

United States Patent

Miyoshi

[15] 3,700,970

[45] Oct. 24, 1972

[54] CURRENT CIRCUIT BREAKER

[72] Inventor: Noriomi Miyoshi, Kawasaki, Japan

[73] Assignee: Fuji Denki Seizo Kabushiki Kaisha,
Kanagawa-ken, Japan

[22] Filed: Feb. 18, 1971

[21] Appl. No.: 116,587

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 791,635, Jan. 16, 1969, abandoned.

[30] Foreign Application Priority Data

Jan. 20, 1968 Japan43/3183
Jan. 31, 1968 Japan43/6193

[52] U.S. Cl.317/58, 317/60 R, 337/409,
317/9 R, 317/40 A, 317/33

[51] Int. Cl.H01h 3/08

[58] Field of Search317/58, 60, 9, 33, 50, 18 A,
317/18 B; 337/405, 409, 144, 142, 281, 290,
409; 102/28 A; 321/2

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Primary Examiner—J. D. Miller

Assistant Examiner—Harvey Fendelman

Attorney—Holman and Stern

[57] ABSTRACT

The electrical energy for detonating an explosive in a circuit-opening mechanism of a current circuit breaker to cut a circuit path is derived through a current transformer from the circuit path to which the circuit breaker itself is connected. The circuit-opening mechanism can thereby be exploded to cut the circuit path without the necessity of supplying electrical energy from any outside agency other than the circuit path. Furthermore, rapid extinguishing of the arc generated by the circuit path cutting is afforded by an insulative medium blown against the arc by the explosion, and the path parts thus cut apart are prevented by a unique construction from recontacting to remake the circuit.

8 Claims, 24 Drawing Figures

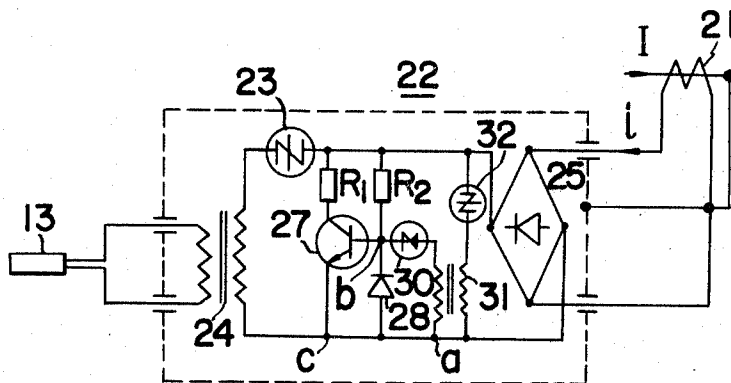


FIG. 1

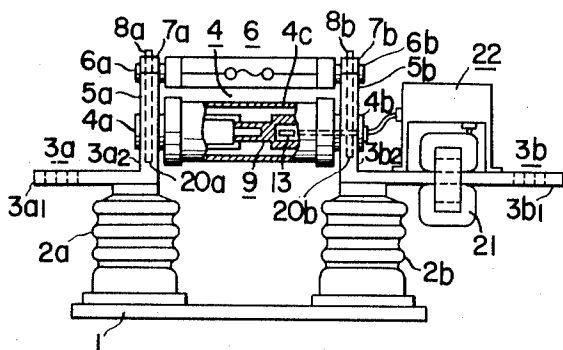


FIG. 2(A)

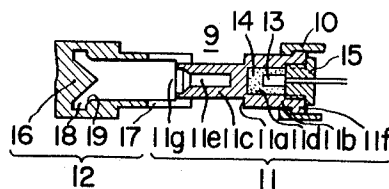


FIG. 2(B)

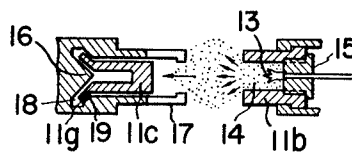


FIG. 3

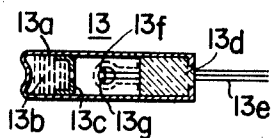


FIG. 4

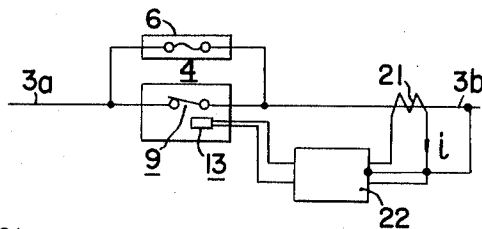


FIG. 5

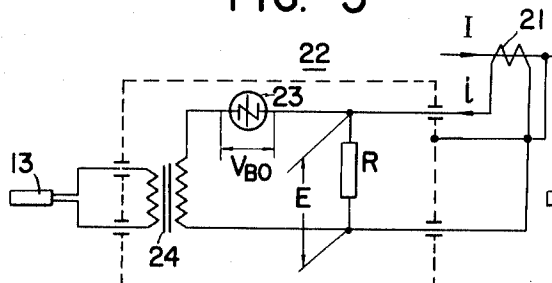


FIG. 8

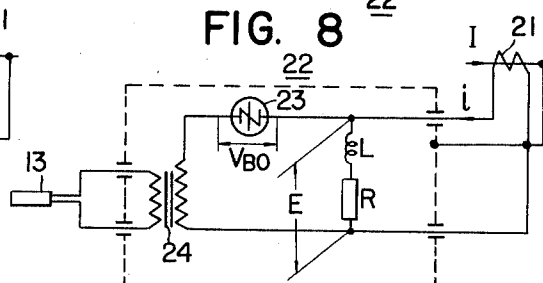


FIG. 10

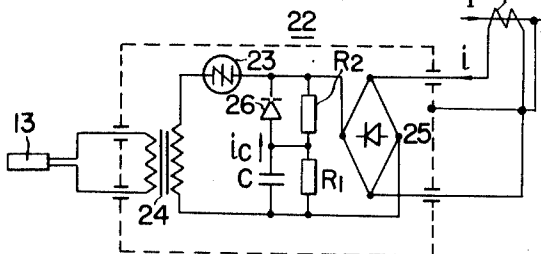
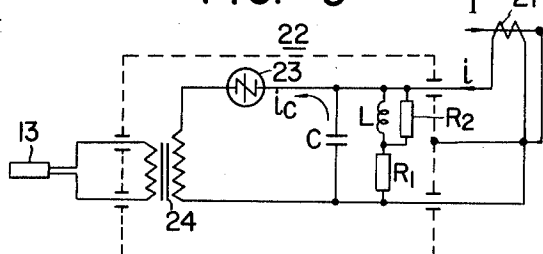


FIG. 9



INVENTOR

NORIOMI MIYOSHI

BY Holman, Glascock, Downing +
Seebold

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FIG. 6

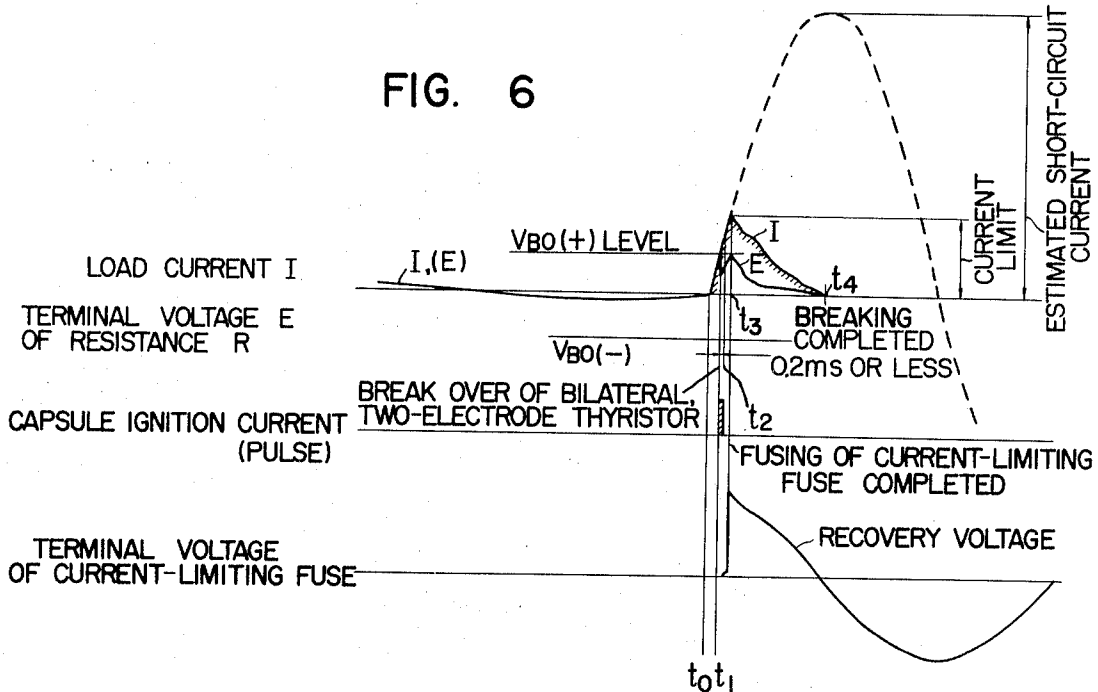
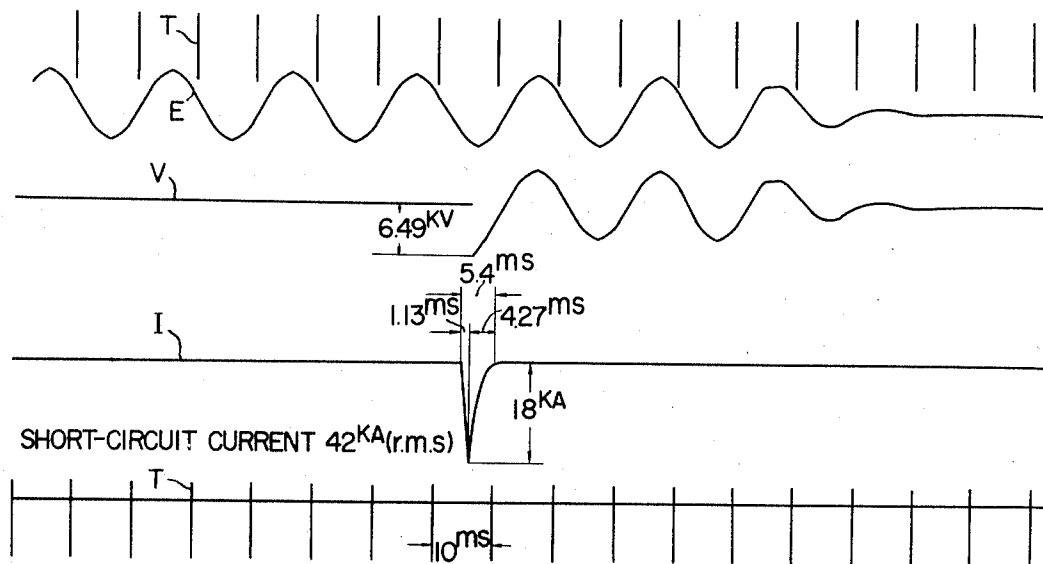


FIG. 7



INVENTOR

NORIOMI MIYASHI

BY Holman, Glascock, Downing & Seibold

ATTORNEYS

FIG. 11

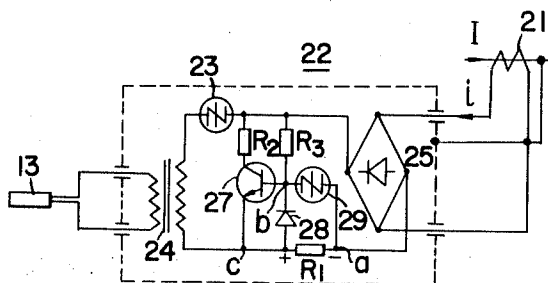


FIG. 15

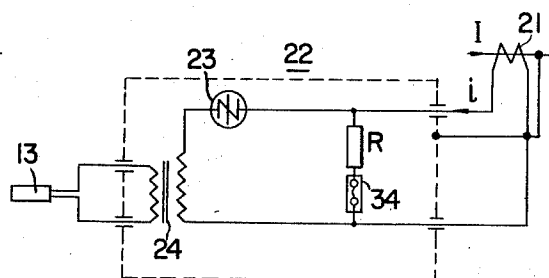


FIG. 12

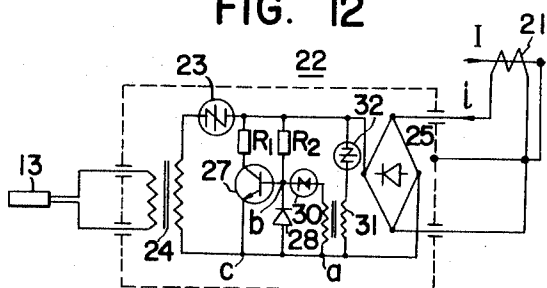


FIG. 16

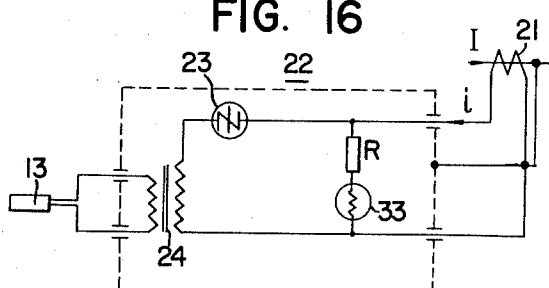


FIG. 13

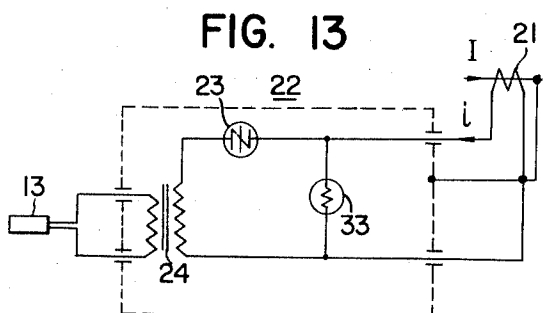


FIG. 17

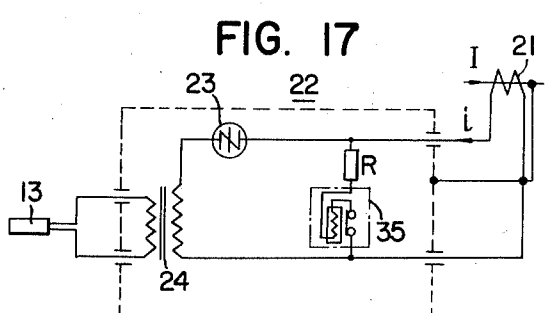


FIG. 14

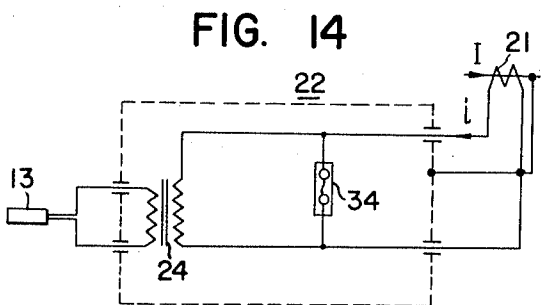
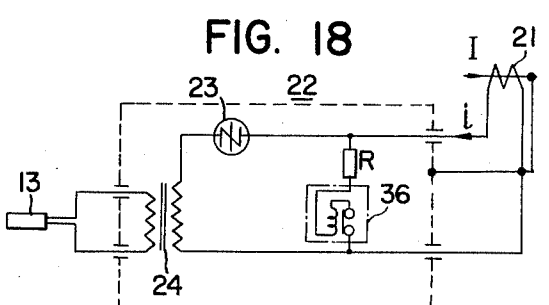


FIG. 18



INVENTOR

NORIOMI MIYASHI

BY *Holman, Glasscock, Downing & Seebald*

ATTORNEYS

SHEET 4 OF 4

FIG. 19

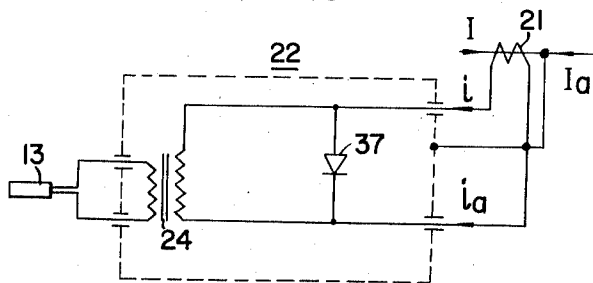


FIG. 20

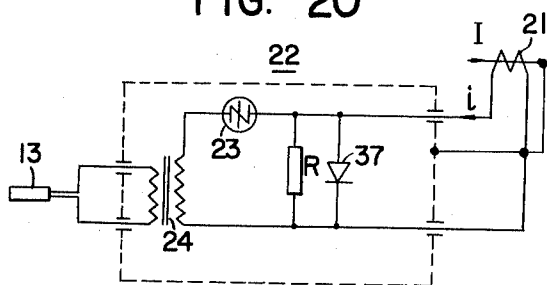


FIG. 21

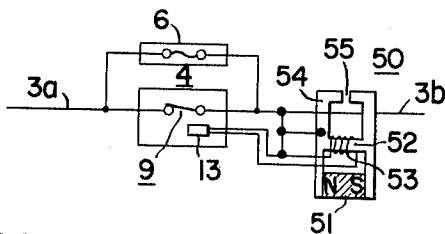


FIG. 22

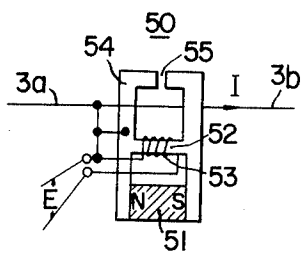
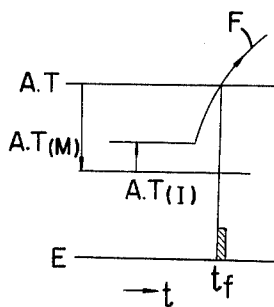


FIG. 23



INVENTOR

NORIAMI MIYOSHI

BY *Holman, Glascock, Downing & Seibold*

ATTORNEYS

CURRENT CIRCUIT BREAKER

This application is a continuation-in-part of application Ser. No. 791,635, filed Jan. 16, 1969 and now abandoned.

This invention relates generally to electrical circuit breakers and more particularly to a new and improved current circuit breaker having at least a circuit-opening mechanism containing an electrically ignitable explosive, the explosive energy of which is utilized to cut an electric circuit path.

In general, current circuit breakers of the type in which circuit-opening means actuated by the explosive energy of an explosive to break an electrical path and a fuse are connected electrically in parallel are known.

In a known circuit-breaking device of this type, however, the electrical energy for detonating the explosive charged into a conductor fabricated as the circuit-opening means is supplied from a special control device provided on the ground (earth) side. For this reason, an electrically coupling means of a highly insulative character as, for example, a high-insulation current transformer or potential transformer, is necessary between the circuit-breaking device connected on the high-potential side and the control device provided on the ground (earth) side.

At the same time, an electric power source as, for example, a source for supplying single-phase alternating current, polyphase alternating current, or direct current, for the operation of the control device is necessary. Moreover, this control device must be composed of accessory components such as a potential transformer, a current transformer, a discharge gap device, and capacitors, and the organization of the electrical circuit of these accessory components tend to become extremely complicated. Consequently, the bulk of the entire control device becomes massive, and the manufacturing cost increases.

Furthermore, current circuit-breaking devices in which such known control devices are used have been accompanied by several difficulties and shortcomings from the technical viewpoint, the principal of which are listed below, and much labor has been necessary for the preservation and maintenance of these devices.

1. One difficulty is that when there is a power failure in the control power source, the circuit-breaking device becomes incapable of operating.

2. Another difficulty is that, in a circuit-breaking device in which a capacitor for storing a detonation charge for detonating the explosive is used, and, moreover, use is made of an impulse transformer having a d-c bias winding as a device for detecting the line current flowing through the current circuit-breaking device, there is the risk of this circuit-breaking device misoperating at the instant that the power failure is remedied and power is restored.

3. Still another difficulty is that a certain specific time, for example, one minute, is necessary for the control device to assume a normal operational state from the instant the control power is supplied to the control device, and in the case when an excessive current is generated in the main circuit within this time, the desired circuit-breaking operation becomes impossible.

For avoiding these difficulties, one expedient which is possible is to prevent power failures, but for this purpose high-priced equipment such as power-failureless power supply devices are necessary. The inevitable

result is that the entire equipment for the current circuit-breaking device will become increasingly expensive and complicated.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a current circuit breaker in which, in contrast to known current circuit-breaking devices as described above, the organization of the electric path opening part differs remarkably, and, at the same time, the control device is greatly simplified, the entire device being highly miniaturized and, moreover, the maintenance of the device being facilitated.

More specifically, an object of the invention is to provide a current circuit breaker having the following principal features.

(1). One feature is that the electrical energy for detonating the explosive charged into the electric circuit-opening mechanism is derived through a current transformer in which the circuit to which the circuit breaker is connected constitutes a primary conductor, without the necessity whatsoever of supplying this electrical energy from a source outside of this circuit.

(2). Another feature is that various current detection devices can be prepared for selecting the circuit-breaking conditions of the current circuit breaker in accordance with at least one quantity such as the magnitude, fluctuation, duration, current waveform, and polarity of the load current flowing through the circuit, whereby the current circuit breaker can be installed in a wide variety of load circuits.

3. Still another feature is that, at the time when the circuit constituting the circuit-opening mechanism is broken by the detonation energy of the explosive, this energy is utilized to blow a medium made of a electrical insulator against the arc which develops at the circuit part where it is broken, whereby the circuit-breaking performance is remarkably improved, and, at the same time, the breaking of the circuit is accomplished rapidly by the use of this medium.

4. A further feature is that the two electrodes whose contact therebetween is broken by the detonation energy of the explosive are fabricated with a special configuration such that a part of one of the electrodes, after the detonation, is guided to the other electrode and automatically held therein, whereby one part of an electrode which has thus been separated is prevented from striking and bouncing on the other electrode to close the circuit again.

5. An additional feature is that the electrodes to be separated by the detonation energy are fabricated with a special configuration such that the work of charging the explosive and the fabrication of these electrodes are simplified.

According to the present invention, briefly summarized, there is provided a current circuit breaker of the type referred to above, characterized by the combination therewith of a current transformer having a primary winding through which at least one portion of a line current flows and a secondary winding through which a secondary current is thereby induced and a current detecting device operating in response to at least one characteristic of the secondary circuit to supply this secondary current to the explosive of the circuit-opening mechanism of the current circuit breaker.

The nature, principles, details, and utility of the invention will be more clearly apparent from the following detailed description with respect to preferred embodiments of the invention when read in conjunction with the accompanying drawings, in which like parts are designated by like reference numerals and characters.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a side elevation, with parts cut away and parts shown in vertical section, showing the essential organization of one example of a current circuit breaker embodying the invention;

FIGS. 2(A) and 2(B) are side elevations, in vertical section, showing the circuit-opening mechanism of the circuit breaker according to the invention and respectively indicating the states prior to and immediately after the circuit-opening operation;

FIG. 3 is a side sectional view showing a capsule in which an explosive is charged;

FIG. 4 is an electrical connection diagram showing the essential electrical organization of the current circuit breaker illustrated in FIG. 1;

FIG. 5 is an electrical connection diagram showing a representative circuit organization of a current detection device for detecting line current;

FIG. 6 is a graphical representation, in the form of a time chart, for an explanation of the operational principle of the current circuit breaker of the invention;

FIG. 7 is a drawing of one example of an oscillogram obtained from an actual test of the circuit-breaking operation of a current circuit breaker according to the invention;

FIGS. 8 through 18, inclusive, are electrical connection diagrams of current detection devices having respective current detection characteristics differing from that of the device illustrated in FIG. 5;

FIGS. 19 and 20 are electrical connection diagrams showing current detection devices capable of detecting reverse current in a d-c circuit;

FIG. 21 is an electrical connection diagram showing the essential organization of a current circuit breaker provided with a special current transformer constituting current detecting means applicable principally to direct-current circuits;

FIG. 22 is a relatively enlarged diagram of the special current transformer shown in FIG. 21; and

FIG. 23 is a graphical representation, with time as the abscissa, indicating characteristics of quantities relating to the operation of the circuit breaker illustrated in FIGS. 21 and 22.

DETAILED DESCRIPTION

Referring first to FIG. 1, the example of a current circuit breaker according to the invention shown therein is mounted on two support insulators 2a and 2b fixed to an iron base 1. On the upper ends of these insulators, terminal conductors 3a and 3b are respectively fastened by mounting bolts (not shown). These terminal conductors are L-shaped as viewed from one side (FIG. 1), having horizontal parts 3a₁ and 3b₁ provided with holes for tightening screws for connecting of line conductors (not shown) thereto.

The terminal conductors also have vertical parts 3a₂ and 3b₂ provided at their upper ends with semicircular

recesses for receiving conductors 4a and 4b of round cross section at the two ends of a circuit-opening mechanism 4. Although this organization is not shown in detail in FIG. 1, the internal construction of this circuit-opening part 4 is described in detail hereinafter.

After the conductors 4a and 4b of the circuit-opening mechanism 4 have been placed in the recesses in the vertical parts 3a₂ and 3b₂ of the terminal conductors, holding members 5a and 5b having at their lower parts semicircular recesses corresponding to the upper semicircular parts of these conductors 4a and 4b are placed on these conductors. These holding members at their upper parts have additional semicircular recesses for receiving end conductor parts 6a and 6b of a fuse 6, which end conductor parts are held in mounted state by final holding members 7a and 7b.

Then the holding members 7a and 7b, fuse 6, holding members 5a and 5b, and the circuit-opening mechanism 4 thus assembled are bolted down onto the vertical parts 3a₂ and 3b₂ of the terminal conductors 3a and 3b by tightening bolts 8a and 8b passed through these holding members on the two sides of the fuse and circuit-opening mechanism and engaging with tapped holes 20a and 20b provided in the vertical parts 3a₂ and 3b₂, whereby the fuse 6 and circuit-opening part 4 are firmly mounted.

The circuit-opening mechanism 4 has a capsule 13 containing an explosive as described more fully hereinafter. The electrical energy for igniting this explosive is supplied from a current transformer 21 in which one of the terminal conductors, for example, the conductor 3b on the right side (as viewed in FIG. 1), is used as a primary winding. Between this current transformer 21 and the capsule 13, there is connected a current detection device 22 for detecting the current through the secondary winding of the current transformer and, when this current reaches a specific value, supplying electrical energy to the capsule 13. The details of this current detection device are set forth hereinafter.

As is apparent from FIG. 4, when normal current is flowing through the line, almost all of this current flows through the circuit opening mechanism 4, and the current flowing through the side of the fuse 6 is very small. Accordingly, the fuse 6 is in a state of almost no deterioration, that is, a state substantially equivalent to a preservation state.

The detection device 22 operates to supply all or a part of the electrical energy received from the current transformer 21, without a time delay or with a specific artificial time delay, to the capsule 13. A representative example of the circuit organization of this detection device is illustrated in FIG. 5. Modifications of this circuit as illustrated in FIGS. 8 through 20, inclusive, respectively have different detection characteristics and, in their respective modified circuit organizations, afford variously different functional effectiveness.

As is apparent from the connections indicated in FIG. 5, a resistance component R having a specific resistance value is connected between the terminals of the secondary winding of the current transformer 21 provided on the terminal conductor 3b. Between the terminals of the resistance component R, there are connected a bilateral, two-electrode thyristor 23 and the primary winding of a transformer 24 connected in se-

ries. The secondary winding of the transformer 24 is connected to the capsule 13.

The organization of the capsule 13, as illustrated by one example in FIG. 3, is of a known character having a metal cylinder 13a having an open end and a closed end and constituting an outer housing structure which contains a predetermined quantity of an explosive powder 13b, an inner cylinder 13c pressing against and holding the explosive powder at the closed end of the housing structure, an ignition ball 13g made up of a platinum bridge 13f and a priming composition surrounding this bridge, lead wires 13e connected to the platinum bridge 13f and extending out of the cylinder 13a, and a sealing plug 13d closing the open end of the cylinder 13a and supporting the lead wires 13e.

Thus, when the aforementioned electrical energy is applied from the detection device 22 to the lead wires 13e to heat the platinum bridge 13f, the ignition ball 13g ignites and sparks to cause the explosive powder 13b to explode. This capsule 13 is combined with and assembled within an electric path structure 9 of special construction as indicated in FIGS. 1 and 2.

The electric path structure 9 is enclosed within a cylinder 4c made of an electrically insulative material of the circuit-opening mechanism 4 and, broadly speaking, is made up of two partial electrodes 11 and 12. One electrode 11 is supported by the inner wall surface of a support conductor 10 fixed to one end of the circuit-opening mechanism 4, while the other electrode 12 is so formed as to maintain a sliding contact with one part of the electrode 11 and is fixed to the other end of the circuit-opening mechanism 14.

The electrode 11 is formed to have an external shoulder part 11a at approximately the middle part thereof. For example, a hollow conductor made of a copper material can be worked into a shape with an external shoulder 11a constituting a boundary to the right of which (as viewed in FIGS. 1 and 2) a large-diameter part 11b is formed, and to the left of which a small-diameter part 11c is formed, the wall thickness of the electrode at the cross section of the shoulder 11a being made substantially thinner than those of the cross sections of the other parts.

Thus, cavities 11d and 11e are formed respectively in parts 11b and 11c. The aforementioned capsule 13 is placed in the cavity 11d, and the remainder of the space within this cavity is filled with a medium made of an electrically insulative material 14 such as, for example, silicon, grease, petroleum oil, or a medium in a form such as powder, this medium being then sealed within the cavity. That is, by screwing a plug 15 into the end 11f of the electrode 11, the capsule 13 and medium 14 are secured in installed state.

The inner wall part of the small-diameter part 11c in the vicinity of the free end 11g thereof is so machined as to have an inner diameter which is greater than that of the cavity 11e, whereby when the small-diameter part 11c is blasted away from the shoulder 11a by the explosion of the capsule 13 as described more fully hereinafter, this part 11c collides with a conical bottom 16 within the cavity of the electrode 12, and the end part 11g thereof is spread toward the radial direction (as indicated in FIG. 2(B)).

In the normal state of the electrodes 11 and 12 prior to breaking of the circuit, the free end 11g is in slidable

contact with and guided by the inner wall surface of a sliding guide contacting member 17 formed at the free end of the electrode 12. An annular groove 18 is formed around the base periphery of the above mentioned conical bottom 16 and has a shoulder 19 around its bank side away from the bottom 16. The electrical conduction path through the path 9 is $10 \rightarrow 11 \rightarrow 12$.

The current circuit breaker of the above described organization according to the invention operates in the following manner. Referring to FIGS. 4, 5, and 6, it will be assumed that, when the circuit breaker is in a state wherein a normal load current I is flowing through conductor 3b, a secondary winding current i of current transformer 21 is flowing through resistance component R , and a voltage E ($|E| = |iR|$) is produced across the two terminals of this resistance R , but that with this voltage E , the breakover voltage V_{BO} of bilateral, two-electrode thyristor 23 cannot be attained, thyristor 23 thereby being in an inconducive state.

Then, if a short-circuiting current (represented by intermittent line in FIG. 6) flows through the circuit breaker at a time instant t_0 , the secondary winding current i of current transformer 21 increases, and the terminal voltage of resistance R will also increase. Accordingly, when the value of this voltage E exceeds the breakover voltage V_{BO} of thyristor 23, a part of current i will be supplied through thyristor 23 to the primary winding of transformer 24. Since the current flowing through this primary winding flows instantaneously, a voltage of pulsive form will be induced in the secondary winding of transformer 24 whereby capsule 13 will immediately explode.

In accordance with the invention, through the use of a detection device as illustrated in FIG. 5 and with the following specific numerical values for the various elements, an instantaneous electrical energy of approximately 100 watts was obtained, and it was possible within 100 microseconds from the instant of flow of the shortcircuiting current to produce an explosion and thereby to break the current flow.

Rated specification of current transformer 21,	Ratio 1:6000
Resistance value of resistance component R ,	300 ohms
V_{BO} of bilateral, two-electrode thyristor,	300 volts
Rated specification of transformer 24,	Ratio 1:15

Referring again to FIG. 6, when capsule 13 explodes at an instant $t_1 + 100$ microseconds, at time instant t_2 , the part of electrode 11 at shoulder 11a is blasted apart, and part 11c, guided by contacting member 17 of electrode 12, is blasted toward conical bottom 16 (i.e., toward the left as viewed in FIG. 2(B)).

At this time, an electrical arc tends to develop between the nearest ends of parts 11c and 11b thus separated. However, since medium 14 charged into cavity 11d together with capsule 13 is ejected by the explosive energy thereof to cut across the arc, the arc voltage is abruptly raised, and the arc is extinguished almost instantaneously. According to the results of actual practice, I have found that silicon grease is definitely suitable for use as this medium 14, but certain kinds of electrical insulators as, for example, petroleum oils and powders of solids are probably capable of exhibiting the same effectiveness.

End part 11g of part 11c blasted away in the above described manner and traveling with high kinetic energy strikes conical bottom 16 and, thereby being deformed and spreading in the radial direction, rams into annular groove 18. Consequently, end part 11g deforms plastically, whereupon it is prevented from returning to the right (as viewed in FIG. 2 (B)) by shoulder 19 formed at the right side of groove 18 and is held in its deformed position (i.e., within electrode 12). Therefore, there is no possibility of the circuit being reclosed by the resulting parts of electrodes 11 and 12.

When electric path 9 is thus broken, the load current I flowing previously therethrough is commutated or switched in a very short time to a current limit fuse 6, which is thereby fused at an instant t_3 in accordance with the fusing characteristic thereof, and the circuit breaking operation is completed at an instant t_4 . From instant t_3 , a recovery voltage appears between the terminals of fuse 6. Furthermore, since this circuit breaker operates very rapidly as described above, and since the fusing characteristic of the current limit fuse is so selected that fusing occurs at a rising part of the circuit current, it is possible to effect circuit breaking at this current rising part even when the circuit current is of high value.

FIG. 7 represents an oscillograph obtained in connection with a current circuit breaker of the invention. In this chart, the uppermost and lowermost scales T indicate a time axis (timing), and E denotes power source voltage, the peak-to-peak value of which is indicated as being $2\sqrt{2} \times 3.14$ kilovolts. V designates a recovery voltage which appeared across the terminals of the circuit-opening mechanism, the maximum value of which was 6.49 kilovolt. Furthermore, I denotes the line current which was cut off by the circuit breaker of the invention, the maximum value thereof indicated on this oscillograph being 18 kilo-amperes. It should be mentioned that this oscillograph was obtained by a test circuit in which the effective value of the short-circuit current was 42 kilo-amperes.

As will be apparent from the above description with respect to one example of practice of the invention, in accordance with the invention, and as is illustrated in the drawings, the current transformer 21 and detection device 22 are provided directly on and connected to a part of the line conductor 3b, whereby the transformer and current detection device are maintained at the same potential as the primary line conductor, and electrical energy is applied through these components to the capsule 13. Accordingly, a special control device, as used heretofore, becomes unnecessary. Furthermore, a control power supply for such a special control device also becomes unnecessary. Therefore, maintenance of the equipment is simplified, and misoperation or malfunction of the circuit breaker as was observable heretofore in known devices can be fully prevented.

In addition, in a control device requiring a separate power source, as in the case of known devices, there is a great potential difference between the potential of the line conductor and that of the control device on the ground (earth) side, and for this reason, in order to detect variations in the line current by means of the detection device, it has been necessary to carry out this detection through a current transformer and a voltage

transformer provided with high insulation. Accordingly, expensive and, moreover, large-size equipment has been necessary.

In contrast, the present invention as illustrated provides a circuit breaker in which the line current is detected by means of a current transformer and a detection device connected to and having the same potential as the line conductor itself, whereby the circuit breaker can be caused to operate positively and reliably with a current transformer and detection device of very miniature size. Thus, the current circuit breaker has high technical and economic advantages.

The detection device illustrated in FIG. 5, as mentioned hereinbefore, is a device which operates in response to the voltage drop across the terminals of the resistance component R , that is, the absolute value of the current. However, if there are means whereby the fluctuation, itself, of the load current could be detected to cause the capsule 13 to explode, it should be possible to achieve a circuit-breaking operation which is more rapid than that depending on the aforescribed detection of the absolute value of the current.

Furthermore, there are instances wherein, in the case where the load connected in the line is a machine such as, for example, a motor, it is desired to render the circuit breaker inoperative with respect to the starting current thereof and to achieve current circuit breaking in the case when a malfunctioning occurs after the current has assumed its steady-state operational value.

Accordingly, the detection device can be appropriately modified in accordance with such desires and demands as illustrated by some examples described below with reference to FIGS. 8 through 20, inclusive.

One detection device as illustrated in FIG. 8 has the characteristic of detecting the absolute value of the current and, in addition, the variation of the current and differs in electrical connection from the device illustrated in FIG. 5 in that a series-connected combination of an inductance L and a resistance R is connected across the terminals of the secondary winding of the current transformer 21.

By this circuit organization, the terminal voltage E thereof can be expressed by $|E| = |L(di/dt)| + |iR|$. Accordingly, by appropriately selecting beforehand the values of the inductance L and the resistance R , the bilateral, two-electrode thyristor 23 can be caused to break over in accordance with a specific sum of the magnitude of the variation of the current and the magnitude of the absolute value of the current. Therefore, this detection device can accomplish a more rapid detection with respect to the same short-circuit current than a device of the circuit organization shown in FIG. 5.

FIG. 9 illustrates a detection circuit in which the secondary burden impedance of the current transformer results from the combination of an inductance L and a resistance R_2 mutually connected in parallel and connected in series with a resistance R_1 across the terminals of the secondary winding of the current transformer 21 and a capacitor C also connected across these terminals. Furthermore, the constants of the various circuit elements are so selected that the total combined impedance becomes the impedance component at the frequency of the line current.

When an excessive current flows through a circuit breaker provided with this circuit thus connected, detection can be accomplished more rapidly than in the circuit illustrated in FIG. 8, and, moreover, when the value of the terminal voltage of the capacitor C exceeds the break-over voltage V_{BO} of the thyristor 23, the electric charge stored in this capacitor is discharged instantaneously through the thyristor 23. Accordingly, the ignition time period of the capsule itself can be shortened further, whereby an even more rapid circuit-breaking operation can be achieved.

Another modification of the detection device as illustrated in FIG. 10 has an effective detection characteristic with respect to loads of machines such as motors. As shown, a rectifying device 25 is connected between the terminals of the secondary winding of the current transformer 21, and, in parallel with this rectifying device, there is connected a series-connected combination of a parallel circuit of a diode 26 and a resistance R_2 and a parallel circuit of a capacitor C and a resistance R_1 . The values of the resistances R_1 and R_2 and the capacitor C are appropriately determined, and the time constant of charging of the capacitor is suitably selected for following operation.

At the time of starting of the motor, for example, to which the circuit breaker is applied, the load impedance becomes low and increases as the charging of the capacitor C progresses. Accordingly, the thyristor 23 does not operate at the time of starting and can be caused to break over by the flow of an excessive current after the steady-state load current has been attained.

That is, when the circuit is undergoing steady-state operation, the series-connected circuit of resistances R_1 and R_2 essentially become the load on the rectifying device 25, and when the terminal voltage of these resistances exceeds V_{BO} of the thyristor 23, the capsule 13 explodes. Since the charge energy stored in the capacitor C is supplied through the diode 26 to the transformer 24, a relatively high energy for ignition is available.

Transistors may be utilized in the detection circuit 22 of the invention as illustrated by the examples shown in FIGS. 11 and 12. In the circuit of FIG. 11, a resistance R_2 and the collector of a transistor 27 are connected between the terminals of a rectifying device 25, a diode 28 being connected between the emitter and base of this transistor, and a series-connected circuit of a resistance R_1 and a bilateral, two-electrode thyristor 29 is connected in parallel with this diode 28. A third resistance R_3 is connected between the base electrode of the transistor 27 and the junction between the resistance R_2 and the thyristor 29.

When this circuit of the above described organization is operating with a steady-state load current, transistor 27 is in a conductive state because of resistance R_3 , and the output current from rectifying device 25 flows principally through resistance R_2 , transistor 27, and resistance R_1 . The value of resistance R_1 is so selected that the voltage drop across the terminals thereof under these conditions does not cause a breaking over of thyristor 29. Furthermore, while a voltage drop of a certain value is produced across the terminals of the series-connected circuit of resistance R_2 and transistor 27, this voltage is not sufficient to cause a break over of thyristor 29.

When current i increases because of the flow of excessive current in the line, and the resulting voltage drop across the terminals of resistance R_1 exceeds V_{BO} of thyristor 29, the potential of point b (junction between resistance R_3 , transistor 27, diode 28, and thyristor 29) becomes equal to that of point a (junction between thyristor 29 and resistance R_1), and the difference between the potentials of points b and c (junction between the emitter of transistor 27 and transformer 24) becomes almost zero. Transistor 27 is thereby caused to shift from the conductive state to a blocking state.

The circuit is then in a state wherein, essentially, only resistance R_3 is connected across the terminals of rectifying device 25, and the voltage across the terminals of this resistance R_3 is applied to the series-connected circuit of thyristor 23 and transformer 24. Since the resistance R_3 is selected at a high value only for maintaining transistor 27 in its conductive state, a high voltage drop can be obtained, and thyristor 23 can be caused to break over at a desired current value. At the same time, most of the generated power of current transformer 21 can be supplied to capsule 13.

The circuit shown in FIG. 12, which is a further modification, differs from that shown in FIG. 11 in that a Zener diode 30, a transformer 31, and a thyristor 32 are used. By this circuit organization, transistor 27 is in its conductive state when a steady-state current is flowing in the line, and consequently only a voltage drop due principally to resistance R_1 is applied to the series-connected circuit of thyristor 23 and transformer 24. The detection circuit 22 in this state is inoperative.

When an excessive line current causes thyristor 32 to break over, a current flows through the primary winding of transformer 31, whereby a specific voltage is induced in the secondary winding thereof. Since this voltage is designed to exceed the limit voltage of Zener diode 30, the potential at point b becomes equal to or slightly lower than the potential at point c , and transistor 27 shifts from its conductive state to a blocking state. Consequently, an ignition current is supplied with high efficiency to capsule 13 in the same manner as in the circuit shown in FIG. 11.

FIGS. 13 through 18, inclusive, illustrate examples of detecting devices each having the characteristic of causing the current circuit breaker to operate with a specific time delay even in the case when an excessive line current of relatively low value is generated.

In the circuit shown in FIG. 13, an electric lamp bulb (incandescent lamp) 33 is connected in parallel with the secondary winding of current transformer 21, and thyristor 23 and the primary winding of transformer 24 are connected in series between the terminals of the lamp bulb 33. Since the internal resistance of lamp bulb 33 increases as the lamp filament is heated, the terminal voltage of this bulb also increases with time, and it is possible to introduce a certain time delay from the instant an excessive current is generated to the instant thyristor 23 breaks over. Furthermore, a component such as a thermistor of positive temperature coefficient can be used instead of this lamp bulb 33 as a component having a similar characteristic.

FIG. 14 illustrates a circuit in which the thyristor 23 is omitted, and a fuse 34 and the primary winding of transformer 24 are connected in parallel between the terminals of the secondary winding of current trans-

former 21. Until fuse 34 fuses and breaks, the primary winding of transformer 24 is in a short-circuited state. When a line current of excessive magnitude such as to cause fuse 34 to fuse flows through the line, fuse 34 fuses and breaks with a certain time delay in accordance with the fusing characteristic thereof, and the secondary winding current of current transformer 21 is supplied to the primary winding of transformer 24 thereby to detonate capsule 13.

The circuits illustrated in FIGS. 15 and 16 are modifications respectively of the circuits shown in FIGS. 13 and 14 and are operable to combine absolute-value detection and time-delay detection. The circuit shown in FIG. 15 has the detection characteristics of the circuits shown in FIGS. 5 and 14, while the circuit shown in FIG. 16 has the detection characteristics of the circuits of FIGS. 5 and 13.

The circuit illustrated in FIG. 17 also combines absolute-value detection and time-delay detection, and a series-connected circuit of a thermal relay 35 and a resistance R is utilized therein. When a steady-state line current is flowing, the break contact of thermal relay 35 is closed, whereby only resistance R, essentially, is connected between the terminals of current transformer 21. When a current exceeding a predetermined value flows for a period longer than a specific time through thermal relay 35, the break contact thereof opens for the first time, whereupon thyristor 23 simultaneously breaks over, and the detection circuit 22 accomplishes its intended operation.

FIG. 18 illustrates a circuit in which a circuit breaker 36 is utilized instead of the thermal relay in the circuit of FIG. 17. The operation of this circuit is substantially the same as that of the circuit of FIG. 17, and, therefore, description thereof will be omitted.

The circuits illustrated in FIGS. 19 and 20 are applicable to the detection of reverse current in the case wherein the line current I is a direct current. It will be assumed that when direct current I is flowing as indicated in FIG. 19 or 20 and, moreover, is progressively increasing, the secondary winding current i of current transformer 21 is of the polarity indicated. It will be assumed further that a load as, for example, an electrolytic bath or cell (not shown), is connected to the line.

When, with a load of this character, the power-supply current to the electrolytic cell from a power source (not shown) stops for some reason, the electrolytic cell functions as a storage cell simultaneously with the supply current stoppage to transmit a current in reverse from the electrolytic cell to the power source. Since such a reverse current is not desirable, there is a demand in some instances for detection of the reverse current and operation of the current circuit breaker to open the circuit.

The circuits shown in FIGS. 19 and 20 are those of detection devices suitable for use in conjunction with such lines and operate in the following manner. It will be assumed that the line current I which has been flowing from the left to the right (as viewed in FIG. 19 or 20) now flows in the reverse direction. In the circuit shown in FIG. 19, when steady-state current I is continually flowing, the iron core of current transformer 21 is saturated. Accordingly, current i does not flow through diode 37, and the detection device 22 is in an inoperative state.

However, when line current I is reversed and becomes reverse current Ia as indicated, the secondary winding current ia of current transformer 21 does not flow through diode 37 but flows directly through the primary winding of transformer 24. The resulting transformer operation then detonates capsule 13.

The detection device shown in FIG. 20 has a circuit organization comprising thyristor 23, resistance R, and diode 37. Accordingly, while the operation thereof is substantially the same as that of the circuit of FIG. 19, this device is advantageous in that the value of the reverse-direction current to be detected can be freely adjusted by means of the resistance.

Another example of a current circuit breaker applicable principally to a direct-current line is illustrated in FIGS. 21, 22, and 23. This circuit breaker differs from that shown in FIG. 4 in that use is made therein of a unique current transformer 50 of special design. As shown in FIGS. 21 and 22, this special current transformer 50 comprises a permanent magnet 51 at one part of an iron core or field frame, a divisional path or yoke 52 forming a closed magnetic path of this magnet 51, a winding 53 wound around the yoke 52, and a magnetic path part 54 of the field frame forming a magnetic path parallel to the yoke 52 and surrounding the aforementioned line conductor 3b, a gap 55 being provided at a portion of this part 54. The winding 53 is connected to the capsule 13.

For the following description of the operation of this circuit breaker, it will be assumed that a current I is flowing as indicated in FIG. 22 through conductors 3a and 3b and that a magnetomotive force $A.T_{(M)}$ induced in winding 53 by permanent magnet 51 is set in the downward direction as indicated by an arrow in FIG. 23.

When current I is thus flowing through conductors 3a and 3b, a magnetic flux is established with respect to winding 53 through field frame part 54 in a direction such as to nullify the magnetic flux passing through yoke 52 due to permanent magnet 51. Accordingly, when a steady-state current I is thus flowing through the line, the magnetic flux Φ passing through yoke 52 is equal to the difference $A.T_{(M)} - A.T_{(I)}$ as indicated in FIG. 23.

Accordingly, if current I increases in accordance with curve F, the magnetic flux through yoke 52 will become zero at a time instant t_f , at which instant a pulse-form voltage E is generated in winding 53, whereby capsule 13 connected to this winding is immediately detonated. After capsule 13 explodes, the current circuit breaking operation is completed as described hereinbefore.

It has been found that, for the yoke parts 52 and 54 of the above described special current transformer 50, a material having a so-called square-loop magnetic characteristic or a magnetic characteristic close thereto is suitable and affords accurate operational setting values. Furthermore, the gap 55 is provided in yoke 54 for the purpose of adjusting the effect of the magnetic flux forming an interlinkage with yoke 52. By appropriately setting the size of this gap, the degree of magnetic coupling can be adjusted. Accordingly, the operational value of the special current transformer 50 can be adjusted.

It is further possible to install two of the above described current transformers 50 parallelly on the

same conductor 3b and to adapt these current transformers so that one detects current in one direction and the other detects current in the reverse direction, mutual connections with respect to the respective windings thereof being made in parallel through an electrical valve such as semi-conductor rectifier (not shown), and the windings being connected to capsule 13. By such an organization, it is possible to cause the capsule to explode at a predetermined value of the line current with respect to both directions thereof. Accordingly, it is possible in this case, by using a suitable detecting device, to apply the current circuit breaker to a line through which an a-c current is flowing.

While the invention has been described above with respect to examples of current circuit breakers in each of which a circuit-opening mechanism and a fuse are electrically connected in parallel, a fuse is not always necessary in cases wherein circuits through which relatively low currents are flowing are to be broken. The reason for this is that in accordance with the invention a liquid, solid powder, or a semisolid of an electrically insulative substance to function as a medium to transmit the explosive power of the explosive in order to rupture the electric line as rapidly as possible from the instant of explosion and to function as a medium to cool the generated arc and to be blown thereagainst to cut the same thereby to promote the arc extinguishing action is contained, together with the explosive, within the line. In such cases, the current can be cut off by the opening of only the circuit-opening mechanism.

What is claimed:

1. A circuit breaker comprising, in combination, a circuit opening part to be opened by the explosive energy of an electrically ignitable explosive, a current transformer means comprising a primary conductor coupled to one pole of said circuit opening part and a secondary winding, a portion of said secondary winding being connected to said primary conductor so as to have the same potential as said primary conductor relative to ground, a secondary current being induced in said secondary winding by the current passing through said primary conductor, and current detecting means maintained at the same potential relative to ground as said circuit opening part and being operative when said secondary current reaches a predetermined value to supply an igniting current to the explosive of said circuit opening part, said secondary current of said current transformer being the sole source for supplying igniting energy to said explosive.

2. A circuit breaker as defined in claim 1, further comprising a fuse means connected in parallel to said circuit opening part.

3. A circuit breaker as defined in claim 1 in which said circuit opening part comprises a unitary member and a contacting member means for guiding a portion

adapted to be broken from said circuit opening part upon explosion of said explosive, said explosive imparting kinetic energy to said broken part whereby one end of said broken part travels into said contacting member, said contacting member further including a means for deforming said one end of said broken circuit part and holding said broken part within said contacting member to thereby sustain the opened state of the circuit path.

4. A circuit breaker as defined in claim 1 further including a fuse means connected in parallel to said circuit opening part, and a contacting member means for guiding a portion broken from said circuit opening part upon the explosion of said explosive and for deforming and holding said broken portion, said broken portion being deformed at its end in its terminal position in said contacting member by the kinetic energy imparted to said broken portion by said explosive, said deformation holding said broken part within said contacting member means and thereby sustaining the opened state of said circuit path.

5. A current circuit breaker as defined in claim 1 in which electric path structure of said circuit opening part is adapted to be broken and cut by said explosive energy and contains an electrically insulative substance having fluidity and defining a medium for transmitting the explosive energy of said explosive and being blown thereby when said structure is thus broken and cut against an arc which is generated at said circuit part thereby to extinguish said arc.

6. A current circuit breaker as defined in claim 1 in which fuse means are connected in parallel to said circuit opening part and in which electric path structure of said opening part is adapted to be broken and cut by the explosive energy of said explosive and contains an electrically insulative substance having fluidity and functioning as a medium for transmitting the explosive energy of said explosive and being blown thereby when said circuit part is thus broken and cut against an arc which is generated at said circuit part, thereby to extinguish said arc.

7. A current circuit breaker as defined in claim 1, wherein said circuit opening part includes electric path structure which is adapted to be broken and cut by said explosive and comprises a conductor of round-bar shape having an external stepped shoulder and thereby having a large-diameter part, and a sealable cavity formed within said large-diameter part in the axial direction thereof with a configuration such that the wall thickness of said shoulder is relatively small, a capsule containing an explosive being installed within said cavity. 8. A current circuit breaker as defined in claim 7, further including fuse means connected in parallel to said circuit opening part.

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