

[54] CIRCUIT BREAKER

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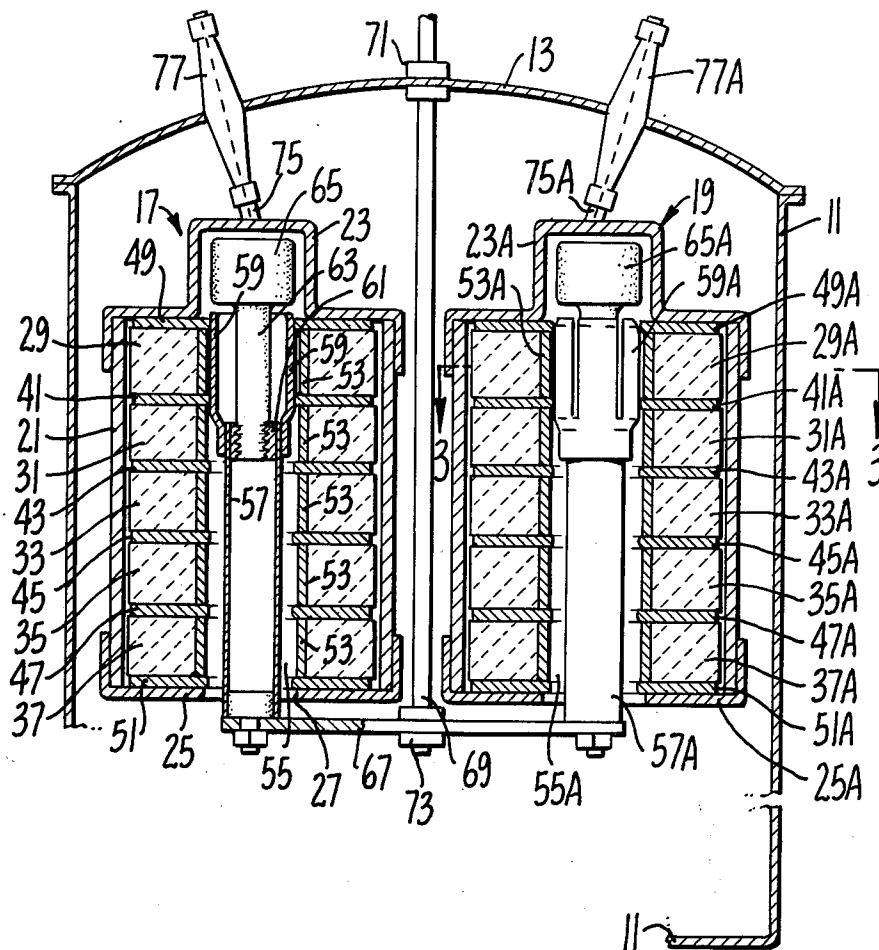
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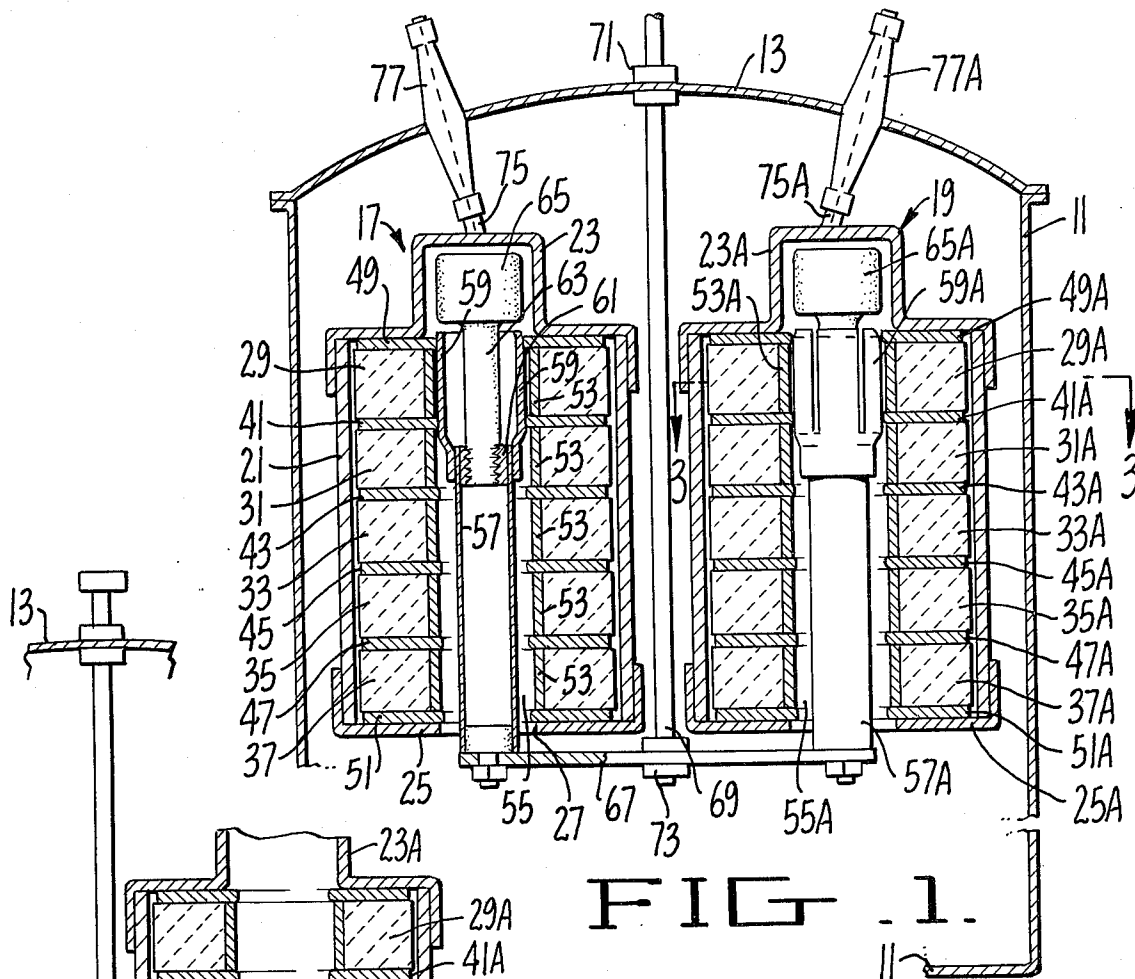
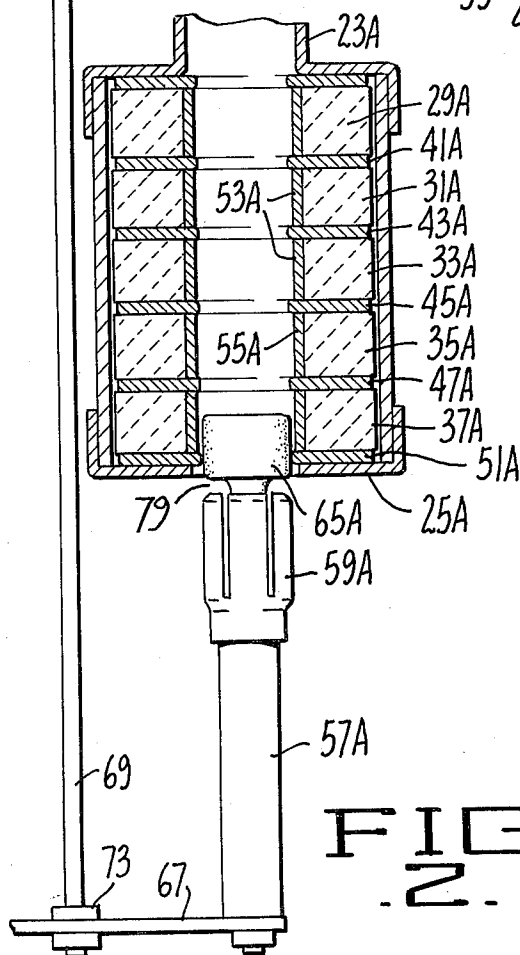
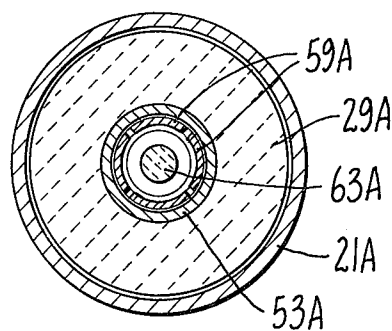
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ABSTRACT

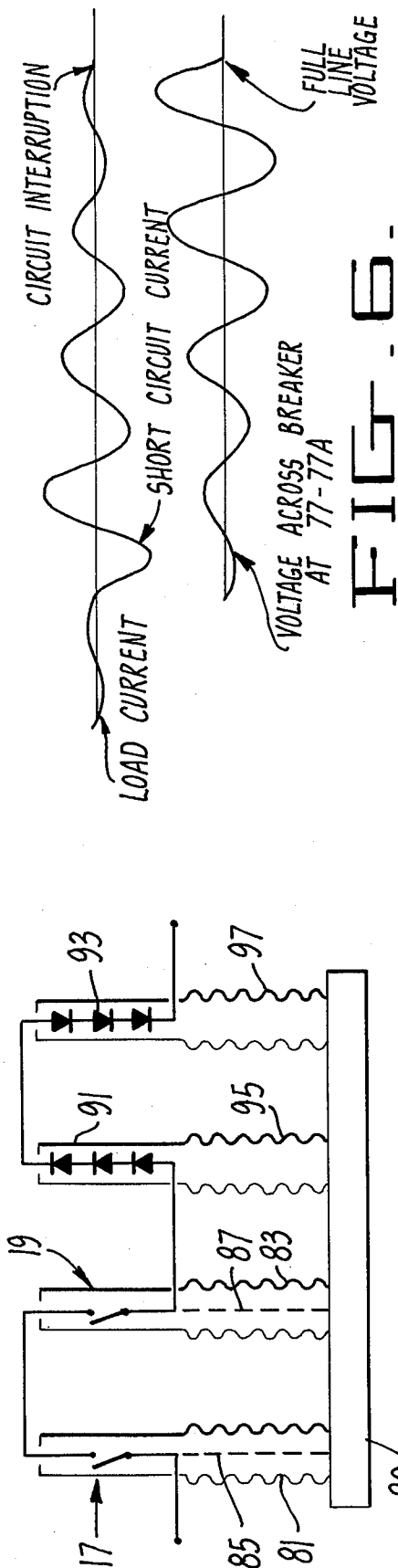
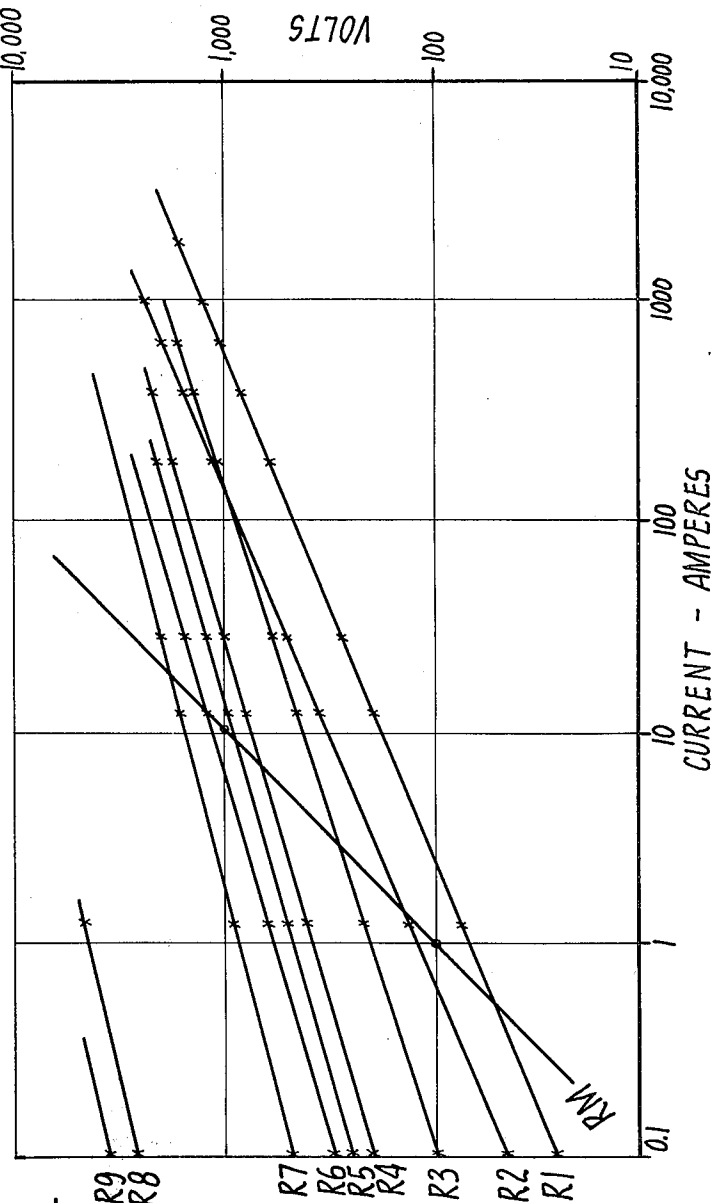
A circuit breaker and method for avoiding the creation of high surge voltages during interruption or completion of a high voltage circuit by gradually reducing the current to a value of zero or near zero when interruption occurs and gradually increasing the current from zero to the full value of the current in the electric circuit during the closing operation.

13 Claims, 6 Drawing Figures





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CIRCUIT BREAKER**RELATED APPLICATION**

This application is a continuation of my co-pending application, Ser. No. 12,179, filed Feb. 18, 1970, and entitled **CIRCUIT BREAKER**.

BACKGROUND OF THE INVENTION

The present invention relates to a circuit interrupter device and, more particularly, to a high voltage electric circuit breaker which is operable to avoid the creation of high surge voltages during the opening or closing thereof by gradually reducing the current to a value of zero or near zero when interruption occurs and gradually increasing the current from zero to the full value of the current in the electric circuit during the closing operation.

A significant amount of research has been conducted relating to switching surges caused by circuit breakers. Various prior art approaches have been devised such as by-pass metallic resistors to reduce high voltage created by switching surges; however, such prior art devices are characterized by their complexity and relatively high costs. Further, prior art mechanisms have not been completely successful in avoiding the creation of high surge voltages nor in the prevention of other undesirable electrical phenomena such as high voltage switching re-strikes, the creation of trapped charges on transmission lines, and the creation of high transient recovery voltages across the circuit breaker poles at the time of circuit interruption. Also, prior art approaches do not readily lend themselves to use with both high alternating voltage circuits or high direct voltage circuits.

SUMMARY OF THE INVENTION

It is, therefore, a principal object of the present invention to provide an electric circuit breaker adapted to avoid the creation of high surge voltages during the opening or closing thereof.

It is a further object of the present invention to provide a high voltage electric circuit breaker which may readily be utilized to switch currents in either high alternating voltage circuits or high direct voltage circuits.

Still another object of the present invention is to provide a circuit breaker so constructed as to prevent re-strikes during switching of high voltage lines.

It is yet another object of the present invention to provide a high voltage electric circuit breaker which substantially eliminates trapped charges on associated transmission lines.

Still another object of the present invention is to provide a high voltage electric circuit breaker so constructed as to prevent high transient recovery voltages across the poles thereof at the time of circuit interruption.

One more object of the present invention is to provide a high voltage electric circuit breaker which avoids the necessity of having accurate coordination adjustments of the breaker pole closing sequence on the various phases at the time of closing the breaker, as is the case with prior art circuit breakers, to prevent closing voltage surges.

It is one more object of the present invention to provide a high voltage electric circuit breaker incorporating means for changing the power factor, in the associated electric circuit, from either lagging or leading to

unity or near unity power factor at the time of circuit interruption.

Yet another object of the present invention is to provide an improved method of interrupting a high voltage circuit.

Still another object of the present invention is to provide an improved method of completing a high voltage electrical circuit.

The above-noted and other objects have been attained in accordance with the teachings of the present invention by providing a method and apparatus adapted for uses with high voltage circuits wherein a movable breaker contactor sequentially traverses a plurality of electrical series connected resistors. The traversal of the breaker contactor from a fully closed to a fully opened condition progressively interposes the resistors into the circuit. The resistors are particularly selected for progressively increasing or decreasing non-linear voltage resistance characteristics to produce an accelerating decreasing or increasing current transient during breaker contact motion, whereby arcing is eliminated. Further, the breaker contactor is connected to an insulator follower which compresses any generated arc gasses into a smaller air space, whereby the arc is extinguished. In an illustrated embodiment of the present invention, two circuit interrupters are disposed in series with each being a substantially complete unit incorporating its own movable breaker contactor. The contactors are actuated by means of a common actuator mechanism.

DESCRIPTION OF THE DRAWINGS

The above-noted and other objects of this invention will be understood from the following description taken with reference to the drawings wherein:

FIG. 1 is a longitudinal sectional view illustrating a circuit breaker having two interrupters constructed in accordance with the teachings of the present invention disposed in series and in a closed circuit condition;

FIG. 2 is a longitudinal cross-sectional view illustrating details of one of the interrupters employed in the arrangement of FIG. 1 with the constituent elements thereof disposed in relative positions assumed thereby when the circuit breaker is in an open condition;

FIG. 3 is a cross-sectional view taken along the line 3—3 of FIG. 1;

FIG. 4 is a diagrammatic view illustrating the circuit breaker constructed in accordance with the teachings of the present invention utilized in series with diodes for converting an alternating circuit into a unidirectional circuit;

FIG. 5 is an illustration of a family of curves showing typical voltage-current characteristics of resistors used in this invention; and,

FIG. 6 is an illustration of a typical oscillogram showing current and voltage during circuit interruption.

DESCRIPTION OF THE ILLUSTRATED EMBODIMENT

Referring now to FIGS. 1-3 of the drawing, a preferred embodiment of the present invention is illustrated. The circuit breaker includes an outer cylindrical housing 11 having associated therewith an integral bottom wall and a top wall 13. Disposed within the housing between the walls are two circuit interrupters, indicated generally by means of reference numerals 17 and 19, which are mounted by means of any desired expedient. The interior defined by housing 11 and wall 13 is

filled with a suitable material, such as dry air under pressure, insulating oil or gas such as SF-6.

Since circuit interrupters 17 and 19 are of substantially identical configuration, only interrupter 17 will be described in detail. Interrupter 17 comprises a cylindrical element 21 having fastened thereto by any suitable expedient a top casting 23 and a bottom casting 25 defining a centrally disposed throughbore 27. Disposed within cylindrical element 21 and spaced from the inner wall thereof are a plurality of doughnut-shaped resistance elements 29, 31, 33, 35 and 37 positioned in stacked relationship. Disposed between the resistance elements in the manner illustrated are contact rings 41, 43, 45 and 47, said rings being constructed of any suitable electrically conducting material. Contact rings of like construction, designated by means of reference numerals 49 and 51, are disposed respectively above and below the stacked resistance elements.

Positioned between the contact rings and disposed adjacent to the resistance elements are a plurality of spacer rings 53, all of which are of generally cylindrical construction and of a longitudinal length substantially equal to that of the resistance elements with which they are associated. It may readily be seen that the spacer rings 53, acting in combination, define a throughbore 55 into which the contactor rings project. Positioned within throughbore 55 and spaced from the contact rings in the manner illustrated is a conductor tube 57 constructed of any suitable electrically conducting material. Secured to the uppermost portion of conductor tube 57 are a plurality of contactors 59. The contactors are in the form of spaced upstanding flexible fingers and are constructed of a suitable electrically conducting material. The contactors 59 are dimensioned such that they are in free sliding engagement with the circuit breaker contact rings. The length of the contactors is such that at least one contactor ring is in engagement therewith at all times. Also secured to the topmost portion of conductor tube 57, as by means of a threaded bushing 61, is a follower 63 constructed of any suitable electrical insulating material and including an enlarged head 65 disposed above contactors 59.

At the bottom thereof, conductor 57 is secured in electrically conducting engagement by means of any suitable expedient to a crossbar 67 which is also constructed of electrically conducting material. Crossbar 67 is secured in any desired manner to an actuator rod 69 constructed of suitable insulating material which is disposed for free sliding movement with respect to top wall 13 and bushings 71. It is to be understood that reciprocal movement of actuator rod 69 is effected by means of any suitable mechanism (not shown) with which it is operatively associated. As may readily be seen with reference to the drawing, crossbar 67 also extends between the interrupters 17 and 19 of the circuit breaker and is affixed in electrically conducting engagement with the conductor tubes 57 and 57A thereof.

Circuit interrupters 17 and 19 are identical in all respects except for the angles assumed by the integral connector members 75 and 75A disposed on the top castings thereof. Connector members 75 and 75A are in electrical engagement with wire leads comprising a portion of electrical circuit with which interrupters 17 and 19 are associated. Insulating bushings 77 and 77A maintain these wire leads out of engagement with top wall 13.

In FIG. 1, both circuit interrupters 17 and 19 are illustrated in a closed position with an electrical circuit being completed therethrough as follows: Electrical current flows through connector 75, top casting 23, and thence to top contact ring 49 which is positioned in engagement with the top contact ring 49 which is positioned in engagement with the top casting. Since contactors 59 are in engagement with top contact ring 49 when the circuit interrupter 17 is in a closed position, current flows from the top contact ring into the contactors and, thence, downwardly through conductor tube 57. Current then flows through crossbar 67 between conductor tube 57 of interrupter 17 and conductor tube 57A of interrupter 19. The circuit is completed through contactors 59A, top contact ring 49A, top casting 23A, integral connector member 75A and, thence, outwardly through insulating bushing 77A.

The opening operation is as follows: The operating mechanism (not shown) pulls actuator rod 69 in a downward direction. Crossbar 67, being affixed to the actuator rod, also moves in a downwardly direction, pulling therewith conductor tubes 57 and 57A along with their associated contactors 59 and 59A, respectively. In the interest of clarity, the opening operation will be specifically described only with reference to circuit interrupter 17; however, it should be understood that, since the contactors of both interrupters move downwardly at the same rate, the opening operations of the interrupters 17 and 19 are identical. As contactors 59 of circuit interrupter 17 disengage from the top contact ring 49 thereof, the path of electrical flow changes so that it is through top contact ring 49, resistance element 29, contact ring 41 and, thence, through the contactors. As the movement continues, the contactors 59 separate from ring 41, which interposes resistance element 31 into the circuit by virtue of the fact that the contactors have now been brought into engagement with contact 43. Contactors 59 then separate from ring 43 which places resistance element 33 in the circuit. Contactors 59 then separate from ring 45 which places resistance element 35 in the circuit. As the contactors disengage from contact ring 47, resistance element 37 is placed into the circuit by virtue of the contact between the contactors 59 and bottom contact ring 51. Finally, contactors 59 disengage from bottom contact rings 51 and 51A and a gap (FIG. 2) is placed between the contactors and the remainder of the circuit breaker. In FIG. 2, the respective positions assumed by the elements of circuit interrupter 19 are illustrated when said circuit interrupter is in a fully opened condition. Since circuit interrupters 17 and 19 are operated in a tandem manner, the circuit interrupter 17 would also be in a similar condition. At this point, current flow through the circuit breaker has fully terminated.

An important feature of the present invention resides in the fact that the doughnut-shaped resistance elements of each circuit interrupter are carefully chosen so that they have progressively increasing or decreasing voltage-resistance characteristics to produce an accelerating decreasing or increasing current transient upon contactor motion, whereby arcing is eliminated. The resistance elements to assume the desired characteristics are constructed of differing materials such as silicon carbide, boron carbide, tungsten carbide, aluminum oxide, zirconia, etc., all of said materials having non-linear voltage-resistance characteristics. In addition, the basic materials of the resistance elements may

have various additives added thereto to obtain the desired resistance, such as the addition of alumina to silicon carbide. In carrying out the teachings of the present invention, any number of resistance elements may be used in series, depending on the circuit voltage and the load current or short circuit current to be interrupted. It is, however, a requirement that the total resistance be of such a high value that the current will be reduced to zero or near zero when the opening movement of the circuit breaker is completed.

By constructing the topmost resistance element of each circuit interrupter of a material having a low spe-

duction in voltage drop across the associated terminal contact rings due to the current reduction.

To assist in the proper understanding of the present invention, reference may be had to the following table which gives typical test results of nine resistance elements, in series, in a circuit breaker which is constructed in accordance with the teachings of the present invention and which constitutes one-half of a two-interrupter assembly, such as that illustrated. The table gives the system voltage, rated current of the breaker and system short circuit current. The power factor of the system is 0.7.

CIRCUIT BREAKER RATING: 15 KV 200 amp.
15 KV 2000 AMPS 0.70 POWER FACTOR SHORT CIRCUIT CONDITIONS

Current Amps	EXTER- NAL IMPED- ANCE DROP	Voltage Drop Across Each Resistance Element								
		1	2	3	4	5	6	7	8	9
1540.0	11541.	1726.								
938.7	7040.	1394.	2582.							
632.9	4747.	1175.	2174.	1778.						
340.0	2550.	898.	1657.	1447.	2222.					
169.0	1267.	663.	1221.	1148.	1803.	2028.				
70.5	529.	454.	834.	859.	1389.	1586.	2113.			
27.0	202.	300.	548.	625.	1043.	1211.	1590.	2080.		
1.2	9.	78.	141.	224.	413.	506.	634.	924.	4574.	
0.1	1.	25.	45.	94.	189.	243.	293.	468.	2671.	3469.

cific voltage-resistance characteristic, this desired end is accomplished. Once again referring to FIG. 1, the resistance elements having the lowest specific voltage-resistance characteristics are resistance elements 29 and 29A. The maximum current of the circuit upon initial opening of the circuit breaker will then pass through these resistance elements and a relatively high voltage will be established between rings 49 and 41 in between 49A and 41A of circuit interrupters 17 and 19, respectively. Due to the non-linear voltage-resistance characteristic of both resistance elements 29 and 29A, these resistance elements will have a low resistance opposing the flow of current. The resistance elements 31 and 31A are so constructed as to have a higher specific resistance than resistance elements 29 and 29A. Also, due to the non-linear voltage-resistance characteristic thereof, resistance elements 31 and 31A will have a low resistance opposing the flow of current; however, the material is selected so that the resistance of resistance elements 31 and 31A is higher than that of resistance elements 29 and 29A. In like manner, resistance elements 33 and 33A are selected so as to have a higher specific resistance than resistance elements 31 and 31A. Also due to the non-linear voltage-resistance characteristic thereof, resistance elements 33 and 33A will have a low resistance opposing the flow of current but selected so as to have a higher resistance than resistance elements 31 and 31A.

As each resistance element is cut into the circuit by the movement of contactors 59 and 59A, the current in the external circuit is reduced in value, with the assumption that the circuit voltage remains constant or near a constant value. For each reduction in the current, each voltage-resistance curve and each resistance element will increase its resistance according to the re-

The voltage drop across each resistance element is given for each step of the associated contactor arrangement, such as contactors 59 in the disclosed embodiment. Upon the insertion of the first resistance element into the circuit, the current is reduced to 1540 amps and the voltage drop across the resistance element is 1726. When movement of the contactor assembly is completed, the voltage drop across the topmost resistance element is only 25.

It is to be understood that the voltage drops across the other resistance elements will also change as each resistance element is cut into the circuit by the movement of the contactors which are employed. As an example, the resistance element designated as number 5 above has an initial drop of 2028. volts and when the movement of the contactors is completed the voltage drop thereof is 243. volts.

FIG. 5 provides a graphic illustration of the results set forth in the above table. The values are plotted on log-log ordinatess which gives approximately a straight line for each resistance element. Each resistance step showing the current decrease resulting from the movement of the circuit breaker contactors is shown in FIG. 5. As an example, the resistance element identified by reference numeral 1 in the table above has nine steps of voltage-current values; resistance element 5 has five steps of voltage-current values and resistance element 9 has only one which is the last resistance insertion before complete circuit interruption. The system current is reduced to 0.1 amp or only 100 milli-amps at the time of total circuit interruption.

The following table gives the individual resistance, in ohms, of the nine experimental resistance elements referred to above which are employed in a circuit breaker comprising one-half of a two-interrupter arrangement such as that disclosed in the illustrated embodiment.

Power Factor	Total Imped.	1	2	3	4	5	6	7	8	9
0.814	9.	1.								
0.932	15.	2.	3.							
0.970	22.	3.	4.	3.						
0.992	42.	4.	5.	4.	7.					
0.998	87.	5.	7.	7.	11.	12.				
1.000	211.	6.	12.	12.	20.	23.	30.			
1.000	554.	11.	20.	23.	39.	45.	59.	77.		
1.000	12422.	65.	117.	185.	342.	420.	526.	766.	3789.	
1.000	168690.	284.	508.	1060.	2130.	2736.	3298.	5261.	30046.	39020.

The first resistance element, i.e., the resistance element designated 1 in the tables above, has a resistance of 1.0 ohm at 1726 volts and, when the movement of the associated contactor is completed, the first resistance element has a resistance of 284 ohms or a resistance ratio of 284/1.0 which is 284 times its original value. This is due to its non-linear, voltage-current characteristic. The voltage drop across the other resistance elements changes when the associated contactor inserts them into the circuit in a non-linear function. For example, the resistance element 5 above changes from 12 ohms to 2736 ohms or an increase of 228 times its original value.

As may clearly be seen with reference to the last table above, the insertion of the non-linear resistance elements in the system changed the overall impedance from 7.5 ohms to 168690. ohms or a ratio of 22490. to 1. This insertion reduced the short circuit current from 2000 amps to 0.1 amp or 100 milli-amps. It also changed the system power factor from 0.7 to unity at the time of circuit interruption.

The curve RM is drawn on FIG. 5 to show the comparison between the one or two metallic by-pass resistors used in the present and prior art circuit breakers, to reduce switching voltage surges, and the non-linear resistance used in this invention.

Referring to the curve RM, it will be seen that at 100 volts the current is 1 amp and the resistance is 100 ohms. At 1000 volts, the current is 10 amps and the resistance is 100 ohms.

For comparison, refer to non-linear curve R2; at 100 volts, the current is approximately 0.9 amp. and the resistance is 110 ohms. At 1000 volts, the current is 120 amps and the resistance is 8.3 ohms.

With reference to both the above-noted tables and FIG. 6 which shows the typical oscillograms of current and voltage across the breaker during circuit interruption, it may be seen that there is a gradual decrease in short circuit current to the low value of 0.1 amp at the final resistance insertion. The voltage across the breaker terminals increase to full line voltage without any arc voltage at the time of circuit interruption. If the external circuit is alternating or direct current, the gap between the contactors and the remainder of the circuit breaker upon total opening thereof will de-ionize and the circuit will be interrupted without any arc energy being dissipated to create surge voltages, trapped charges on a transmission line, or re-strikes. The results set forth in the above tables can quite easily be interpolated to predict the performance of a circuit breaker constructed in accordance with the teachings of the present invention and having a higher or lower capacity than the noted test circuit breaker. For example, if the circuit breaker of this invention were designed for a 150,000 volt circuit, rather than a 15,000 volt circuit,

and it was desired to reduce the current to 0.1 amp at circuit interruption, the total resistance would be 10 times 168,690 or 1,686,900 ohms.

To better understand the performance of the circuit breaker of the present invention, it is necessary to compare it with typical prior art breakers with metal by-pass insertion non-linear resistors.

For any linear metal resistor, the formula $I = E/R$ applies, where I is the current, E is the voltage and R is the ohmic resistance.

The approximate expression for the resistance elements utilized in this invention, however, is $I = [E]/[C]^n = KE^n$, where:

I = the instantaneous a.c. or d.c. current passed through the resistance elements;

E = the instantaneous a.c. or d.c. voltage drop across the contact rings;

C = a constant (volts at 1 ampere);

K = a constant (amperes at 1 volt); and,

n = an exponent.

The constants K and C depend upon the resistivity of the material and the dimensions of the particular resistance elements employed. The exponent n depends on the various materials and the manufacturing processes used in making the resistance elements. The exponent may be of any value from 1 up to 3.5, 7, 11 or above.

Utilizing the formulas given above, the doubling of the applied voltage in a plain metallic resistor will increase the current by a ratio of 2. Utilizing the circuit breaker according to the present invention, however, doubling of the voltage of the resistance elements will increase the current by a ratio of 11, if $n = 3.5$, and by a ratio of 128, if $n = 7$. If the volt-amp characteristic of the illustrated topmost resistance elements 29 and 29A is compared to the overall volt-amp characteristic of all of the resistance elements in series, the ratio of either resistance element 29 or resistance element 29A to the other resistance elements operatively associated therewith becomes an enormous value for any given circuit voltage.

In the design of a circuit breaker constructed in accordance with the teachings of the present invention, the determination of the characteristics of the various resistance elements to be interposed therein becomes a task for a computer, as each resistance element when cut into the circuit, on the opening movement, must have a higher non-linear voltage-resistance characteristic than the previous one. As additional resistance elements are cut into the circuit, each previous resistance element in the circuit works on a different point on its current-voltage curve. The maximum current to be interrupted at the start of the opening movement will be determined by the circuit voltage and the impedance of the external circuit. This current is reduced to a value of zero or near zero when the opening movement is

completed with the contactors being spaced from the remainder of the circuit breaker and all resistors having been cut into the circuit.

When the circuit voltage and overall impedance of the external circuit is known, the various resistance elements and the total number thereof required in the circuit breaker is most readily determined by submitting all information, such as specific resistance-voltage or voltage-current curves, etc., to a computer for the selection of the particular resistance element for each position in the breaker. Utilizing such a procedure cross-over of the characteristic curves of the resistance elements (such as that between resistance elements 2 and 2 in FIG. 5) will be avoided. The task of the computer is to select the proper resistance elements so that at any given value of current being interrupted, the voltage across any resistance element will not flash over from contact ring to contact ring when the movable contactors separate therefrom.

In the event the circuit breaker constructed in accordance with the present invention is subjected to a current higher than that for which it is designed and there is an arc established when the contactors separate from the contact rings, the enlarged heads 65 and 65A of followers 63 and 63A, respectively, force the arc into a narrow annular space between each follower and the spacer rings with which they are associated. The gasses generated from the materials used in the construction of the follower, such as acetal resin compositions such as Delrin, hard fiber, or the like, will blow out the arc by an expulsion action thereby aiding in the overall circuit interruption.

Upon closing of the subject circuit breaker, the resistance elements thereof are placed into the circuit in an order which is the reverse of their order of disengagement. When the movable contactors 59 and 59A contact bottom contact rings 51 and 51A, the total resistance of all resistance elements is in the circuit. As the contactors move upwardly, each resistance element is cut out of the circuit until the top control rings 49 and 49A complete the circuit by direct engagement with their respective contactors 59 and 59A.

With reference to the foregoing description, it will be seen that there is no high in-rush current to various apparatus in the overall electric systems. This is especially helpful when closing in on large transformers where residual magnetism in the core may be in a position to augment the inrushing magnetizing current instead of being in opposition.

Referring now to FIG. 4, circuit interrupters 17 and 19 are illustrated as being utilized in an operating context to control direct or unidirectional currents. Circuit interrupters 17 and 19 are disposed in series and mounted on supporting insulators 81 and 83, respectively. For purposes of illustration, circuit interrupters 17 and 19 are illustrated as being provided with separate actuator rods 85 and 87, rather than a single actuator rod such as shown in FIGS. 1-2. Actuator rods 85 and 87 are positioned by means of a suitable mechanism (not shown) disposed in support housing 89. The interrupters 17 and 19 are in series with two stacks of diodes 91 and 93 mounted on insulators 95 and 97 of any suitable size and number depending on the voltage and current to be rectified. The combination of circuit interrupters 17 and 19 and diodes 91 and 93 becomes a controlled high voltage rectifier for high voltage d.c. transmission systems. Such an arrangement will eliminate the necessity of silicon controlled rectifiers com-

monly called thyristors and mercury-arc valves. The circuit interrupters 17 and 19 when in this context provide rapid and sure protection against line and apparatus faults and the present method of extinguishing insulator flashovers and apparatus faults by mercury-arc valve control will no longer be necessary.

The circuit interruption of d.c. currents with the circuit breaker of this invention is somewhat different than when the circuit breaker is employed with an a.c. current. With a.c., the current and voltage of the system will pass through a zero position on the a.c. wave and at a zero voltage the non-linear resistance elements will attain an enormously high value of resistance, thus interrupting the circuit even if the system current has not been reduced entirely to zero with all the resistance elements cut into the circuit.

When interrupting d.c. with the circuit breaker of this invention, the current will be reduced to near zero when all resistance elements are cut into the circuit. The distance between the contactors 59 and 59A and the bottom castings 25 and 25A will be chosen so that the space therebetween will become de-ionized and thus interrupt the d.c. circuit.

With reference to the foregoing description, it will be apparent to those skilled in the art that various changes and modifications may be made to the illustrated embodiment without departing from the spirit of the invention or from the scope of the appended claims.

I claim as my invention:

1. In an electrical circuit breaker, the improvement comprising:

a plurality of resistors of generally washer shape disposed in aligned stacked relationship to define a throughbore extending therethrough, each of said resistors having a non-linear voltage-resistance characteristic;

electrically conductive washer-shaped contacts sandwiched between and in electrical contact with said resistors, said contacts being generally concentrically disposed relative to said resistors and having contact portions exposed inwardly of the throughbore; and,

an electrically conductive contactor movable with respect to said contacts in a path within the throughbore to selectively engage the contact portions of said contacts, said contactor comprising a portion of a high voltage electrical circuit and functioning to introduce the resistors into the circuit as it moves in one direction within the path and to remove the resistors from the circuit as it moves in the opposite direction within the path and wherein at the end of movement of said contactor in said one direction the contactor assumes a condition out of engagement with said contacts and resistors and deionization occurs to interrupt the high voltage circuit.

2. The electrical circuit breaker improvement, according to claim 1 wherein said movable contactor includes an enlarged extension constructed of electrically conducting material and disposed in said high voltage circuit, said extension being adapted to slidably engage said contact portions only when said circuit breaker has not assumed a fully opened condition.

3. The electrical circuit breaker improvement, according to claim 2, wherein said extension is of a length greater than the length of one said resistors whereby two contact portions may be engaged at one time, at

least temporarily, by said extension during movement along said path of movement.

4. An electrical circuit breaker for use in high voltage circuits and adapted to selectively assume a fully closed condition wherein said high voltage circuit is completed through said breaker and a fully opened condition wherein current flow through said circuit is terminated, said circuit breaker comprising, in combination:

- a plurality of resistor elements of generally washer shape disposed in aligned stacked relationship to define a throughbore extending therethrough, each of said resistor elements having a preselected non-linear voltage-resistance characteristic whereby resistance of the element increases as the voltage drop thereacross decreases, and wherein the non-linear voltage-resistance characteristics of at least some of said elements differ from one another;
- electrical contact portions for the respective resistor elements, said portions being exposed inwardly of the throughbore; and,
- a contactor movable within the throughbore of said resistor elements to selectively engage said contact portions to cumulatively and sequentially introduce said resistor elements into said high voltage circuit as said circuit breaker assumes said fully opened condition from said fully closed condition whereby the resistance of each of the respective resistor elements introduced into the circuit increases as successive elements are introduced into the circuit, said breaker assuming the fully open condition as the result of movement of the contactor to a position out of engagement with the contact portions and resistor elements wherein deionization occurs to interrupt the circuit after the resistor elements have been introduced into the circuit.

5. The electrical circuit breaker, according to claim 4, wherein said resistor elements are introduced into said circuit by said contactor in a predetermined sequential order wherein each resistor element introduced into said circuit has a higher non-linear voltage-resistance characteristic than the non-linear voltage-resistance characteristic of the immediately preceding resistor element introduced into said circuit.

6. In an extra high voltage circuit, a circuit breaker comprising:

- a plurality of resistors of generally washer shape disposed in aligned stacked relationship to define a throughbore extending therethrough, each of said resistors having a non-linear voltage-resistance characteristic, whereby resistance of the resistor increases as the voltage drop thereacross decreases, and wherein the non-linear voltage-resistance characteristics of at least some of said resistors differ from one another;

- electrical contact portions for the respective resistors, said portions being exposed inwardly of the throughbore; and,

- a contactor movable within the throughbore for engagement with the contact portions to sequentially insert said resistors into the extra high voltage circuit whereby the resistance of each of the respective resistors inserted into the circuit increases as successive resistors are inserted into the circuit and so that each resistor inserted has a resistance higher than the previous resistor inserted in said circuit until the total resistance of said resistors reduces the current in the circuit to a substantially

zero value at a time of circuit interruption to avoid switching surges, said contactor being movable out of engagement with the contact portions and resistors after introduction of the resistors into the circuit whereby the circuit is interrupted as the result of deionization within a gap in the breaker.

7. In an extra high voltage circuit, a circuit breaker comprising:

- a plurality of resistors of generally washer shape disposed in aligned stacked relationship to define a throughbore extending therethrough, each of said resistors having non-linear voltage-resistance characteristics whereby resistance of the resistor decreases as the voltage drop thereacross increases;

- electrical contact portions for the respective resistors, said portions being exposed inwardly of the throughbore; and,

- a contactor movable from a position out of engagement with the contact portions and resistors wherein the circuit is interrupted through means of a deionization gap within the breaker to a position for movement within the throughbore for initial engagement with the contact portions to insert all of said resistors into the extra high voltage circuit to avoid high in-rush currents upon initial closing of said circuit breaker and continued movement within the throughbore to sequentially eliminate the resistors from the circuit whereby the resistance of each remaining resistor in the circuit decreases as the voltage drop thereacross increases as successive resistors are sequentially removed from the circuit as said circuit breaker progresses toward a fully closed condition until all resistors are eliminated from the circuit.

8. In a circuit breaker:

- a plurality of resistors of generally washer shape disposed in aligned stacked relationship to define a throughbore extending therethrough, said resistors having non-linear voltage-resistance characteristics whereby resistance of the resistor increases as the voltage drop thereacross decreases;

- electrical contact portions for the respective resistors, said portions being exposed inwardly of the throughbore; and,

- a contactor movable within the throughbore for engagement with the contact portions for inserting said resistors into the circuit with which said circuit breaker cooperates in a step-wise manner whereby the resistance of each of the respective resistors inserted into the circuit increases as successive resistors are inserted into the circuit and with each inserted resistor having a higher resistance than the resistance of each of said previously inserted resistors, said contactor being movable out of engagement with the contact portions and resistors after insertion of the resistors into the circuit whereby the circuit is interrupted as the result of deionization within a gap in the breaker when the current is reduced to a low value and unity power factor.

9. In a unidirectional high voltage electrical circuit: a circuit breaker for interruption of the circuit comprising a plurality of resistors of generally washer shape disposed in aligned stacked relationship to define a throughbore extending therethrough, each of said resistors having non-linear voltage-resistance characteristics whereby resistance of the resistor increases as the voltage drop thereacross decreases; electrical contact portions for the respec-

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tive resistors, said portions being exposed inwardly of the throughbore; and a contactor movable within the throughbore for engagement with the contact portions to sequentially insert said resistors into the circuit in series whereby the resistance of each of the respective resistors inserted into the circuit increases as successive resistors are inserted into the circuit and so that each resistor inserted in series has a resistance higher than the resistance of the previous resistor inserted in series until the total resistance reduces the unidirectional current in the circuit to a substantially zero value, said contactor being movable out of engagement with the contact portions and resistors after insertion of the resistors into the circuit whereby the circuit is interrupted as the result of deionization within a gap in the breaker when the current therein is reduced to substantially zero value.

10. In a unidirectional high voltage electrical circuit, means for controlling unidirectional currents comprising, in combination:

a circuit breaker including a plurality of resistors of generally washer shape disposed in aligned stacked relationship to define a throughbore extending therethrough, each of said resistors having non-linear voltage-resistance characteristics whereby resistance of the resistor decreases as the voltage drop thereacross increases; electrical contact portions for the respective resistors, said portions being exposed inwardly of the throughbore; and a contactor movable from a position out of engagement with the contact portions and resistors wherein the circuit is interrupted through means of a deionization gap within the breaker to a position for movement within the throughbore for engagement with the contact portions to insert all of said resistors at the initial closing of said circuit breaker and sequentially remove said resistors after initial closing of said breaker until the breaker becomes

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completely closed and all resistors are eliminated in the circuit.

11. In an electrical circuit breaker, the improvement comprising:

a plurality of resistors disposed in stacked superposed relationship, each of said resistors being of a generally circular shape defining a throughbore and having a non-linear voltage-resistance characteristic, at least some of which characteristics differ from one another;

contacts disposed in electrically conducting engagement with said resistors;

electrically conductive contactor means movable with respect to said contacts and in a path of movement within said throughbores to selectively engage said contacts, said contactor means comprising a portion of a high voltage electrical circuit, whereby selected resistors may be introduced or removed from said circuit upon relative movement of said contactor means with respect to said contact; and,

an insulator follower having an enlarged head fixedly mounted with respect to said contactor means and movable therewith within said throughbores to extinguish any arc which may be created along said path of movement upon disengagement of said contactor means from a contact.

12. The electrical circuit breaker improvement, according to claim 11, wherein said resistors are stacked so that each resistor has a higher non-linear voltage-resistance characteristic than does the resistor lying in superposed position with respect thereto.

13. An electrical circuit breaker improvement, according to claim 12, further comprising resilient members on the contactor having a length greater than the width of each individual resistor whereby two contacts may be engaged at one time by said resilient member during movement of contactor.

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