zero.

**2.** The circuit interrupting arrangement of claim **1** in which said gap device is broken down by the voltage developed thereacross by said recovery voltage.

**3.** The circuit interrupting arrangement of claim **1** in which said circuit interrupter comprises a vacuum-type circuit interrupting unit.

**4.** The circuit interrupting arrangement of claim **1** in which said resistor has a resistance in ohms between

$$\tfrac{1}{2}\sqrt{\frac{L}{C}} \text{ and } 2\sqrt{\frac{L}{C}}$$

where L is the inductance of said smoothing reactor in

henries and C is the capacitance of said commutating capacitor in farads.

5. The circuit interrupting arrangement of claim 1 in which said circuit-making means comprises a triggered vacuum gap device that includes a trigger gap, said means for closing said circuit-making means comprising means for sparking over said trigger gap to render said vacuum gap device conductive.




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SAMUEL BERNSTEIN, *Primary Examiner.*

R. V. LUPO, *Assistant Examiner.*