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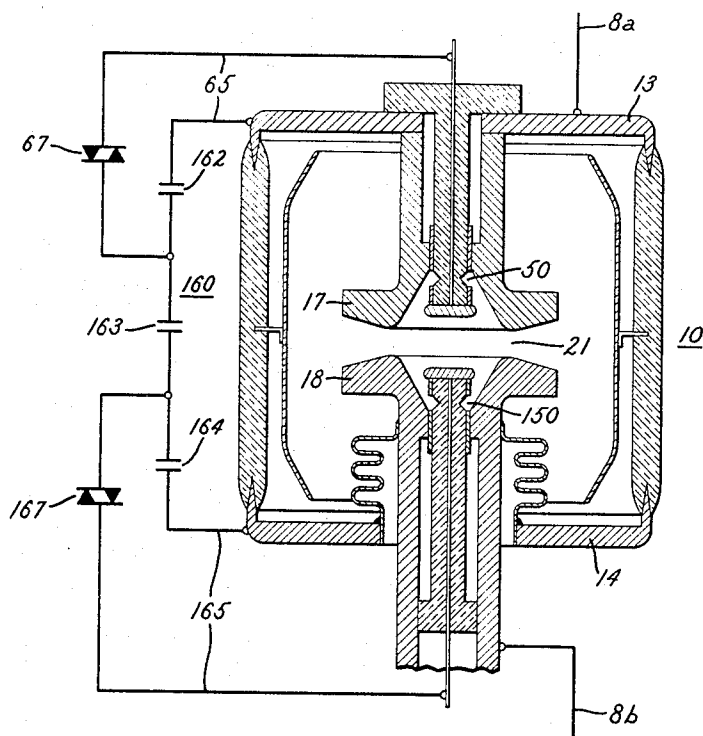
3,411,038

VACUUM-TYPE CIRCUIT INTERRUPTER

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Fig. 3.



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VACUUM-TYPE CIRCUIT INTERRUPTER
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This invention relates to an electric circuit interrupter of the vacuum type and, more particularly, relates to means for reducing the severity of any switching overvoltages developed by an operation of the interrupter.

In most circuit breakers, circuit interruption is effected by separating a pair of relatively movable contacts to draw an electric arc. Assuming the circuit is an alternating-current circuit, this arc will persist until about the time of the first natural current zero, at which point the arc vanishes. Immediately thereafter a recovery voltage appears across the gap between the contacts. If dielectric strength can be built up across the gap at a faster rate than the rate of recovery voltage buildup, then the interruption is successfully completed. But if the interrupter cannot recover its dielectric strength as rapidly as the recovery voltage transient builds up, then the arc is re-ignited and current continues flowing.

Although it is usually desirable to recover dielectric strength as rapidly as possible in order to withstand the recovery voltage transient, there are certain unusual switching conditions where a very rapid dielectric recovery can lead to excessive overvoltages.

An example of such a condition may arise if the circuit interrupter's gap restrikes and clears in a repetitive fashion after having temporarily cleared the power frequency current at a current zero. In the event of a first such restrike, a high frequency current discharges through the gap as a consequence of local oscillations of capacitance and inductance. If the interrupter has a high dielectric recovery rate, it may clear this high frequency current upon its passage through zero, instead of conducting until the next current zero of power frequency current. This early clearance of the high frequency restrike current can result in a relatively high voltage developing across the contacts as the aforementioned local oscillations continue. This voltage can reach even higher levels if this process is immediately repeated, i.e., if the gap should restrike shortly after clearing the high frequency current and then immediately clear the high frequency current that flows following the second restrike. This cumulative voltage build-up that can result from closely-successive restrikes and clearings of the high frequency current is explained in greater detail in a paper entitled, "Effect of Restriking on Recovery Voltage," by Concordia and Skeats, AIEE Transactions, vol. 58, 1939, pages 371-376. In their paper, Concordia and Skeats described the conditions which the inductances and capacitances must satisfy in order for this phenomena to occur. These conditions correspond to unusual circuit configurations and therefore they do not occur very frequently. But when these conditions are satisfied, this voltage build-up phenomena has also been observed in vacuum interrupters when the interrupter opens its contacts just prior to a natural current zero. Since contact-separation has just begun, the gap between the contacts is very short when the recovery voltage transient builds up, and the gap therefore may not be able to withstand this voltage. This would result in a restrike, followed by the flow of a high frequency current. Because of the extremely rapid rate of dielectric recovery that characterizes vacuum interrupters, the vacuum interrupter tends to clear this high frequency current upon its passage through current zero, thus setting the stage for possible additional restrikes and

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clearings, which are accompanied by increasing voltage build-up. This voltage build-up phenomena that can result from parting contact just prior to current will be referred to hereinafter as the "short arc angle" phenomena.

5 An object of the present invention is to prevent excessive overvoltages from being developed by a vacuum interrupter as a result of its high rate of dielectric recovery and its high dielectric strength characteristics.

Another object is to provide simple and inexpensive means for controlling the voltage withstandability of a vacuum interrupter.

10 Another object is to prevent excessive overvoltages from being developed by repetitive restrikes and clearings during a circuit interrupting operation.

15 Another object is to provide for a triggered vacuum interrupting device a simple triggering circuit that is able to consistently operate in response to a precise value of voltage despite repeated operations thereof.

In carrying out the invention in one form I provide a vacuum type circuit interrupter for alternating current circuits comprising a highly evacuated envelope and a pair of contacts within said envelope relatively movable from a position of engagement to a disengaged position to establish a primary gap therebetween. I also provide triggering means including a trigger gap within said envelope for initiating an arc-over of said primary gap in response to sparkover of said trigger gap. Means responsive to the voltage appearing across said primary gap is provided for producing a spark-over of said trigger gap when the voltage across the primary gap reaches a predetermined value of between 2 and 3.5 times normal line-to-ground peak voltage.

In a preferred form of the invention, the voltage responsive means comprises (1) a voltage divider connected across the primary gap and comprising series-connected capacitors, and (2) a trigger circuit comprising a bidirectional diode thyristor having a resistance that changes from a very high value to a very low value when the voltage applied thereto reaches a predetermined avalanche value, (3) means for connecting said trigger circuit across one of said capacitors whereby a predetermined percentage of the voltage across said primary gap is applied to said trigger circuit, and (4) means for applying a voltage pulse to said trigger gap in response to said thyristor switching to its low resistance state.

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 sectional view, partially schematic, of a vacuum-type circuit interrupter embodying one form of the invention. The interrupter of FIG. 1 is shown in its closed position.

FIG. 2 is a sectional view of the interrupter of FIG. 1 where the interrupter is shown in its open position.

FIG. 3 is a schematic illustration of a modified form of the invention.

Referring now to FIG. 1, there is shown a vacuum-type circuit interrupter 10 that comprises a sealed envelope 11 evacuated to a pressure of 10^{-4} mm. of mercury or lower. The envelope 11 comprises a casing 12 of suitable insulating material and a pair of metallic end caps 13 and 14 joined in vacuum-tight relationship to the respective opposite ends of the casing by suitable seals 15.

Located within the evacuated envelope 11 are a pair of relatively movable contacts 17 and 18 that are normally maintained in the engaged, or closed-circuit, position shown in FIG. 1. The upper contact 17 is a stationary contact or electrode that is joined to the lower end of a tubular conductive supporting rod 17a having its upper end joined to the upper end cap 13. The lower contact 18 is a movable contact that is joined to the upper end of a movable conductive contact rod 18a. This contact rod 18a projects

freely through an opening in the lower end cap 14, and a flexible metallic bellows 20 is provided about the contact rod 18a to permit vertical movement thereof without impairing the vacuum inside envelope 11. This bellows 20 is secured by suitable seals at its respective opposite ends to the operating rod 18a and the end cap 14.

The interrupter 10 is used for controlling the flow of current through a power circuit comprising conductors 8a and 8b. Conductor 8a is electrically connected to the upper end cap 13 and conductor 8b is electrically connected to the contact rod 18a. When the circuit interrupter is closed, current flows between conductors 8a and 8b through the interrupter.

An opening spring 24 external to envelope 11 is provided for urging movable contact 18 downwardly toward an open position (shown in FIG. 2) where it is spaced from the stationary contact 17 by a primary gap 21. The movable contact 18 is, however, normally maintained in its engaged position of FIG. 1 against the bias of opening spring 24 by suitable holding means, shown as a trip latch 26. The illustrated trip latch 26 comprises a tripping solenoid 27 which is connected in a tripping circuit 28. When tripping circuit 28 is completed, the tripping solenoid 27 responds by releasing the trip latch 26 and allowing the opening spring 24 to drive contact 18 downwardly through an opening stroke.

For opening the interrupter in response to an overcurrent through power circuit 8a, 8b, I provide a current transformer which comprises a secondary winding 29 inductively coupled to conductor 8b. Connected across winding 29 is the coil of an overcurrent relay 30. When the current through power circuit 8a, 8b exceeds a predetermined value, the relay 30 picks up to close its contacts 30a and complete the tripping circuit 28 to initiate an opening operation of interrupter 10.

The interrupter 10 may also be opened at will by a manually controlled switch 32 connected in parallel with contacts 30a of the overcurrent relay. When switch 32 is operated to closed position, the tripping circuit 28 is completed, thereby initiating an opening operation of interrupter 10.

When contact 18 moves out of engagement with contact 17 during an opening operation, an arc is established between the contacts across the primary gap 21. This arc vaporizes some of the contact material to form a plasma through which the arcing current flows. The arc persists until about the time of the natural current zero, at which time it disappears. The vacuum rapidly recovers its dielectric strength following disappearance of the arc. If this dielectric strength can be recovered at a higher rate than the rate at which the usual recovery voltage transient builds up across the gap 21, then interruption is completed. If not, the arc reignites, and the same process is repeated at successive current zeros until the gap is capable of withstanding the recovery voltage transient.

During the above-described interrupting operation, the metallic vapors that are produced by the arc are condensed on the cool surfaces of the interrupter. For providing a vapor condensing surface for this purpose, a tubular metallic shield 35 is provided about the gap 21. This shield is preferably electrically isolated from both contacts.

Although it is usually desirable to recover dielectric strength as rapidly as possible in order to withstand the recovery voltage transient, certain unusual switching conditions may occur where a very rapid dielectric recovery can lead to excessive overvoltages. One such switching condition is the "short arc angle" switching condition referred to in the introductory portion of this specification. As was there pointed out, if a restrike should occur across the short vacuum gap present at the first current zero, the vacuum interrupter, because of its high rate of dielectric recovery will tend to clear the resultant high frequency current on its first passage through current zero. This can produce a high voltage which will build up to an even

higher level in the event of repeated restrikes and clearings.

To prevent such overvoltages from developing, I incorporate a trigger gap 50 within the vacuum interrupter 10. This trigger gap 50 is preferably constructed in substantially the same manner as disclosed and claimed in U.S. Patents 3,087,092—Lafferty, assigned to the assignee of the present invention. Accordingly, it comprises a cylindrical ceramic support 52 located within a recess 51 near the stationary contact structure 17, 17a. Two thin layers 54 and 56 of metal are bonded to the external surface of the ceramic support in spaced apart relationship along its length. These two layers 54 and 56 constitute the electrodes of the trigger gap. They are separated by a V-shaped groove 57 that extends about the circumference of the ceramic support and has its walls defined by the ceramic material itself. One of the trigger electrodes 54 is electrically connected to the main electrode 17. The other trigger electrode 56 is normally electrically isolated from the electrode 17.

These layers 54 and 56 are formed of a metal such as titanium, which is a good getter for active gases such as hydrogen and which is capable of absorbing a large quantity thereof. In a preferred form of the invention, each of the two layers of titanium is charged with a large quantity of hydrogen in the manner explained in the aforementioned Lafferty patent. As is well known, the lines of electrical field distribution at the interface between a metal and a ceramic body in intimate contact are highly favorable to a breakdown at such an interface. Accordingly, a relatively low voltage applied across the trigger gap can initiate a spark-over from one of these interfaces across the trigger gap.

When the trigger gap 50 sparks over, the resultant arc at the trigger gap liberates hydrogen gas from the trigger electrodes 54 and 56. This hydrogen gas is ionized by the arc and the ionized hydrogen is rapidly injected into the main gap 21, thus drastically reducing its dielectric strength causing it to breakdown in response to the voltage then prevailing between the main electrodes 17 and 18.

For enabling a voltage to be applied across the trigger gap 50, a conductive lead is provided extended through a passageway in ceramic support 52. At its inner end, this lead 58 is brazed to a metal cap 59 which is in electrical contact with the trigger electrode 56. Metal cap 59 is hermetically sealed to the inner end of ceramic support 52 by a conventional ceramic-to-metal seal so as to maintain the hermetic seal of the envelope.

For applying a triggering pulse to trigger gap 50 when the voltage appearing across the primary gap 21 of the interrupter reaches a predetermined value, I connect a voltage divider 60 across the primary gap 21. This voltage divider 60 comprises a plurality of capacitances, represented as capacitors 62 and 63, connected in series. A predetermined percentage of the total voltage appearing across the primary gap 21 will appear across capacitor 62.

The voltage appearing across capacitor 62 I apply to a triggering circuit 65 that is connected across capacitor 62. This triggering circuit 65 comprises the series combination of the trigger gap 50 and a bidirectional diode thyristor 67. The bidirectional diode thyristor, sometimes referred to as a Diac or a bilateral diode switch, is a semiconductor switch having a resistance that can be changed from a very high value to a very low value by raising the voltage applied thereacross to a predetermined avalanche value. Irrespective of its polarity, when the applied voltage reaches a predetermined avalanche value, the bilateral diode thyristor switches to its low resistance state. The bidirectional diode thyristor is characterized by a breakdown voltage that remains substantially constant despite repeated breakdowns. This thyristor is described in detail on pages 139-141 of the book Semiconductor Controlled Rectifiers by Gentry et al., Prentice-Hall, Inc., 1964.

Usually when the interrupter 10 is open, the voltage appearing across the capacitor 62 is not sufficiently high

to produce a breakdown of bidirectional thyristor 67. But if the voltage across the interrupter should exceed a predetermined value, the bidirectional thyristor 67 will abruptly switch to its low resistance state, and this will result in the sudden application of substantially the entire capacitor 62 voltage across the trigger gap 50. The trigger gap 50 will spark over in response to application of this voltage pulse, whereupon the capacitor 62 will discharge through the trigger gap to supply the current for triggering the interrupter 10.

The level of total voltage across the primary gap 21 at which the bidirectional thyristor 67 will break down is determined by the relative values of capacitances 62 and 63. By changing capacitance 62 relative to capacitance 63, I can change the amount of total voltage required to cause breakdown of thyristor 67 and resultant spark-over of trigger gap 50. In some cases, it may be desirable to add high ohmic resistors in parallel with each capacitor 62, 63; and in such cases, the total voltage for triggering can also be changed by adjusting the resistances of these resistors. Such resistors are shown in dotted line form in FIG. 1 at 68 and 69.

For a triggered vacuum device, such as 10, a relatively high triggering current is required in order to consistently fire the vacuum device upon sparkover of the trigger gap. My triggering circuit 65 is able to provide this high triggering current even though the capacitor 62 is relatively small, because the resistance of the bidirectional diode thyristor 67 is extremely low following its breakdown. Thus, when the trigger gap 50 sparks over immediately after breakdown of the bidirectional diode thyristor 67, a high current can flow through the triggering circuit 67 limited only by the small inductance in the loop comprising the capacitor, the bidirectional diode thyristor and the trigger.

Since the bidirectional diode thyristor 67 has symmetrical characteristics, it performs in substantially the same manner irrespective of the polarity of the voltage appearing across capacitor 62. Thus, the bidirectional thyristor 67 will break down at the same total voltage across the interrupter irrespective of the polarity of this voltage; and upon breakdown in response to voltage of either polarity, will immediately switch from its high resistance state to its low resistance state to permit the desired high triggering current to flow through the trigger gap 50.

Assume now that a power circuit is being interrupted by the vacuum interrupter 10 and that a voltage build-up takes place across the contacts 17 and 18 as a result of the "short arc angle" phenomena described hereinabove. Under the worst conditions of repetitive restrikes and clearings, the voltage across the interrupter can approach voltages of five times peak system voltage and even higher. This is a completely intolerable voltage for most systems.

For preventing such overvoltages from developing, I cause the trigger gap 50 to sparkover when the voltage across the interrupter reaches a preset value of between 2.0 and 3.5 times the normal line-to-ground peak voltage. Thus, if a first restrike followed by immediate clearance of the resulting high frequency current occurs during an interrupting operation and the voltage across the primary gap thereafter rises toward a high value, trigger gap 50 will spark over at its preset value to produce an arc-over of the primary gap 21. This arc-over of primary gap 21 allows the capacitance of the load (not shown) being switched to discharge through the interrupter before the voltage thereon can reach a value that could lead to the above-described excessive overvoltages.

I wish to avoid initiating a first restrike with the trigger gap 50 because the interrupter 10 can usually interrupt the circuit without allowing such a first restrike. By setting the trigger circuit-operating voltage at about twice normal line-to-ground peak voltage or higher, I can prevent the trigger gap 50 from initiating the first re-

strike since the peak high frequency voltage usually available to produce a first restrike will be slightly less than twice normal line-to-ground peak voltage. Thus, despite the presence of the trigger gap 50, the interrupter 10 is given an opportunity to interrupt the circuit without producing a restrike. Generally speaking, only when a first restrike has occurred do I rely on the trigger gap 50 to prevent excessive voltages from developing during the interrupting operation.

As explained in U.S. Patent 2,391,672—Boehne et al., a capacitance switching operation is another type of switching operation that can produce repetitive restrikes and clearances which can lead to excessive voltages. My trigger gap 50 and its control can also be used during capacitance switching to prevent such overvoltages from developing should a restrike occur. The interrupter that performs such switching operations is connected in a predominantly capacitive circuit between a source and a capacitive load (not shown). The trigger gap 50, being set to spark over only when at least twice normal line-to-ground peak voltage appears across the interrupter, does not initiate a first restrike. But if a first restrike should occur and higher voltages should develop as a result of such first restrike and immediate clearance of the resulting high frequency current, then the trigger gap will be sparked over to produce an arc-over of the primary gap 21. This arc-over of the primary gap 21 allows the capacitance being switched to discharge through the interrupter, thereby preventing a charge from being trapped on the capacitance, thus preventing the resultant development of excessive overvoltages similar to those previously referred to.

Still another type of switching situation in which the trigger gap 50 will be called upon to initiate an arc-over of the primary gap 21 is when the interrupter 10 chops an excessive amount of current. Chopping is the premature and abrupt cut-off of current just before current zero. If such chopping occurs at a relatively high value of instantaneous current, a relatively high overvoltage may be generated across an interrupting device. My trigger arrangement will prevent such overvoltages from developing since, in response to a severe chop, the trigger arrangement will reestablish arcing across the primary gap 21, permitting it to continue to a lower value of instantaneous current.

A basic function of the interrupter 10 is to interrupt inductive circuits. Typically the maximum recovery voltage developed when interrupting such circuits is slightly less than twice normal line-to-ground peak voltage. I set the operating level of my triggering means sufficiently high that it will not produce a sparkover of the trigger gap 50 in response to such transients.

In certain alternating current applications it is desirable to provide a vacuum interrupter with a separate trigger gap adjacent each main electrode in order to assure consistent breakdown of the primary gap in response to sparkover of the trigger gap. This provides assurance that a triggering arc will be established adjacent the primary electrode that is the cathode irrespective of the then-existing polarity of the voltage across the primary gap. The interrupter of FIG. 3 is substantially the same as the interrupter of FIG. 1 except that an additional trigger gap 150 has been added to the interrupter adjacent its lower electrode. This trigger gap 150 is of essentially the same construction as the trigger gap 50 adjacent the upper electrode.

A voltage divider 160 comprising series-connected capacitors 162, 163, and 164 is shown connected across interrupter 10. Across the upper capacitor 162, a trigger circuit 65, corresponding to trigger circuit 65 of FIG. 1, is connected. This trigger circuit includes the series combination of bidirectional diode thyristor 67 and the trigger gap 50. Across the lower capacitor 164 is connected a similar trigger circuit 165 comprising the series combina-

tion of bidirectional diode thyristor 167 and the trigger gap 150.

In a preferred form of the invention, capacitors 162 and 163 are of the same size and the bidirectional thyristors have substantially the same avalanche or breakdown voltage. When a voltage surge of a predetermined value appears across the primary gap 21, sufficient voltage appears across the two capacitors 162 and 164 and hence across the thyristors 67 and 167 to cause their breakdown. This produces immediate spark-over of the trigger gaps 50 and 150, which initiates an arc-over of primary gap 21 in the same manner as described in connection with FIG. 1.

In the embodiment of FIG. 3, the values of the voltage dividing capacitors 162, 163, and 164 are so selected that triggering of the interrupter 10 occurs at the same total voltage across the interrupter as in the embodiment of FIG. 1, i.e., at 2 to 3.5 times normal line-to-ground peak voltage.

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 vacuum-type circuit interrupter for alternating current circuits comprising:

- (a) a highly evacuated envelope having a normal pressure of 10^{-4} mm. of mercury or less,
- (b) a pair of electrodes within said envelope having a spaced-apart position defining a primary gap therebetween,
- (c) triggering means including a trigger gap within said envelope for initiating an arc-over of said primary gap in response to spark-over of said trigger gap,
- (d) means for producing a spark-over of said trigger gap when the voltage across said primary gap reaches a predetermined value, comprising:
 - (i) a voltage divider connected across said primary gap and comprising series-connected capacitors,
 - (ii) a trigger circuit comprising a bidirectional diode thyristor having a resistance that changes from a very high value to a very low value when the voltage applied thereto reaches a predetermined avalanche value,
 - (iii) means for connecting said trigger circuit across one of said capacitors, whereby a predetermined percentage of the voltage appearing across said primary gap is applied to said trigger circuit,
 - (iv) and means for applying a voltage pulse to said trigger gap in response to said thyristor switching to its low resistance state.

2. The circuit interrupter of claim 1 in which said bidirectional thyristor and said trigger gap are connected in series in said trigger circuit.

3. The vacuum-type circuit interrupter of claim 1 in which said electrodes are contacts relatively movable from a position of engagement to a position of disengagement to form said primary gap.

4. A vacuum-type circuit interrupter for performing capacitance-switching operations that involve interrupting the current flowing in a predominantly capacitive circuit between a source and a capacitive load, said vacuum-type circuit interrupter comprising:

- (a) a highly evacuated envelope having a normal pressure of 10^{-4} mm. of mercury or less,
- (b) a pair of relatively movable contacts located within said evacuated envelope and having an engaged position in which they are adapted to carry current between said source and said load,
- (c) one of said contacts being movable from said engaged position to a position of disengagement to form a primary gap between said contacts,

(d) triggering means including a trigger gap within said envelope for initiating an arc-over of said primary gap in response to a spark-over of said trigger gap,

(e) and control means responsive to the voltage appearing across said primary gap for producing a spark-over of said trigger gap following a first restrike during a capacitance-switching operation,

(f) and means for rendering said control means ineffective to initiate said first restrike.

5. A vacuum-type circuit interrupter for performing capacitance-switching operations that involve interrupting the current flowing in a predominantly capacitive circuit between a source and a capacitive load, said vacuum-type circuit interrupter comprising:

- (a) a highly evacuated envelope having a normal pressure of 10^{-4} mm. of mercury or less,
- (b) a pair of relatively movable contacts located within said evacuated envelope and having an engaged position in which they are adapted to carry current between said source and said load,
- (c) one of said contacts being movable from said engaged position to a position of disengagement to form a primary gap between said contacts,
- (d) triggering means including a trigger gap within said envelope for initiating an arc-over of said primary gap in response to spark-over of said trigger gap,
- (e) and means for producing a spark-over of said trigger gap when the voltage across said primary gap reaches a predetermined value less than 3.5 times normal line-to-ground peak voltage,
- (f) said predetermined value being high enough to prevent a first restrike from being initiated by said triggering means during a capacitance-switching operation.

6. A vacuum-type circuit interrupter comprising:

- (a) a highly-evacuated envelope having a normal pressure of 10^{-4} mm. of mercury or less,
- (b) a first contact within said envelope,
- (c) a second contact within said envelope that is movable from a position of engagement with said first contact to a position of disengagement to form a primary gap between said contacts,
- (d) triggering means including a trigger gap within said envelope for initiating an arc-over of same primary gap in response to spark-over of said trigger gap,
- (e) control means responsive to switching surges generated by opening of said interrupter and operable to produce a spark-over of said trigger gap in response to the switching surge voltage rising to a predetermined minimum level,
- (f) said predetermined minimum level being sufficiently high that said control means is ineffective to produce a spark-over of said trigger gap in response to typical recovery voltage transients appearing at current zero during the interruption of inductive circuits.

7. A vacuum-type circuit interrupter comprising:

- (a) a highly evacuated envelope having a normal pressure of 10^{-4} mm. of mercury or less,
- (b) a first contact within said envelope,
- (c) a second contact within said envelope that is movable from a position of engagement with said first contact to a position of disengagement to form a primary gap between said contacts,
- (d) triggering means operable to initiate an arc-over of said primary gap,
- (e) control means responsive to switching surges generated by opening of said interrupter and operable to produce operation of said triggering means in response to the switching surge voltage rising to a predetermined minimum level,
- (f) said predetermined minimum level being suffi-

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ciently high that said control means is ineffective to produce operation of said triggering means in response to typical recovery voltage transients appearing at current zero during the interruption of inductive circuits.

8. The vacuum-type circuit interrupter of claim 7 in which said triggering means comprises a trigger gap within said envelope that sparks over when said triggering means operates, said primary gap arcing over in response to spark-over of said trigger gap.

9. The vacuum-type circuit interrupter of claim 7 in which said control means is operable in response to a switching surge voltage of a predetermined minimum level appearing across said primary gap.

10. The vacuum-type circuit interrupter of claim 7 in combination with:

(a) means for normally maintaining said contacts in a position of engagement to permit current to flow therethrough, and

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(b) overcurrent responsive means for separating said contacts in response to current therethrough in excess of a predetermined value.

11. The circuit interrupter of claim 7 in which said interrupter is unshunted by any impedances of a size that would substantially modify the rate of rise of a switching surge voltage.

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