The circuit breaker comprises two coaxial conductor elements each having a free end in a same transverse plane, an annular hollow between these two elements, a conductive plate applied against the ends of the two conductors and explosive means to apply high pressure on the plate, which cuts off or bursts this plate at the zone of the hollow. An explosible element is mounted in parallel on the plate.

13 Claims, 12 Drawing Figures
CIRCUIT BREAKERS FOR HEAVY CURRENTS

The present invention relates to circuit breakers for heavy currents. More particularly it relates to very rapid opening electric current breakers (an opening less than 1 millisecond) capable of cutting off currents of high intensity, this intensity being greater than 1,000 A, preferably than 10,000 A, and capable of reaching and even exceeding several million Amperes, with very high excess cut-off voltages generally greater than 10,000 V.

An advantageous field of application of these breakers is that of automatic safety breakers. It is a particular object of the invention to render said interrupters such that their duration of opening is particularly short (of the order of a microsecond) and their operation is only manifested by slight destruction easy to repair.

The breakers of the type concerned according to the invention comprise:

- two parallel conductor elements of which one surrounds the other connected respectively to two portions forming the conductor line to be broken, and both having one axial end in a same transverse plane P,
- an insulating sleeve interposed radially between these two elements and hollowed on this side of the plane P by an annular cup open in the direction of this plane,
- a conducting plate applied on the concentric terminal bearing surfaces, of the two conductor elements, situated in the plane P,
- and means to create suddenly a high pressure on the outer surface of the plate at the time desired for breaking the circuit so as to cut out or burst this plate annularly between the two conductive elements and to project the cut out or burst part towards the bottom of the cup.

In preferred embodiments, recourse is had also to one and/or the other of the following features, although these are not indispensable:

- the terminal bearing surface, of one, at least, of the two conductive elements, which extends in the plane P, is connected to this element along a sharp angled edge,
- the means for generating a high pressure comprise a closed chamber connected directly or not to the plate and containing a gaseous detonating mixture, composed for example of one part by volume of oxygen and two parts by volume of hydrogen at a pressure of some tens of bars, and an electrical device adapted to initiate the explosion of said mixture in the same chamber,
- in a circuit breaker according to the preceding paragraph, a volume of electrically insulating substance is inserted between the outer surface of the plate and the detonating mixture,
- in a circuit breaker according to the preceding paragraph, the volume of insulating material is separated from the detonating mixture by a fluid-tight diaphragm,
- an element of electrical resistance very much higher than that of the plate and capable of being destroyed by explosion when it is traversed by a heavy current is mounted in parallel on this plate preferably outside the enclosure in which the latter is located,
- the circuit breaker mounted on the conducting line to be broken comprises several elemental circuit breakers constructed according to the preceding paragraph but one each mounted in series with a choke, the assemblies constituted respectively by each elemental circuit breaker and its choke being mounted in parallel between the two portions constituting the line.

The circuit breaker mounted in the conducting line to be interrupted comprises an assembly of elemental circuit breakers with explodable elements and chokes mounted in parallel according to the preceding paragraph, the assembly being mounted itself in series with several elemental circuit breakers without explodable elements mounted in series, an explodable element being mounted in parallel on the whole between the two portions constituting the line.

The invention comprises, apart from these main features, certain other features which are preferably used at the same time and which will be more explicitly considered below.

In the following there will be described several preferred embodiments of the invention with reference to the accompanying drawings given of course purely by way of illustrative but non-limiting example.

In the drawings:

FIG. 1 shows in axial section one embodiment of an electric circuit breaker constructed according to the invention, in the closed state, prepared for its opening.

FIG. 2 shows in part the same circuit breaker just after its opening.

FIG. 3 is the electrical diagram of this circuit breaker.

FIGS. 4, 5 and 6 are graphs facilitating the explanation of the operation of the said circuit breaker.

FIGS. 7 to 10 are electrical circuit diagrams according to the invention of several elemental circuit breakers of the above type, mounted respectively in series in FIGS. 7 and 8, in parallel in FIG. 9 and in series-parallel in FIG. 10.

FIG. 11 shows in cross-section another embodiment of a circuit breaker according to the invention composed of elemental circuit breakers mounted according to the electrical diagram of FIG. 10.

FIG. 12 is a sectional view of FIG. 1 immediately above the conductive plate looking downwardly, with the cups shown partially in phantom lines.

The circuit breaker proper or elemental circuit breaker comprises two parallel elements conductive of electricity enveloping one another, preferably coaxial, one central 1 and the other peripheral 2 (FIGS. 1 and 2).

These two elements each have an axial end terminated by a flat bearing surface situated in a transverse plane P: in the embodiment illustrated, these two flat bearing surfaces have respectively the shape of a central disk 3 and a ring 4 concentric with this disk.

The two elements 1 and 2 are connected respectively to the two portions which form the conducting line to be interrupted: in the embodiment illustrated FIG. 1, the current I to be controlled is applied to the central element 1, and the outer element 2 is grounded at 5 through the metallic casing 6 of the circuit breaker.

An electrically insulating sleeve 7 is interposed radially between on one hand the element 1 and on the
other hand the conducting ground formed by the element 2 on the casing 6. An annular cup 8 is hollowed in a sleeve 7, on the side of the plane P, which cup is open in the direction of this plane.

The inner lateral surfaces of the cup 8 are connected to one at least of the flat terminal bearing surfaces 3 and 4 by a sharp edge 9, 10, forming in profile an acute angle or right angle.

These lateral surfaces can be entirely bounded by the conductive elements 1 and 2 themselves, but in the embodiment illustrated they are bounded by thinned extensions of the sleeve 7, which have themselves bevelled edges connected without discontinuity to the enlarged ends of the conductive elements.

The general shape of the hollow 8 is advantageously cylindrical, as illustrated.

Its radial width can be constant over the whole of its height, as illustrated, or on the contrary variable.

On the coplanar bearing surfaces 3 and 4 is applied a metallic plate 11 conducting electricity: a sheet of copper whose thickness is of the order of several tenths of a mm is quite suitable to constitute this plate; in the case where it is desired to cause the circuit breaker to be constantly traversed by current, a thicker metallic (copper or the like) sheet is resorted to, whose thickness can reach several mm, thinned locally by a circular groove constituting a breakage initiator in line with one at least of the sharp edges 9, 10.

The maintenance in position of the plate is ensured by gripping its edges between two parts of the casing applied against one another by screwing, wedging or in any other way.

The portion, of the casing 6, axially opposite that which encloses the conducting element 1 and 2 contains a closed chamber 12 inside of which is mounted an electrical firing wire 13 connected to an external source 14 of electrical pulses: This wire is for example a copper wire of 6/100 of mm diameter, 2 mm in length.

The chamber 12 is filled with a gaseous detonating mixture adapted to generate suddenly, when it explodes, a very high pressure propagating as a shock wave.

This mixture is advantageously constituted by the components of water (namely one volume of oxygen and two volumes of hydrogen) at a pressure of the order of 60 bars, but it could of course be constituted by any other suitable mixture, for example air to which methane or propane has been added.

The detonating mixture could be placed directly in contact with the plate 11, but if this mixture is electrically conducting there is inserted between it and the plate a cushion 15 of oil or insulating grease, for example, transformer oil. This cushion is preferably itself separated from the detonating mixture by a diaphragm 16 bounding with the plate 11 a compartment 17 inside the casing 6.

This diaphragm 16 can be kept in position by clamping at the same time as the plate 11 and by similar means.

To render the circuit breaker suitable for traversal by a permanent current, continuous or alternating, the heat dissipated by the plate can advantageously be removed by causing oil 15 to circulate in a closed system successively along this plate and in a cooling device.

The operation of this circuit breaker is as follows.

In a closed state, that is to say normal service, of the circuit breaker, the plate 11, the wire 13 and the diaphragm 16 are in position, the chamber 12 is filled with the detonating mixture under pressure and the compartment 17 is full of oil: the electric current passes from the conductor element 1 to the conductor element 2 through the plate 11.

To open the circuit breaker, it suffices to send from the source 14, to the starting wire 13, an electric pulse of very low energy, of duration of the order of a microsecond.

The wire 13 explodes, which causes the mixture contained in the chamber 12 to explode: this detonation generates suddenly a considerable pressure, generally exceeding 1,000 bars, which is propagated from the exploded wire as a shock wave; this pressure, by means of the oil 15, cuts out or bursts annularly the plate 11 in line with the sub-adjacent sharp edges 9, 10; the oil then projects the cut-out or burst fragment 18 (FIG. 2) of the plate towards the bottom of the cup 8 and itself fills this cup.

The plate 11 hence no longer ensures the continuity of electrical connection between the two elements 1 and 2: on the contrary, the oil 15 completely insulates these two elements from one another.

The desired cut-off is thus effected in a very brief time, which can be of the order of some microseconds, and with very slight destruction: to restore the circuit breaker into operating condition, it suffices to remove the contents of the cup 8, to replace the plate 11, the wire 13 and the diaphragm 16 and to recharge the chamber 12 with the detonating mixture and the compartment 17 with oil.

In an improved modification, there is mounted between the elements 1 and 2, in parallel on the plate and preferably outside the casing 6, a conductor element 19 of resistance very much greater than that of the plate, for example, 1,000 times greater.

The element 19 is advantageously constituted by a copper or aluminum wire of some tenths of a millimeter diameter surrounded by an insulating sheet, or by a thin sheet of the same metal also insulated.

As will be explained with reference to FIGS. 4 to 6, the assembly of such an element 19 in parallel on the plate 11 further reduces the duration of opening of the circuit breaker and the value of the excess breaking-off voltage generated inside the casing 6.

In FIGS. 4 to 6, there is shown as abscissa the time t.

There is shown as ordinates on FIG. 4 the intensity of the electric current, the curve in full lines representing the current I1, which flows in the plate, that is dotted line the current I2 which flows in the element 19 and that in mixed lines, the total current I which passes through the whole of the circuit breaker associated with the element 19, which current is equal to the sum of the currents I1 and I2.

In FIG. 5 there is shown in ordinates the temperature 6 of the element 19.

In FIG. 6 there is shown as ordinates the excess cut-off voltages U.

In a normal closed state of the circuit breaker, almost the whole of the current I passes through the plate 11, a minute portion of the latter passing through the much more resistant element 19.
To trigger the opening of this circuit breaker, the gaseous mixture contained in the chamber 12 is made to detonate as previously.

As soon as the cutting out of the plate commences (instant $t_0$), the current $I_0$, initially equal to $I$, drops by an amount $I_0$ transferred to the element 19, which hence starts to heat up.

Due to the fact of this transfer of the current to be cut off to the element 19, the arc started at the level of the plate is very rapidly extinguished, that is to say before the excess cut-off voltage has reached a high level: to fix ideas purely by way of illustration, it is indicated that, all things being otherwise equal, instead of lasting about 20 microseconds (from $t_0$ to $t_2$) and giving rise to an excess cut-off of voltage $U_2$ of the order of 2,000 V — which would be the case of the assembly without the element 19 — the arc of breaking at the level of plate is here practically extinguished at the end of 5 microseconds only (instant $t_3$) after having only developed a relatively low excess voltage of cut-off $U_2$ of the order of 300 V, the insulation between the two elements 1 and 2 being completely ensured from this instant $t_1$.

The dissipation of energy caused inside the casing by the opening of the circuit breaker is hence very low which leads:

1. to very slight deterioration of the oil 15 whose insulating properties are thus preserved, and which can in any case be easily regenerated by conventional methods;
2. to excellent mechanical resistance of the facing portions of the elements 1 and 2 on successive cut-offs.

The current $I_0$ then increases gradually to the detriment of the current $I_4$ up to instant $t_4$ from which the current $I_4$ has become null and the current $I_0$, equal to the total current $I$.

The element 19 then heats up more and more according to the curve C (FIG. 5) and from the moment $t_5$ corresponding to its maximum temperature $\Theta_5$, it explodes, which creates a relatively high excess voltage of rupture $U_5$ (capable of reaching several tens of kV) and very briefly, the duration of this explosion corresponding to the interval of time comprised between the moments $t_5$ and $t_4$.

It should be noted:

1. that the release of energy from said explosion takes place outside the circuit breaker and hence causes no damage,
2. and that the true duration of the cut-off of the total current $I$ is substantially more brief than the duration of rupture of the plate itself (interval of time comprised between the moments $t_5$ and $t_4$).

To enable the cut-off of very high currents and at particularly high voltages, several elemental circuit breakers of the type as described above can be grouped.

For high voltages, these elemental circuit breakers are grouped in series, as illustrated in FIG. 7 and 8, their explosoable elements 19, being themselves mounted in series. The terminals of each element 19, can be connected (FIG. 7) or not (FIG. 8) to its associated plate 11.

For high currents, the elemental circuit breakers are mounted in parallel as shown diagrammatically in FIG. 9.

In this case, to avoid the consequences of a possible slight shift between the moments of cut off of the circuit breakers (11, 19), in parallel, there is mounted in series with each of them a choke 20, of which the value can be relatively low, for example, of the order of some tens of nanohenrys.

The assembly in series-parallel shown diagrammatically in FIG. 10 enables the cut off of currents both intense and at high voltage.

This assembly comprises a group of three elemental circuit breakers 21 each associated with a small explosive wire 22 and with a choke 23 mounted in parallel according to FIG. 9, the group itself being mounted in series with a group of three elemental circuit breakers 24 mounted in series without explosoable wires, and a large common explosoable wire 25 is mounted parallel to the lot according to FIG. 8.

The operation of this assembly is as follows:

Initially the current flows through all the closed elemental circuit breakers and practically no current circulates in the wires 22 and 25.

First the opening of the elemental circuit breakers 21 is initiated, which diverts the current to be cut off first into the small wires 22, which heat up, then explode, then into the large wire 25.

The opening of the elemental circuit breakers 24 is itself started just after the explosion of the small wires 22 so that the whole of the current to be cut off then passes into the large wire 25, which heats up and explodes in its turn thereby opening the circuit and thereby generating a considerable voltage, which is rendered possible by the previous opening of the circuit breakers 24.

This assembly of FIG. 10 lends itself to a very simple technique illustrated in FIG. 11: the axial ends of the elemental circuit breakers 21 and 14 open respectively in two transverse planes displaced axially by a value such that the time taken by the pressure wave to pass from one to the other corresponds to the desired retard between the respective cut-offs of the said circuit breakers 21 and 24.

The said axial ends are connected according to the invention by a deformed single conducting plate 11 of the above type applied on them or by two such plates axially displaced with respect to one another.

The severable portions of the three circuit breakers 21 are small washers 26 spaced between themselves and centered at the three apices of an equilateral triangle inside the disk 27, and the severable portions of three circuit breakers 24 are three washers 28 separated between themselves surrounding the disk 27 and concentric with the latter.

As a result of which, and whatever the embodiment adopted, there is finally provided an electrical circuit breaker of which the constitution and operation emerge sufficiently from the foregoing and which have with respect to those currently known, numerous advantages, in particular the following:

1. shorter cut-off, generally of the order of some microseconds,
2. increased reliability,
3. minor amount of deterioration and simplicity of resetting,
4. low energy expenditure required for its opening.

As is self-evident, and as emerges already from the foregoing, the invention is in no way limited to those of its types of application and embodiments which have been more especially envisaged; it encompasses, on the contrary, all modifications, especially those where the
insulating sleeve 7 would be constituted itself by a hollow extending the cup 8 and lined only in part by cross-bracing or centering elements of solid insulating material.

We claim:

1. Rapid circuit breaker for a heavy electric current comprising: two parallel conductors one of which surrounds the other, connected respectively to two portions forming the conducting line to be broken and having both one axial end in a same transverse plane P, an insulating sleeve interposed radially between these two elements and hollowed on this side of the plane P by an annular cup open in the direction of this plane, a conducting plate applied on the concentric terminal bearing surfaces, of the two conducting elements, situated in the plane P, and means for suddenly generating a high pressure on the outer surface of the plate at the desired moment for breaking the current so as to cut out or burst this plate annularly between the two conductor elements and project the cut out or burst portion towards the bottom of the cup.

2. Breaker according to claim 1, wherein the terminal bearing surface, of at least one of the two conductor elements, which extends in the plane P, is connected to this element along an edge with a sharp angle.

3. Breaker according to claim 2, wherein the plate is constituted by a relatively thick sheet thinned locally by a circular groove constituting a breakage initiator in line with one at least of the sharp edges.

4. Breaker according to claim 1, wherein the high pressure generating means comprise a closed chamber connected to the plate and containing a gaseous detonating mixture, and electrical device adapted to initiate the explosion of this mixture in this chamber.

5. Breaker according to claim 4, wherein the detonating mixture is composed by one part by volume of oxygen and two parts by volume of hydrogen at a pressure of several tens of bars.

6. Breaker according to claim 4, wherein a volume of electrically insulating material is interposed between the outer surface of the plate and the detonating mixture.

7. Breaker according to claim 6, wherein the volume of insulating material is separated from the detonating mixture by a fluid-tight diaphragm.

8. Breaker according to claim 7, wherein the insulating material is a fluid, associated with means for causing said material to circulate in a close system successively along the plate and in a cooling device.

9. Breaker according to claim 1, wherein an element of electrical resistance very much higher than that of the plate and capable of being destroyed by explosion when it is traversed by an excessive current, is mounted in parallel on said plate.

10. Rapid opening heavy current breaker, comprising several elemental breakers constructed according to claim 9 and mounted in series with their explosive elements themselves mounted in series.

11. Rapid opening heavy current breaker, comprising several elemental breakers according to claim 9 mounted each in series with a choke, the assemblies constituted respectively by each elemental breaker and its choke being mounted in parallel between the two portions constituting the line.

12. Rapid opening heavy current breaker, comprising an assembly of elemental breakers with explosive elements and chokes mounted in parallel according to claim 11, the assembly itself being mounted in series with several elemental breakers, without explosive elements, mounted in series, an explosive element being mounted in parallel with the whole between the two sections constituting the line.

13. Rapid opening heavy electric current breaker, according to claim 9, wherein the electrical resistance element is mounted outside the enclosure in which said plate is located.

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