

June 20, 1944.

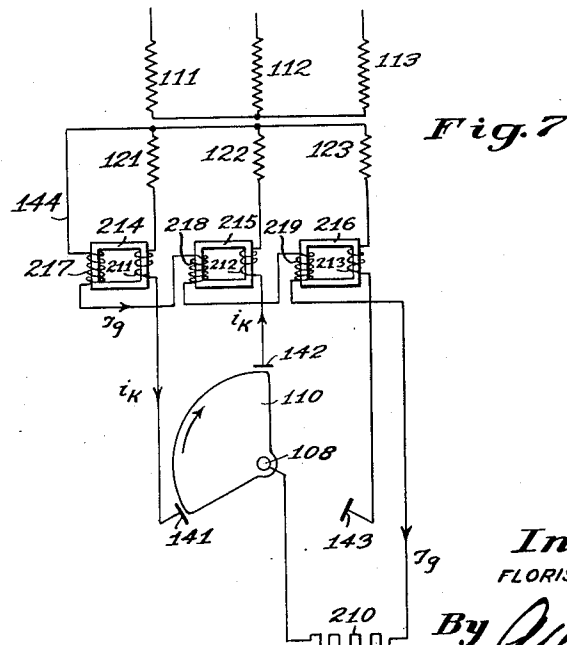
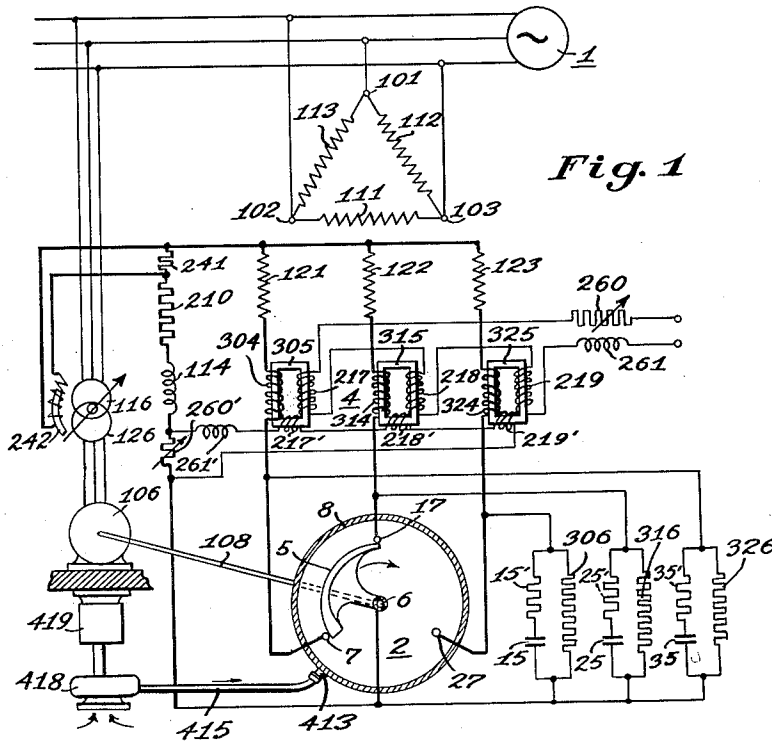
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2,351,975

APPARATUS FOR INTERRUPTING ALTERNATING CURRENTS

Filed Dec. 9, 1936

6 Sheets-Sheet 1



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Fig 8

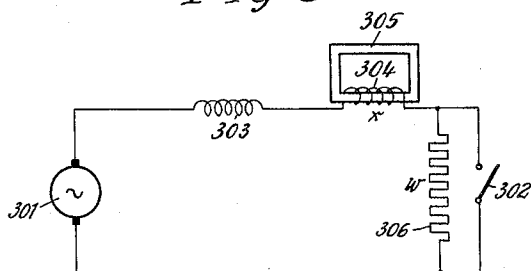


Fig 9

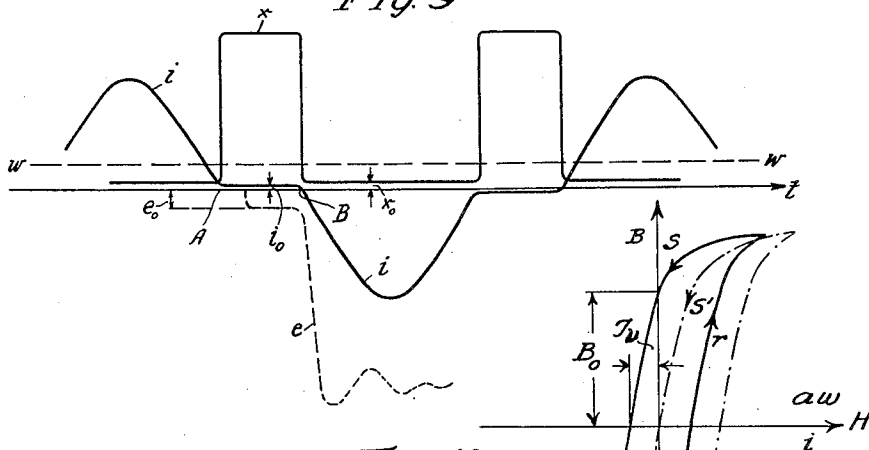


Fig 10

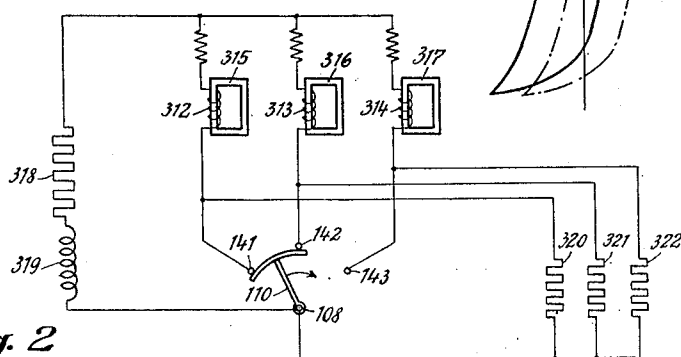
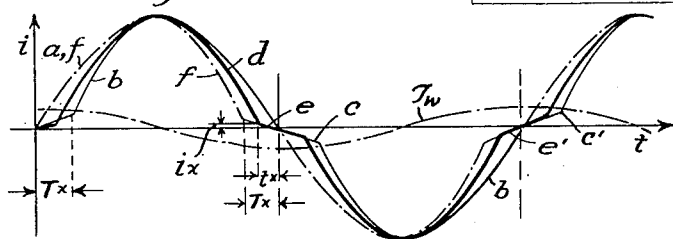


Fig. 6.

Fig. 2



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Fig. 3

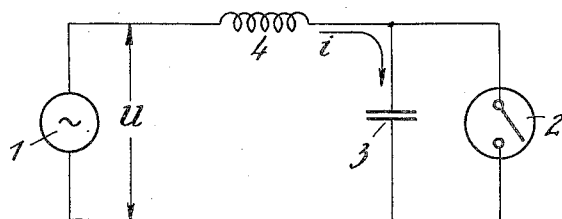


Fig. 4

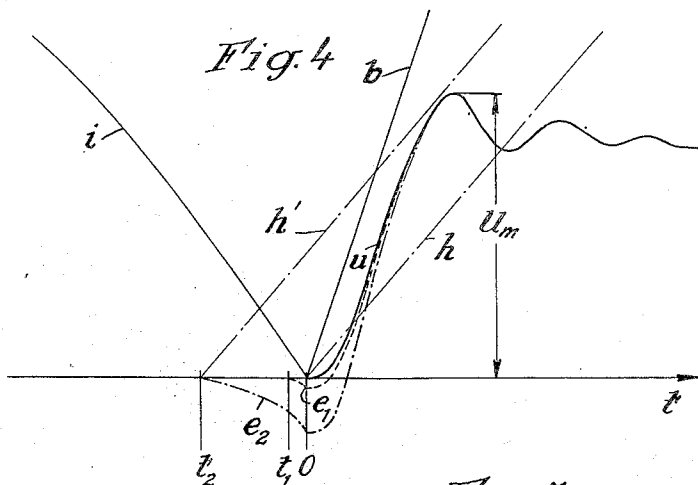
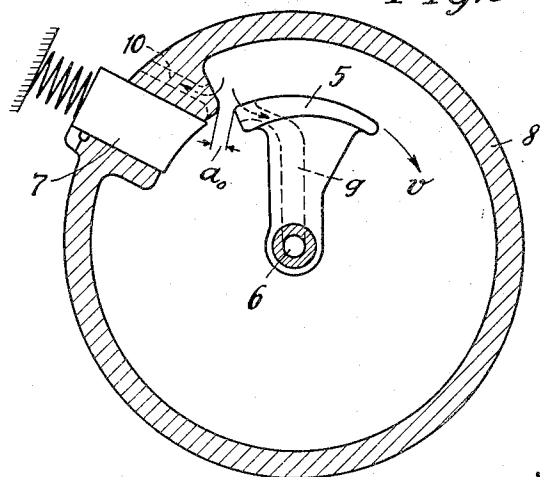


Fig. 5



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Fig. 11

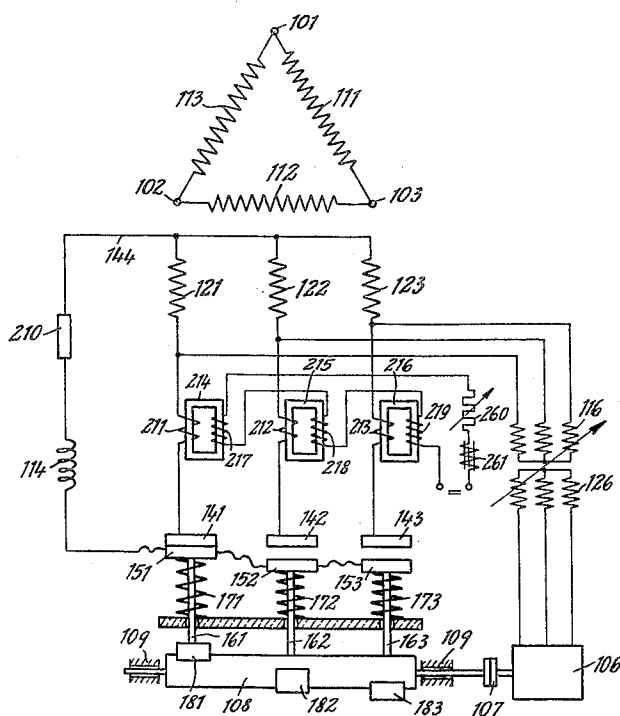


Fig. 12

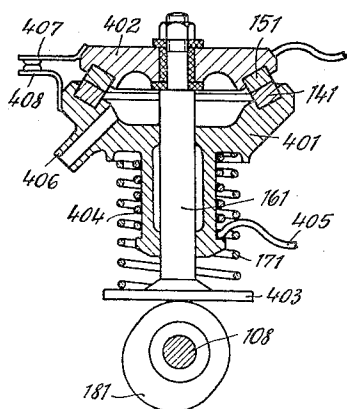
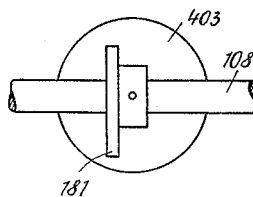


Fig. 13



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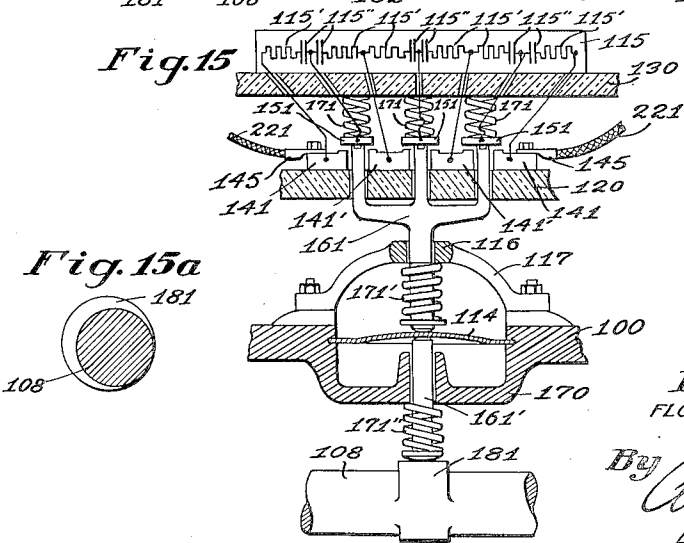
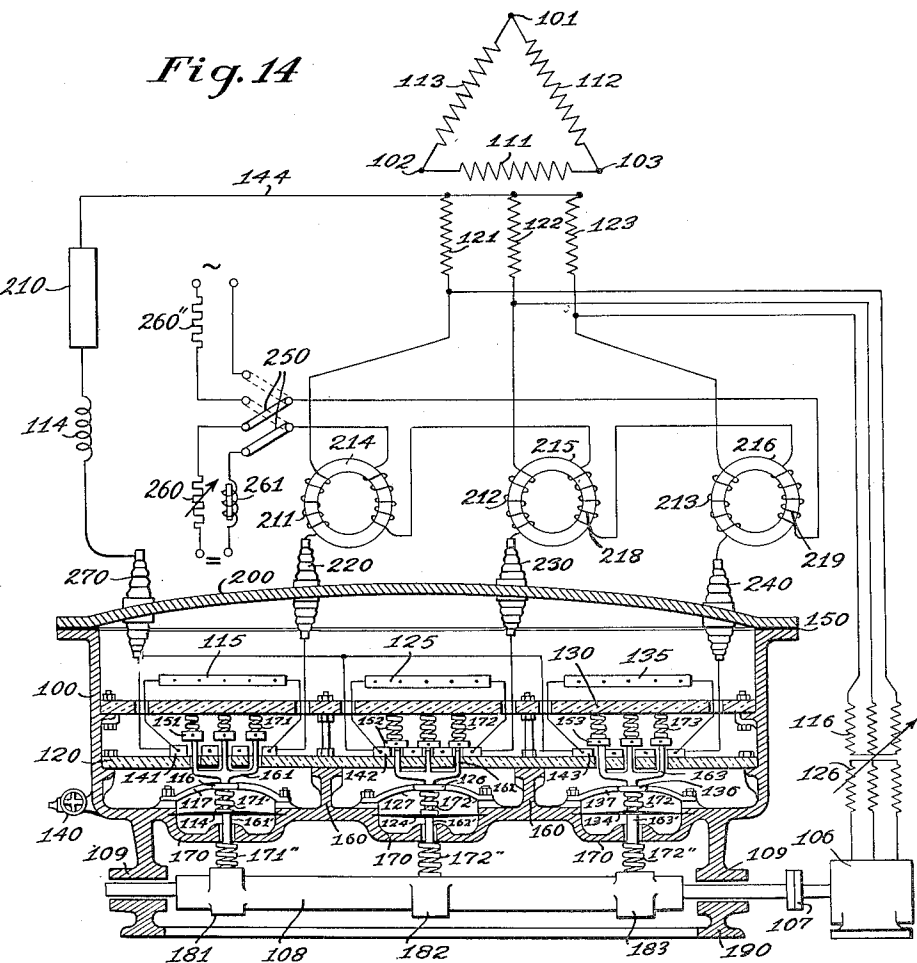
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6 Sheets-Sheet 5



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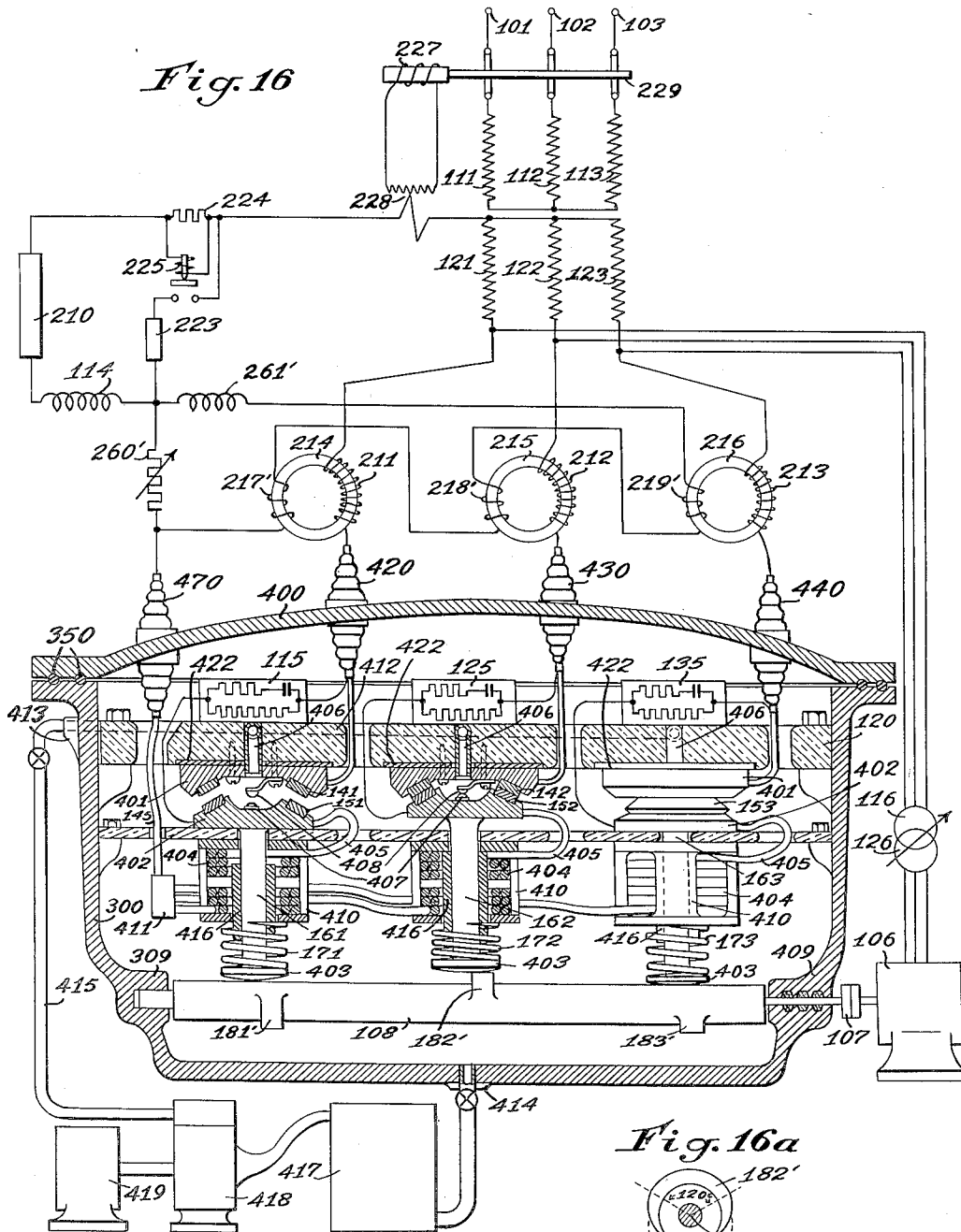
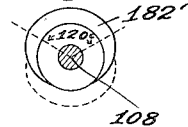


Fig. 16a



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UNITED STATES PATENT OFFICE

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APPARATUS FOR INTERRUPTING
ALTERNATING CURRENTSFloris Koppelman, Berlin-Siemensstadt, Ger-
many; vested in the Allen Property CustodianApplication December 9, 1936, Serial No. 114,965
In Germany December 13, 1935

49 Claims. (Cl. 175—364)

My invention relates to improvements in apparatus for interrupting alternating currents, particularly for the purpose of rectifying, changing the frequency of currents and of converting direct current to alternating current, with the aid of circuit breakers which are driven by a synchronous motor and interrupt the current in the neighborhood of its passage through the zero value.

The known switching devices of the above-indicated character involve difficulties in the case of great interrupting capacities, i. e. currents of high intensity or high voltage. These difficulties are essentially due to the fact that noxious discharges occurring at the break contacts, particularly destructive arcs, could not be sufficiently avoided in the case of high capacities.

It has already been proposed to provide the circuit to be interrupted with reactors which are unsaturated at a low current intensities and saturated at high operating current intensities. By these reactors the current intensities in the neighborhood of the zero value of the current are diminished and the formation of arcs is reduced. These known apparatus, however, were also not suitable for high capacities, particularly for current intensities amounting to hundreds and thousands of amperes. The occurrence of arcs could not be prevented in a reliable manner during the entire period of the contact break or interruption. These apparatus further present a relatively great loss of voltage at the contact points.

This is the reason why the switching apparatus of the above-indicated character could not compete with motor-generator sets for rectifying alternating current or converting direct current in alternating current of high intensity and why they have been completely superseded by the mercury vapor rectifiers and other tube rectifiers highly developed in the last decade.

An object of my invention is to remove the above difficulties encountered in switching apparatus for alternating current of high capacity operating with synchronously driven circuit breakers.

Another object of my invention consists in improving the efficiency of switching apparatus of the above-indicated character in such a manner as to attain in this respect also an improvement over discharge tubes, particularly mercury arc rectifiers.

A further object of my invention consists in reducing the loss of voltage as compared to the loss of voltage occurring in vapor discharge apparatus or in the above-mentioned known contact circuit breakers.

Other objects of my invention concerning the increase of the reliability of operation, the pro-

tection of the control device upon the occurrence of undesired loads as well as other improvements will be apparent from the following description taken in connection with the accompanying 5 drawings.

According to my invention the apparatus for interrupting alternating current, particularly for rectifying, changing the frequency of currents or converting direct current into alternating current are designed as follows: In each phase of the alternating-current circuit to be interrupted is arranged a contact circuit breaker. The circuit breakers are provided with a common driving mechanism which is operated by a synchronous 15 motor. The connection between the motor and the circuit breaker contacts is so arranged that the interruptions are effected in the neighborhood of the zero value of the current in such a manner that through each circuit breaker a current flows, in general, only in a given direction and that a direct current may be taken from the output circuit of the apparatus.

The apparatus may be designed for multiple-phase current and provided with known means 20 for smoothening the curve of the direct current obtained by conversion. An essential feature of this switching apparatus is according to the invention the use of means for reducing the intensity of current in the neighborhood of the zero value of the current by distorting the current and voltage characteristics of the alternating current to be interrupted, the means comprising current-controlling reactance devices series-connected to each break as well as voltage-controlling impedances connected in parallel 25 relation to the contacts. By the use of these means the intensity of current is, on the one hand, considerably reduced during the entire interruption period and, on the other hand the voltage, present between the contacts moving away from each other and increasing during their movement, is kept lower than the disruptive voltage during this movement of the contacts.

The invention renders it possible to control 30 a high effective current intensity of the order of magnitude of hundreds or thousands of amperes while maintaining in the individual circuit breakers only current intensities of at most a few amperes or less than 1 amp. during the period of interruption, so that the apparatus may be considered as a weak-current device as regards the interruption operations, even if high powers and high voltages are interrupted.

In the accompanying drawings are illustrated 35 some embodiments of my invention as well as graphs for explaining the operation of these embodiments.

Fig. 1 shows diagrammatically a complete converting system according to my invention. Figs. 40 2 to 6 are diagrams illustrating the operation

of devices according to my invention, Fig. 5 also showing constructive details of a rotary circuit breaker. Fig. 7 shows a second embodiment. Fig. 8 is an explanatory diagram representing a part-circuit of the converting system shown in Fig. 1. Fig. 9 gives a diagrammatic representation of the relation between current and voltage with reference to Fig. 8. Fig. 10 shows a third embodiment in the form of a three-phase rectifier. Fig. 11 illustrates a fourth embodiment of my invention. Fig. 12 shows in detail one of the circuit breakers employed in the embodiment of Fig. 11, which may also be used in connection with the other embodiments. Fig. 13 shows a modified detail of the circuit breaker according to Fig. 12. Fig. 14 represents a fifth embodiment, and Figs. 15 and 15a show details of Fig. 14. Figs. 16 and 16a, finally, show an embodiment having circuit breakers similar to that of Fig. 12.

Fig. 1 shows a three-phase rectifier having the following construction: 101, 102, 103 are terminals connected to the supply leads of the current to be rectified. 1 designates the alternating current generator. To the terminals are connected the three primary windings 111, 112, 113 of a transformer, the secondary windings 121, 122, 123 thereof being connected through the coils 304, 314, 324 to the stationary contacts 7, 17, 27 of a switching apparatus 2. The coils 304, 314, 324 form part of saturable reactors serving to distort the alternating current in the neighborhood of its zero value so as to reduce the current values during the commutating period. Further details of these reactors and the effect obtained thereby will be more fully described hereinafter.

The switching apparatus or commutator 2 has a casing 8 designed to be filled with compressed dielectric fluid, such as compressed air. The movable contact element 5 is mounted to a shaft 6. Shaft 6 is connected by a shaft 108 with a synchronous motor 106. An adjustable phase shifter represented by its windings 116 and 126 is interposed between the motor 106 and the alternating current leads. A compressor 418 driven by a motor 419 serves to supply apparatus 2 with compressed fluid. Compressor 418 is connected by a conduit 415 with the inlet 413 of casing 8. Further details of the switching device will be described later with reference to Fig. 5.

The neutral point of the secondary side of the main transformer is connected to the direct current load, represented by resistor 210. The direct current circuit further includes a reactance coil 114 and a resistor 260' and is connected to the movable contact 5. Directly in parallel to each of the three breaks formed between movable contact 5 and the three stationary contacts 7, 17, 27 is arranged an impedance. The impedances may consist of ohmic resistances, inductances, capacities or combinations thereof. In the embodiment shown, each impedance includes an ohmic resistance 306, 316 and 326 respectively, and a capacitor resistor arrangement 15, 15' and 25, 25' and 35, 35' respectively in parallel to the first-mentioned resistance. These complex impedances in cooperation with the throttles, aforementioned, periodically decrease the current intensity and the voltage acting between the break contacts.

The motor 106 is so driven or the connection between the motor and contact 5 is so adjusted that the interruptions of the individual phases

are brought about at a time in the neighborhood of the zero value of the current. The contacts are closed during such time intervals in which the current flowing through each contact has a given direction. In this manner only half a cycle, for instance the positive half wave passes through each contact.

In order to describe the operation of the arrangement, the alternating current curves shown in Fig. 2 are referred to.

In considering only the initial portion of the first half cycle in Fig. 2 the curve *a* represents the sinusoidal variation of the alternating current. *b* indicates the distorted current characteristic if the current is influenced according to the invention. As shown in curve *b* the current values are materially decreased over a considerable time interval T^x . This time interval T^x is designated in the following as "weak current interval" if the current curve is very strongly flattened. If the contacts are opened during this interval the discharges, which may otherwise occur after the opening of the contacts and previous to the moment when the current is interrupted by passing through the zero value, are substantially suppressed.

In the above-described switching apparatus, in which the contact motion is synchronized in such a manner with the alternating current that the contact distance is zero or very small when the current passes through the zero value, the ratio between the speed of the separating contacts, the disruptive strength of the break, and the increase in the periodic voltage of the circuit is chosen according to the invention in such a manner that the disruptive strength of the break formed between the contacts remains always greater than the returning periodic voltage stressing the break.

In this manner the switching apparatus itself operates, even at high current intensities and voltages to be interrupted, practically without formation of arcs or with very short arcs of a very slight energy which may be easily extinguished with the aid of simple devices. The consumption of the contacts remains within moderate limits even in the case of apparatus which have a high frequency of interrupting operations.

To increase the disruptive strength of the breaks, the contacts may be arranged in vacuum. Another means which is employed to advantage consists in surrounding the contacts with a particularly high-graded medium of high disruptive voltage. As dielectric gases or liquids, particularly gases or liquids under pressure are essentially employed.

At the point of break a stream of the liquids or gases may be preferably set up so as to serve at the same time as extinguishing medium. The quenching action is particularly strong if the blowing is effected with varying strength in a rhythm adapted to the switching operations. The contacts are preferably designed in the form of tuyères through which the quenching medium flows. In this case when the quenching is being effected, i. e., when the current passes the zero value, both the contact distance and at the same time the tuyère distance is small so that the quenching medium acts very effectively. Accordingly, the movable contact 5, shown in Fig. 5, contains a gas passage 9 entering the bore of the hollow shaft 6. 10 is a gas passage arranged in the stationary contact 7. The gas employed for extinguishing the arc is carried off through both

passages into a chamber of low pressure or to the outside atmosphere. The position as shown in Fig. 5 corresponds to the position in which the extinction takes place. The tuyères, i. e. the mouths of the gas passages in the contacts 5 and 7, are spaced a small distance equal to a_0 . The arc is effectively extinguished by the stream of gas, as indicated by the arrows.

It is preferable to reduce the natural frequency of the circuit to be interrupted by additional capacities, inductances, resistances or by combinations thereof to such an extent as only to involve moderate contact break speeds. The auxiliary apparatus are especially advantageous in periodically working switching devices having a great number of switching operations per time unit.

Another requirement for avoiding or effectively diminishing arc formations between the contacts consists in an appropriate adjustment of the speed of the contact movement and of the starting moment of the periodical interruptions with respect to the cycle of the current. The following explanations, referring to Figs. 3 and 4, will show how these timely adjustments are to be made in accordance with the present invention.

Fig. 3 represents a simplified scheme of one of the phases of a three or polyphase rectifier according to Fig. 1. If a circuit, as shown in Fig. 3, is supplied with energy by an alternating-current generator 1 producing a voltage U and if this circuit is interrupted by the switching device 2 when the current passes the zero value, the voltage at the electrodes of the switching device does not instantly increase to the full value U of the generator voltage since the capacity 3 acts as a short circuit when the circuit is being interrupted. The current which can no longer flow through the circuit breaker 2 flows through the inductance 4 into the capacitor 3, the voltage drop occurring substantially at the inductance 4, so that the voltage at the electrodes of the switch 2 increases only gradually from the value zero.

The increase in voltage is illustrated in Fig. 4 in which is plotted $u=f(t)$. The curve has at the initial point a horizontal tangent. The increase in voltage may be calculated approximately from the equation

$$u = \frac{U_m}{2LC} t^2$$

where L is the inductivity and C the capacity of the circuit, U_m is the maximum value of the periodic voltage and t is the time. In Fig. 4 is further plotted the straight line g which represents approximately the increase in the disruptive voltage between the opening contacts under the supposition of a predetermined break speed v of the contacts. The break speed v is chosen according to the invention in such a manner that g is always greater than u .

In the most unfavorable case the contacts are separated from one another at the moment t_1 before the current passes through the zero value so that small arcs occur having an arc voltage e_1 . In this case the voltage varies as shown by the dotted line e_1 in Fig. 4. If, however, the break speed according to the invention is not employed but a smaller speed corresponding to an increase in the disruptive voltage according to the straight line h , long arcs of a higher voltage e_2 must be put up with. The contacts should be separated somewhat sooner, i. e., at the moment

t_2 in order that after the current has passed through the zero value a gap of such a length and disruptive strength is present that it is able to withstand the recurring voltage. In Fig. 4 this shift of the opening moment required for the above purpose is indicated by shifting h in parallel to the position h' , where it no longer intersects the voltage curve u . The point of intersection of h' with the horizontal zero axis determines the time t_2 .

The desired break speed v may be approximately calculated from the following equation:

$$v \geq \frac{U_m}{E} \sqrt{2\pi f_s}$$

where E is the disruptive field strength of the medium which forms the dielectric of the switching apparatus and

$$f_s = \frac{1}{2\pi} \sqrt{\frac{1}{LC}}$$

is the natural frequency of the circuit.

For $U_m=100,000$ volts, $E=100,000$ volts/cm. (air at about 5 at. super-atmospheric pressure) and $f_s=1,000$ cycles

$$v \geq 50 \text{ meter/sec.}$$

When using a rotary circuit breaker, for instance as shown in Fig. 5, the desired break speed is obtained in the simplest manner by correspondingly selecting the distance of the rotary electrode from the shaft. However, also the speed and, therefore, the angular speed may be given a correspondingly high value. Since the disruptive voltage between the opening contacts increases considerably with increasing disruptive strength of the dielectric, a dielectric of the greatest possible disruptive strength is preferable. In the case of gases, a particularly high static pressure may be applied in order to reduce the contact speed.

The flattening of the current characteristic before the current passes through the zero value and the desired distortion of the voltage characteristic are obtained by inserting in the circuit variable resistances, particularly reactors like the saturable reactors 304, 314 and 324 shown in Fig. 1.

Impedances are particularly employed to advantage whose inductance assumes periodically great values in the neighborhood of the zero value of the current, for instance, reactors having an iron core which is instantaneously saturated during the current carrying half cycle, i. e., within the interval in which the current passes twice through the zero value. In the following, such reactors are designated as "switching reactors."

These switching reactors are so dimensioned that the ferromagnetic material is unsaturated only at small current values in the neighborhood of the zero value and saturated at higher values of the current cycle, preferably so that the saturation bend of the magnetization curve is already surpassed at current values above 1 amp.

The switching reactor acts the more favorably, the less leakage it presents. It is, therefore, designed with a large iron cross-section and with a relatively small number of turns. To this end, kinds of iron are employed to advantage, such as Permalloy or Hyperm, which have a very small remanence and a small coercive force, a high permeability, a sharp saturation bend as well as a high saturation induction. In order to employ iron having a considerable residual magnetism a magnetic bias may be brought about according to the invention by direct current or alternating

current or also by permanent magnets. In this case it is to be considered that the sudden change of the magnetic flux induces in the magnetizing turns a counter-E. M. F. This detrimental action may be compensated for by another reactor in the exciting circuit of the switching reactor or by the induction of additional voltages, particularly of separate phases.

The pre-excitation by direct current presents certain advantages when switching out; it may, however, under circumstances increase the current intensity when switching in. The current closing intensity may be maintained according to the invention at a low value by applying within the range of the switching-in period a small or opposed magnetic bias. To fulfil both the conditions of the switching-out operation and those of the switching-in operation a magnetic bias may be provided for the switching reactor by an alternating current of suitable frequency and position of phase so that the magnetization is properly effected when switching in and when switching out as well. It may, under certain circumstances, be preferable in order to attain the required degree of magnetic bias to superpose, for instance, by the load current a direct-current pre-excitation upon the alternating-current pre-excitation. This way of effecting the magnetic bias of the switching reactors is applied in the arrangement shown in Fig. 1. Each ferromagnetic core 305, 315 and 325 of the reactors 304, 314 and 324 is provided with two supplementary windings 217 and 217', 218 and 218', 219 and 219' respectively. Windings 217, 218 and 219 are series-connected in an excitation circuit which includes a variable resistor 260 and a stabilizing coil 261. Windings 217', 218' and 219' are arranged in series and connected through a stabilizing coil 261' to the variable resistor 260' arranged in the direct current branch. Windings 217', 218' and 219' serve to produce the desired dependency of the magnetic bias upon the load current.

Fig. 6 explains how the deformation of the current characteristic shown in Fig. 2 is brought about with the aid of a switching reactor. Fig. 6 represents the hysteresis loop of a switching-in coil, such as coil 304 in Fig. 1 or 3, the field strength H which is proportional to the current i being plotted as abscissa and the magnetic induction B as ordinate. On the sloping portion of the curve, i. e. when the field strength decreases, the induction B_0 exists—owing to the residual magnetism—when the current passes through the zero value and the iron core is, therefore, still approximately saturated magnetically. After the current has passed through the zero value the induction reaches the unsaturated region so that the flattened portions c, c' of the curve b (Fig. 2) occur after the current has passed through zero owing to the inductance increasing in this region. The curve portion d (Fig. 2) at the end of the first half cycle represents the variation of the current when a magnetic bias of the magnitude J_v (Fig. 6) which compensates the remanence is applied to the switching reactor. According to Fig. 6 the hysteresis loop owing to the magnetic bias shifts to the right as indicated by the dot-dash lines in case the magnetic bias has the same direction in both current half waves. Consequently, the induction on the sloping portion of the curve s' reaches at both sides of the zero value of the current the unsaturated region and the flattened portion e of the current curve d lies according to Fig. 2 at both sides of the zero value of the current. The current values, consequently,

are small in the time t^* up to the moment when the current passes through zero. At the point of the saturation bend, the current has the magnitude i^* . If this effect is to be also attained for the increasing current, a magnetic bias of varying polarity must then be introduced as shown by the curve J_w in Fig. 2. All flattened portions $e, e' \dots$ of the current curve d then lie at both sides of the zero value of the current.

By properly adjusting the magnetic bias, the flattened portion of the current curve may be shifted so far to the left, i. e. to a point before the current passes through the zero value, that in the extreme case as indicated by the curve f the point at which the current goes through zero lies on the right-hand saturation bend of the current curve. In this case a particularly long time interval, i. e. the entire weak current interval T_x , is available for the interruption of the current.

In commutating apparatus according to the invention, the following different ways of construction and adjustment may be applied: In the neighborhood of the zero value of the current a short circuit is established by the movable contact, in which circuit the current of the phase to be disconnected dies away and the current of the phase to be connected increases to the value of the load current. When the phase current to be disconnected passes through the zero value, this commutation ceases. Its duration depends upon the value of the load current. The period of commutation is, consequently, the longer, the larger the load current will be. To attain a contact break under all operating conditions before the current passes the zero value, the apparatus must be so adjusted that a contact break is properly brought about with the smallest load. While such a predetermined and fixed adjustment can be obtained with particularly simple means, it has in some cases the disadvantage that a rather long arc may arise at higher loads.

Another way of adapting and adjusting the arrangement aims at maintaining substantially the same favorable operating conditions of the switching apparatus as regards an extinction as free as possible of arcs for all loads. This may be accomplished, for instance, by maintaining the phase displacement between the point at which the commutation current passes the zero value and the contact break constant for all loads so as to ensure an operation of the electric discharge apparatus with short arcs. To this end, the displacement of the point at which the commutation current passes the zero value with respect to the contact break—the displacement varying with the load—is at least partly compensated for by influencing the commutation current in accordance with the load current.

One of the possibilities of thus controlling the commutation in accordance with load variations consists in using the load current or part of it for premagnetizing the current-flattening saturable reactors. Fig. 7, for instance, shows a simplified diagram of an embodiment in which the commutation circuit of a three-phase rectifier is controlled with the aid of switching reactors which are directly biased by the direct-current load. 121, 122 and 123 are the secondary windings of a three-phase transformer. The rotary contact element 110 of the switching apparatus which is synchronously rotated by the shaft 108. The fixed electrodes of the electric discharge apparatus are denoted by 141, 142 and 143. The direct-current load 210 is arranged between the neutral point of the transformer and the revolving pole

of the electric discharge apparatus. In the three alternating-current phases are inserted the three switching reactors 211, 212 and 213 which are arranged on one limb of each iron core 214, 215 and 216 respectively. The other limb of each core carries a coil having a greater number of turns: 217, 218 and 219 respectively. The coils 217, 218 and 219 for producing a pre-excitation of the magnetic cores 214, 215 and 216 respectively, are inserted in the direct-current circuit and may also serve as stabilizing reactance coils instead of coil 114 in Fig. 1.

A load-responsive premagnetization or bias as exemplified by Fig. 7 has the effect of controlling the phase relation of the period of increased reactive resistance to the switching operation of the synchronous contact device so as to maintain this relation substantially unaffected by load variations.

Another possibility of obtaining favorable commutating conditions consists in maintaining the position of phase between the switching rhythm and the point at which the current passes through the zero value for different loads at a constant value. The displacement of the current zero passage relative to the phase of the switching rhythm—which displacement depends upon the load—can be annulled by means of load-responsive control devices which influence the phase position of the motor actuating the switching apparatus so as to adapt this position automatically to the displacement of the point at which the current passes through the zero value. To this end, high-speed regulators are employed to advantage in order that the switching apparatus may follow the variations of load as rapidly as possible. Such a regulator is exemplified in Fig. 1 by the electromagnetic device 242 which operates the phase-shifting means 116 and 126. The device 242 is connected with a resistor 241 so that it is actuated in accordance with the voltage drop caused by the direct current load, such regulations are the more favorable, the slower the fluctuations of load come into play. A further improvement may be, therefore, obtained by retarding the variations of load by particular devices. To this end, reactors may be employed, for instance reactance coils usual in rectifier circuits as coil 114 in Figs. 1, 11, 14 and 16 or the above-mentioned switching reactors which, if necessary, may cooperate with additional reactors. Other kinds of protective devices, for instance devices for setting the apparatus temporarily out of action in case of irregular load, current or voltage conditions, may also be used. An example will be described hereinafter with reference to Fig. 16.

To reduce the slope of the periodic voltage the apparent resistance of the path parallel-connected to each break, that is the resistance of each combination 306, 15, 15' and 316, 25, 25' and 326, 35, 35' illustrated in Fig. 1, may be so rated according to the invention that its value is smaller than that which the variable series resistance, for instance the switching reactor, has when the current passes the zero value. By the use of this parallel-connected impedance in connection with the switching reactor, a lengthened weak voltage interval is attained which lasts from the starting moment of the contact separation up to the moment at which occurs the saturation bend of the switching reactor, i. e. when the inductive resistance of the switching reactor suddenly drops to a small value. Only from this moment on is the full voltage

applied to the break, while at first the voltage stress remains very small so that the interruption is considerably facilitated.

In order to explain this function of the parallel path, Fig. 8 shows a circuit representing in schematical simplification the elements of one of the branches of the rectifying circuit of Fig. 1, and Fig. 9 shows the variations of the current, voltage and resistance at the break of the circuit illustrated by Fig. 8. In Fig. 8, 301 denotes the alternating-current generator, 302 the switching device, for instance, a switch representing one of the contacts of a periodical interrupter shown in Fig. 1. 303 denotes the self-inductance of the external circuit. 304 is the switching reactor with iron core 305. 306 is an ohmic or inductive parallel-connected resistance whose value W is chosen smaller than the resistance x of the switching reactor 304 in its unsaturated state. In Fig. 9, i denotes the current which flows in the circuit Fig. 8. The weak current interval designated by the reference character i_0 which extends beyond the point at which the current passes the zero value, is brought about by the fact that the resistance x of the switching reactor greatly increases beyond the point at which the current passes the zero value. The resistance of the switching reactor varies as shown by the curve x , and the parallel-connected resistance is indicated by the straight line W . e denotes the variations of the periodic voltage at the electrodes of the break. Assuming that the interruption starts at the time A , the voltage does not increase at once up to its full value of the voltage of the circuit, but only to the value e , since part of the voltage is applied to the parallel-connected resistance W and part to the series-connected inductive resistance x and since the portion of voltage applied to W is small owing to the high value of the inductive resistance x . Only at the moment B when the iron core 305 of the switching reactor 304 is saturated so that its resistance suddenly decreases to a small value x_0 , can the voltage e increase to the full value of the line voltage. Consequently, a weak voltage interval is available extending from A to B in which the break may be easily effected.

Fig. 10 shows a simplified diagram of another three-phase rectifier which also corresponds to the principle exemplified by Figs. 8 and 9. 141, 142 and 143 denote as in Figs. 1 and 7 the three stationary contacts of the rectifier and 110 the contact rotating about the shaft 108. 312, 313 and 314 are three switching reactors lying in each phase and provided with periodically saturating iron cores 315, 316 and 317, respectively. 318 is the direct-current load and 319 a reactance coil. 320, 321 and 322 are the parallel-connected impedances consisting in this embodiment of resistors. Each resistor has one end connected to the conductors leading to the stationary contacts 141, 142 and 143 and the other end connected to a conductor leading to the rotating contact 110. The resistors 320, 321 and 322 may, for instance, represent the resistances of driving motors or other current-consuming devices. They may also form premagnetizing coils for biasing the reactors 312, 313 and 314.

This embodiment of the invention may be applied to advantage to circuits which carry currents of high intensity, but have a moderate voltage (for instance, for electrogalvanic purposes), since in this case the loss in the parallel-

connected resistances or inductances is not considerable.

With the aid of the above-mentioned variable resistances, for instance switching reactors in the circuit to be interrupted it is possible by suitably dimensioning the individual auxiliary devices not only to reduce the sparking, but also to completely suppress it. That is to say, there is a limit depending upon the current intensity and the value of the voltage below which a steady discharge in the form of a stable arc can no longer take place. This limit corresponds under normal conditions to a current intensity up to 1 amp. and, consequently, comprises the range which, as a rule, is designated as weak-current range. Various other physical magnitudes, such as pressure and nature of the surrounding medium, its temperature, material and temperature of the contacts influence the position of the upper limit of this range.

This fact may be explained in the following manner: Immediately before the contact break, a heating of the contacts takes place owing to the contact resistance which increases rapidly upon the reduction of the contact pressure. It can be assumed that immediately prior to the contact break the contacts are in engagement only at one point, so that the current is concentrated to this point. Below the current limit i_0 , the heat of the contacts is no longer able to volatilize metal, so that there is no possibility of a sparking at the contacts. Although the average current effective in contact devices according to the invention may be of very high intensity, only a current of very low intensity is permitted to flow at the point of break upon the opening of the contacts, so that the above-mentioned current limit is not exceeded until the circuit is definitely interrupted. As a result, the contacts are not subjected to consumption. Discharges are completely suppressed during the switching operations, and a great number of switching operations per time unit may be obtained.

If as a variable resistance a switching reactor is employed whose iron core is already saturated when the current attains a value which lies below the value necessary for maintaining a stable arc, it is, for instance, possible to control currents having an effective value of the order of magnitude of 10^4 amp., while during the switching period the instantaneous value thereof lies below 1 amp.

If the operating voltage is so high that by the mere use of the above-described reactors discharges are liable to occur, the voltage may be reduced during the period of interruption according to the invention by the fact that the resistor connected in parallel relation to the break attains a value which is a correspondingly small fraction of the resistance of the switching reactor in the unsaturated state.

In high-power systems the control of high current intensities presents difficulties, particularly in the case of a high frequency of make and break, since a considerable consumption of the contact material is caused by the continuously repeated formation of break arcs, thereby deteriorating the contact surfaces. Sliding contacts had been, therefore, hitherto employed for the periodical interruption of currents of high intensities by means of mechanically operated contacts, for instance, in electric interrupters even in the case of relatively low voltages, since with sliding contacts it is possible to cause the

contact surface to be ground off by the rubbing action of the moving contact. This is, however, not possible when using pressure and other anti-friction contacts, for instance, rolling contacts, since when the latter are brought into engagement no rubbing movement takes place. The use of pressure or anti-friction contacts is, therefore, only possible if at the same time the above-mentioned provisions according to the invention are so made as to completely suppress the sparking causing the consumption of the contacts.

Pressure and anti-friction contacts present over sliding contacts the advantage that great contact pressures can be employed, which result in a very small loss of voltage at the contact point. This is of particular importance in systems which are operated at low working voltages, as is the case, for instance, in the electrochemical industry. While in the customary rectifier systems losses up to 40% had to be put up with, these losses can be reduced according to the invention to a considerably smaller amount.

The use of pressure or anti-friction contacts, however, is to some extent difficult in the case of a periodically operating switching device. This is due to the fact that pressure and anti-friction contacts should be operated only with a relatively small speed in contradistinction to sliding contacts, since the reciprocating masses of the pressure contacts must be accelerated or retarded during each stroke and since the material of the anti-friction contacts is highly stressed at high operating speeds coinciding with high contact pressure.

The invention overcomes these difficulties and thus allows utilizing the advantages of non-sliding contacts for converters or rectifiers having periodically working interrupters as well as for non-periodically operated switching devices. An embodiment of this kind is described hereinafter.

As an embodiment of the above-mentioned kind, Fig. 12 shows a three-phase apparatus in diagrammatic form and Fig. 13 the construction of a contact device employed therefor. In Fig. 12 the main transformer and the individual parts of the contact device are designated by the same numerals as in Fig. 1, the series-connected reactors are denoted by the same numerals as the corresponding parts in Fig. 7. The cores 214, 215, 216 of the reactors are already saturated below the critical current intensity necessary for the occurrence of sparks at the break. The windings 211, 212 and 213 of the reactors are connected to the contacts 141, 142, 143. The contacts 151, 152, 153 are alternately brought into engagement, opposite to the action of springs 171, 172, 173, with the stationary counter-contacts 141, 142, 143 by means of the shaft 108 provided with angularly spaced cams 181, 182, 183 actuating the tappets 161, 162, 163. The shaft 108 is synchronously driven by a motor 106 through a coupling 107. The motor 106 is connected to the secondary side 121, 122, 123 of the main transformer through an induction voltage regulator 116, 126 with the aid of which the interruption may be timely adjusted with respect to the cycle of the current to be interrupted. The direct-current circuit extends from the movable contacts to the neutral point of the transformer windings through a reactance coil 114 and the load 210. The iron cores 214, 215, 216 are biased by exciting coils 217, 218, 219 which are series-connected for the three phases and are

connected to a direct-current source through a rheostat 260 and a stabilizing coil.

According to Fig. 12 the contacts 141 and 151 present circular contact surfaces and may be designed in the form of conical surfaces. This form is also employed in inlet and exhaust valves for the cylinders of internal combustion engines for obtaining the greatest possible contact surface. The rules usual for the construction of such valves may be employed to advantage in designing the contact device according to the invention, for in both cases mechanical parts are reciprocated in a rapid sequence over a given stroke so that the movable masses play a rather important part.

The contact 141 is arranged on a stationary body 401. The contact 151 is arranged on a body 402 mounted on a tappet 161 having the form of a pusher rod similar to that of a valve of a combustion engine and carrying at the lower end a plate 403. A spring 171 exerts a pressure on the body 401 and on the plate 403. The cam 181 mounted on the shaft 108 contacts with the disc 403. The bodies 401 and 402 consist preferably of a highly conductive material, for instance copper. However, they may be also made of iron or provided with an iron core. In the embodiment shown, it is assumed that both bodies are wholly or in part made of iron. In this case the body 401 may be provided with some turns which are connected to the lead 405 and which magnetize the body 401 and the iron core thereof. The function of this magnetic arrangement will be described in a later place. The body 401 is provided with a branch 406 for the supply of compressed air or compressed gas. On the bodies 401 and 402 are arranged auxiliary contacts 407 and 408 which are brought sooner into and out of engagement than the main contacts 141, 151.

It is preferable to cause at least one of the circular contacts to rotate about its geometrical axis so that always other points of the contact surface come into engagement with one another in order to prevent or retard the formation or the spreading of damaged points. To this end, a modified circuit breaker as shown in Fig. 13 which represents a plan view of the lower side of the disc 403, may be employed. In contradistinction to the form of the circuit breaker shown in Fig. 12 the cam 181 is spaced from the center of the disc 403. The disc 403 and the contact 402 associated therewith are, therefore, upon being moved in the vertical direction rotated a certain amount. In this arrangement the auxiliary contacts, if any are employed, must be arranged different from those shown in Fig. 12, as will be seen from the corresponding parts of Fig. 16 later described.

To prevent unilateral pressures on the cam shaft 108 opposite forces may be applied to the same point of the shaft, for instance, by diametrically opposite poles arranged on the shaft. To this end, the switching apparatus must be provided with an even number of poles, for instance six poles.

Particular care must be given to the design of the contacts at the contact points. In the device shown in Fig. 12, one of the contacts 141, 151 consists preferably of a soft metal and the other of a hard metal. If, in this case, the pressure with which the contact surfaces are pressed together is at least so great that it suffices to deform the softer metal a direct contact is obtained at many points of the contact surfaces even if they are, for instance, not ground. At

least one contact surface of each contact pair may be provided with perforations in a sieve-like manner through which the air or a particular gas surrounding the contacts may be supplied or discharged when opening or closing the contacts. To render the contact surfaces more resistant to disruptive discharges occurring at certain points, the surfaces are preferably made of materials of a high melting point. One of the contact surfaces may, for instance, be provided with a carbon coating. For protecting the contact surfaces to a greater extent, the main contacts, as shown in Fig. 12, are preferably provided with auxiliary contacts which close sooner and open later than the main contacts and are resiliently secured to the main contacts. Also the known means for suppressing or rapidly extinguishing sparks may be employed, for instance, by subjecting the breaks to a high pressure, surrounding them with an inert gas, or arranging them in vacuum. Also the use of a flowing quenching medium may under circumstances be of advantage. Embodiments having these features will be more fully described with reference to Figs. 14-16.

According to the invention the contacts are pressed together by electromagnetic or electrodynamic forces. To this end, the load current flowing through the switching apparatus is preferably employed by providing the contacts with iron cores around which the current leads extending to the contacts are wound to form one or more turns 404. By the tractive force produced by the load current the force exerted on the contacts to press them together is greatest when the current reaches its maximum value. With decreasing current intensity also the contact pressure decreases and disappears completely when the current passes through the zero value. The electromagnetic or electrodynamic devices may be employed in connection with the above-described mechanical devices, for instance, in the manner that they exert a frictional pressure which prevents a movement of the contacts. In the last-mentioned arrangement the electromagnetic devices remain stationary, which advantageously decreases the amount of mass to be periodically accelerated. An embodiment of this kind is shown in Fig. 16 and will be described later.

It is preferable to tune the mechanical forces relative to the electric force, or to control the electric force, when energized by a separate energy source, in response to a magnitude present in the circuit to be interrupted, for instance in response to current intensity, voltage, or the frequency of the harmonic vibrations, in such a manner that a disengagement of the contacts can be effected only below a current intensity which is not detrimental to the contacts. This, for instance, is the case if a sliding coupling 107 (Fig. 11) is arranged between the movable contact and the drive, which coupling is released as soon as the current intensity, which presses together the contacts, or the blocking frictional pressure exceeds a predetermined value.

Together with the mechanical means for separating the contacts, compressed air or compressed gas may be employed which is blown in between the contact surfaces. The contact device is then preferably shaped similar to that shown in Fig. 12 and at the same time designed as a compressed gas valve. Upon the separation of the contacts, the compressed gas escaping from between the contacts impinges upon the con-

tact surfaces, whereby not only small arcs which might be set up are extinguished but also the neat is carried off. The current is supplied to the movable contact by means of movable belts or, particularly in the case of high current intensities, by metallic diaphragms. If movable current leads are to be dispensed with, the fixed contact is divided into two parts insulated from each other to which the supply leads are connected, and the movable contact is used as a bridge between the fixed contacts. In this manner at the same time a subdivision of the break is attained, i. e. in the case of an equal stroke the double break length. By a further subdivision of each circuit breaker into a plurality of series-connected breaks, the permissible operating voltage is multiplied. By connecting resistances in parallel relation to the gaps the total voltage is distributed in equal proportions over the individual partial gaps forming the break.

An embodiment having contacts of the last-mentioned kind, which also shows some other improvements mentioned before, is illustrated in Fig. 14 showing a complete three-phase apparatus, and in Figs. 15 and 15a showing details of one of the contact breakers.

The three-phase rectifying circuit of the arrangement corresponds in general to that of Fig. 11 and is provided with the same reference numerals, so that an explanation of this part need not be repeated. That applies also to essential parts of the mechanical structure, that is, to the motor-driven elements and the circuit for actuating the synchronous motor 106. The pre-excitation windings 217, 218, 219 may by means of a switch 250 be connected to an alternating current circuit including resistor 260'' or to a direct current circuit including inductance 261 and resistor 260. The purpose and function of these means have been mentioned before. The impedances 115, 125 and 135, parallel connected to the breaks, consist of resistors 115' and capacitors 115'' (Fig. 15).

The contact breakers are enclosed by a vessel 100 vacuum-tightly covered by a cover 200 which is provided with tightened bushings 270, 220, 230 and 240 and a gasket 150. Outlet and valve 140 serve to connect the vessel to a vacuum pump. The contact elements are disposed on isolating supports 120 and 130, mounted on extensions 160 of the vessel 100.

The bottom of the vessel has a bulge 170 and carries a bridge 117, 127 and 137 respectively for each circuit breaker. In order to obtain a vacuum-tight enclosure also at the places where the periodical movement is to be transferred into the vessel, the actuating tappet of each breaker consists of two parts 161 and 161', 162 and 162', 163 and 163', respectively, which are individually biased by springs 171' and 171'', 172' and 172'', 173' and 173'', respectively, and separated from each other by an elastic and vacuum-tight diaphragm 114, 124, 134 respectively. The upper tappet 161, 162 and 163 of each breaker carries three contact elements designated by 151, 152 and 153, and is biased by springs 171, 172 and 173. Each breaker contains four stationary contact pieces. The supply leads 221 and 222 are connected by means of terminals 145 to the stationary contacts 141. The movable contacts are disposed to close the gaps between these outer contacts and the intermediate pieces 141'. Each break, accordingly, is subdivided into six series-connected gaps, each of which is bridged

by a portion of the parallel path 115 comprising one of the resistors 115' in series with one of the capacitors 115''. Since the six portions of the parallel path are equal, the total voltage acting on the breaker is distributed equally over the series-connected gaps. The subdivision of each break into a plurality of series-arranged gaps and the application of a vacuum considerably increase the capacity of the apparatus with respect to current, voltage and frequency, according to the preceding explanations.

Another embodiment, some features of which are already discussed in the foregoing, is illustrated by Figs. 16 and 16a. Essential parts of this arrangement correspond as to structure and reference numerals to Figs. 11, 12 and 14, and hence are now self-explanatory. This rectifier contains a vessel 300, gas-tightly enclosed by means of a cover 400, a gasket 350, gas-tight bushings 470, 420, 430, 440 and a packing in boss 409 through which shaft 108, journaled at its other end in boss 309, is connected to coupling 107 of motor 106.

The stationary contact element 401 of each contact breaker is mounted to support 120. 422 designates an elastic intermediate layer. Each breaker is constructed as a gas valve similar to the inlet and outlet valves of an internal combustion engine, the contact pieces 151 and 152, 153 and 141, 142 and 143, respectively, forming the seat and the disc, and the tappet 161, 162, 163, respectively, forming the pusher rod of the valve. Each valve is connected by a conduit 406 with a gas pipe 415 leading through inlet 413 to a pump 148 driven by a motor 419. The gas outlet 414 of vessel 300 is connected to a container 417 serving to filter, cleanse or cool the gas, in order to liberate detrimental gaseous or liquid admixtures, or for similar regenerating purposes as known in connection with other switching devices. Container 417 is connected to pump 418. Each circuit breaker when opening causes a stream of arc-quenching gas to sweep the contact surfaces. Besides, each movable contact element 402 is rotated by the means already described with reference to Fig. 13 while being moved into opening and closing positions. The auxiliary contacts 407 and 408 are arranged in the axis of each breaker so as to allow the movable contacts to rotate.

Each contact breaker is supplied with a magnetic device for preventing a contact movement in order to set the breaker automatically out of operation in case an irregularly high current intensity should occur at the regular opening moment. This device consists of the following parts: Each tappet 161 carries a magnetic armature 416. A frame-like body 410 for guiding the movable member is supplied with windings 404 connected to the circuit similar to coil 404 of Fig. 12. In case of irregular current intensities, for instance overloads, the coils 404 at the usual opening moment remain energized to attract armature 416 with a force sufficient to retain the movable contact in closing position in counteraction to spring 171. Thus the apparatus is automatically set out of action and the contact surfaces are protected against damage. Besides, the magnetic device is disposed to exert an increased pressure upon the contacts in the same manner as described above with reference to Fig. 12.

Fig. 16 illustrates additional means for protecting the arrangement against being damaged by irregularities which may occur after the breaker has been in proper operation. An inter-

rupter 229 is arranged in the alternating current circuit and has its tripping device 227 connected with the direct current circuit through a current transformer 228. If a sudden increase or drop of the direct current load occurs, the current transformer 228 supplies a voltage to the tripping device 227 proportional to the speed with which the load changes. If this voltage exceeds a given value, the interrupter 229 is tripped and disconnects the whole arrangement.

In Fig. 16, further, a small auxiliary load 223 is provided which is controlled by a relay 225 connected with a control resistor 224. The relay connects the auxiliary load 223 as soon as the main load drops below a given value and disconnects the auxiliary load when the main load again exceeds that value.

I claim as my invention:

1. A contact device for alternating currents, comprising at least one mechanical interrupter, a synchronous motor designed to be operated with the frequency of the current to be interrupted, an operative connection between said motor and the movable contact of said interrupter, said connection being adjusted so as to effect the interruption in the neighborhood of the zero value of the current, means for periodically reducing the current intensities in the neighborhood of said zero value and at least one impedance arranged in direct parallel connection to the break of said interrupter, the opening speed of said interrupter and the increase of the periodic voltage of said alternating current biased by said impedance being adapted to each other so that the disruptive voltage between the opening contacts of said interrupter is always greater than the instantaneous value of said periodic voltage.

2. A multiple phase contact device for alternating currents, comprising a mechanical interrupter for each phase of said current, a motor designed to be operated in synchronism to the current to be interrupted and operatively connected with said interrupters so as to open each interrupter in the neighborhood of the zero value of the current, induction windings series connected to each interrupter for reducing the current intensities in the neighborhood of said zero value, said windings being arranged on a ferromagnetic body designed to be unsaturated at small current values in the neighborhood of the zero value and to be saturated at higher values of the current cycle, and an impedance in direct parallel connection to the break of each interrupter, the opening speed of said interrupter and the increase of the periodic voltage of said alternating current biased by said impedance being adapted to each other so that the disruptive voltage between the opening contacts of said interrupter is always greater than the instantaneous value of said periodic voltage.

3. A contact device for alternating currents, comprising a mechanical interrupter for each phase of said current, said interrupter having its contacts arranged in a vessel disposed for maintaining around said contacts a medium of higher disruptive strength than air of atmospheric pressure, a synchronous motor designed to be operated with the frequency of the current to be interrupted, an operative connection between said motor and said interrupter adjusted to open the contacts of said interrupter in the neighborhood of the zero value of the current, means for periodically reducing the current intensities in the neighborhood of said zero value,

and an impedance in direct parallel connection to the break of said interrupter, the disruptive strength of said medium, the increase of the periodic voltage between the opening contacts of said interrupter biased by said impedance and the opening speed of said interrupter being adapted to one another so that the disruptive voltage between the opening contacts of said interrupter is always greater than the instantaneous value of said periodic voltage.

4. A contact device for alternating current, comprising a mechanical interrupter for each phase of said current, common driving means for said interrupters disposed to actuate said interrupters in synchronism with the current to be interrupted and to open the contacts of each interrupter at a time near the zero value of the current in the phase of said interrupter, means for agitating the medium surrounding the contacts of said interrupters during the interrupting operation, a reactor series-connected to each interrupter for reducing the current intensities in the neighborhood of said zero value, said reactor having a ferromagnetic core designed to be unsaturated at small values and to be saturated at higher values of the current cycle, and an impedance parallel connected to each interrupter, the opening speed of said interrupter and the increase of the periodic voltage of said alternating current biased by said impedance being adapted so as to maintain the disruptive voltage between the opening contacts of said interrupter greater than the instantaneous value of said periodic voltage.

5. A contact device for alternating current, comprising a mechanical interrupter for each phase of said current, common driving means for said interrupters disposed to actuate said interrupters in synchronism with the current to be interrupted and to open the contacts of each interrupter at a time near the zero value of the current in the phase of said interrupter, at least one nozzle arranged near the contacts of said interrupter and disposed for producing a blowing fluid stream during the interrupting operation, means for periodically reducing the current intensities in the neighborhood of said zero value, and at least one impedance connected to the contacts so as to be in parallel to the break of said interrupter for maintaining the disruptive voltage between the opening contacts of said interrupter always greater than the instantaneous value of the periodic voltage of said current.

6. A multiple phase contact device for alternating current, comprising a circuit breaker for each phase of said current, common driving means for periodically operating said circuit breakers so as to open the circuit in each phase near the time when the current of said phase passes its zero value, the opening speed of said breakers, the disruptive strength of the medium surrounding the contacts of said breakers, and the increase in the periodic voltage being adapted to one another so that the disruptive voltage between the opening contacts is always greater than the instantaneous value of said periodic voltage, a reactor series-connected to each breaker and having a ferromagnetic core unsaturated at small current values in the neighborhood of said zero value and saturated at higher values of the current to be interrupted, and a combined impedance including a capacity and a resistance connected in parallel to the break for reducing the initial magnitude of the periodic voltage recurring between the contacts of the breaker when opening the circuit.

7. A multiple phase contact device for alternating current, comprising a circuit breaker for each phase of said current, a common drive for said circuit breakers designed to actuate said breakers in synchronism with the current to be interrupted and to open each breaker at a time near the zero value of said current, the opening speed of said breakers, the disruptive strength of the medium surrounding the contacts of the breaker and the increase of the periodic voltage being adapted to one another so that the disruptive voltage between the opening contacts of said breakers is always greater than the instantaneous value of said periodic voltage, a reactor allotted to each breaker, said reactor having a ferromagnetic body provided with two windings, one of said windings being series-connected to said breaker, a current source connected with said other winding for pre-exciting said ferromagnetic body so that said body is unsaturated at small values and saturated at higher values of the current to be interrupted, and at least one impedance connected in parallel to each breaker for reducing the initial voltage recurring between the contacts of the breaker when opening its contacts.

8. A contact device for alternating current, comprising a mechanical interrupter for each phase of said current, common driving means for said interrupters disposed to actuate said interrupters in synchronism with the current to be interrupted and to open the contacts of each interrupter at a time near the zero value of the current in the phase of said interrupter, a reactor allotted to each of said interrupters, said reactor having a ferromagnetic body and two windings on said body, one of said windings being series-connected to the break of said interrupter, said other winding being connected to the load circuit of the contact device so as to bias said reactor in accordance with load fluctuations.

9. A rectifier for two- or multi-phase rectification comprising a contact circuit breaker in each phase of the circuit of the alternating current to be rectified, a common drive disposed for operating said circuit breakers in succession in accordance with the phase position thereof, said drive including a synchronous motor connected to said alternating current circuit, means for adjusting the phase position of each circuit breaker with respect to the moment when the current in the phase of said breaker passes through its zero value, a reactor being series-connected to each circuit breaker, said reactor having a ferromagnetic body disposed to be unsaturated at small current intensities in the neighborhood of the zero value of the current and to be saturated at high intensities of the alternating current to be rectified, and impedance means connected in parallel relation to the break of each contact circuit breaker for reducing the recurring operating voltage across the break in the initial part of the opening period, each of said impedance means comprising an ohmic resistance.

10. A rectifier comprising a circuit breaker in each phase of the alternating current to be rectified, means for periodically actuating said breakers in synchronism with said current, variable means for adjusting the phase difference between the operation of said breakers and the time at which said current passes through its zero value, load responsive means connected to the direct current circuit of said rectifier and

designed to operate said adjusting means in order to automatically adjust said phase difference in accordance with the direct current load of said rectifier, variable impedances series-connected to each circuit breaker and designed for periodically reducing the current intensities in each phase at a time near said zero value, and impedances disposed in parallel to each breaker for reducing the returning voltage intensities at the opening time of said breaker.

11. A multi-phase commutating device for alternating current, comprising a mechanical interrupter in each phase of the alternating current circuit, common driving means for actuating said interrupters in synchronism with said current so as to open each phase at a time near the zero value of the phase current, an inductance in each phase series-connected to said interrupter, said inductance being designed to increase its impedance value at small current intensities so as to reduce the current intensities in the neighborhood of the zero value, an impedance disposed in parallel to said interrupter in order to reduce the intensities of the returning voltage between the opening contacts of said interrupter, and load responsive means arranged on each of said interrupters for setting said interrupter out of operation in accordance with irregular load conditions, said means being designed to act independently of said common drive.

12. A multi-phase commutating device for connecting an alternating current circuit with a direct current circuit for rectifying and other converting purposes, comprising a mechanical interrupter in each phase of said alternating current circuit, a common synchronous motor operatively connected with said interrupters, variable means for adjusting the phase position of the operation of said breakers with respect to the time at which the current passes its zero value, means connected with said alternating current circuit for periodically reducing the current intensities in the neighborhood of said zero value, and a regulator coil arranged in said direct current circuit and designed to actuate said variable means in order to adjust said phase position in response to load variations in said direct current circuit.

13. A rectifier comprising a circuit breaker in each phase of the alternating current to be rectified, means for periodically actuating said breakers in synchronism with said current, a reactor series-connected to each of said circuit breakers and having a magnetic body designed to be unsaturated at low current intensities in the neighborhood of the zero value of the current and to be saturated at higher current intensities which are smaller than the effective alternating current intensity, a resistance connected in parallel to each circuit breaker for reducing the initial operating voltage restriking across the breaker when opening, and regulating means responsive to the intensity of the rectified direct current for controlling said alternating current so as to compensate the phase displacement of the moment of said zero value with respect to the phase position of said breakers in accordance with variations of the direct current load.

14. A rectifier comprising a circuit breaker in each phase of the alternating current to be rectified, means for periodically actuating said breakers in synchronism with said current, a reactor series-connected to each of said circuit breakers,

said reactor having a magnetic body designed to be unsaturated at low current intensities in the neighborhood of the zero value of the current and to be saturated at higher current intensities which are smaller than the effective alternating current intensity, a pre-excitation winding disposed on each magnetic body and being connected to an auxiliary circuit of a current having its intensity varying with the same frequency as that of the current to be rectified, variable means in said auxiliary circuit for varying the pre-excitation exerted by said windings on said magnetic body in order to control the phase position of said zero value with respect to the phase position of said breakers, and impedances connected in parallel to said circuit breakers for reducing the operating voltage across the breakers at the beginning of each current-interrupting operation.

15. A contact device for alternating current, comprising a mechanical interrupter for each phase of said current, common driving means for said interrupters disposed to actuate said interrupters in synchronism with the current to be interrupted and to open the contacts of each interrupter at a time near the zero value of the current in the phase of said interrupter, an induction winding series-connected to said interrupter, said winding being arranged on a magnetic core of a ferromagnetic material having a high permeability and a magnetization curve with a sharp saturation bend, said magnetic core being dimensioned so as to be unsaturated at low current intensities and saturated at the effective intensity of the alternating current to be interrupted, and an impedance parallel connected to each interrupter for reducing the periodic voltage recurring between the contacts when opening, the opening speed of said interrupter and the increase of the periodic voltage of said alternating current reduced by said impedance being adapted to each other so as to maintain the disruptive voltage between the opening contacts of said interrupter greater than the instantaneous value of said periodic voltage.

16. A rectifier for two- or multi-phase rectification, comprising a circuit breaker in each phase of the alternating current to be rectified, common driving means for operating said circuit breakers in synchronism with said alternating current so as to open each circuit breaker periodically at a time near the moment when the current passes its zero value, resistances connected in parallel relation to the breaks of each of said circuit breakers for reducing the periodic voltage recurring between the contacts when opening, a reactor being series-connected to each circuit breaker, said reactor having a ferromagnetic body the magnetization curve of which has a sharp saturation bend, said body being designed to be saturated at current intensities smaller than 1% of the effective intensity of the current to be rectified.

17. A rectifier, particularly for loads of the order of magnitude of at least 100 amperes, comprising a circuit breaker in each phase of the alternating current to be rectified, said circuit breaker having the contacts of both its poles consisting of metallic bodies in order to reduce the voltage drop, common driving means for operating said circuit breakers sequentially in accordance with the phase position thereof, said driving means comprising a synchronous motor connected to the circuit of the alternating current to be rectified and being designed for open-

ing said circuit breakers near the time when the current passes through its zero value, impedances connected in parallel relation to the breaks of each of said circuit breakers for reducing the periodic voltage recurring between the contacts when opening, and a reactor series-connected to each circuit breaker and having a ferromagnetic body saturated at current intensities of about 1 ampere.

18. A two- or multi-phase contact device for alternating current, comprising a circuit breaker for each phase of said alternating current, common means for operating said breakers in synchronism so as to open each breaker at a time near the moment of the zero value of said current, an impedance for each phase of said current, said impedance being series-connected to the circuit breaker of said phase and designed to periodically vary its impedance value in synchronism with said current so as to reduce the current intensity in the neighborhood of the zero value of said current, a second impedance connected in parallel to the break of the circuit breaker in each phase, said second impedance having its impedance value in the neighborhood of said zero value smaller than the impedance value of said first impedance.

19. A rectifying contact device comprising a mechanical circuit breaker in each phase of the alternating current to be rectified, a common synchronous motor operatively connected with said circuit breakers for operating said breakers periodically with the frequency of said current, common means for adjusting the phase of said operation with respect to the moment when said current passes through its zero value, a reactor series-connected to each break and having a magnetic body designed to decrease the reactance of said reactor between two successive passages of the current through the zero value, and impedances parallel connected to the breaks of said breakers, said impedances having their apparent resistance smaller than the highest effective reactance of said reactors.

20. A mechanical interrupting apparatus for periodically interrupting alternating current in converters, inverters or rectifiers, comprising a contact circuit breaker in each phase of the alternating current to be interrupted, a common synchronous motor for periodically opening the contacts of said circuit breakers during a time interval in the neighborhood of the zero value of the current, means for periodically distorting and flattening the current curve of the alternating current to be interrupted, said means comprising a resistor in each phase parallel connected to the break of said breaker, and an inductor in each phase series-connected to said break, said inductor having an iron core designed to be saturated during a time interval sufficient for opening the circuit breaker contacts and at a current value smaller than the current intensity necessary for maintaining a stable arc.

21. In a commutating apparatus for interrupting, rectifying or converting purposes, the combination of a mechanical circuit breaker for each phase to be commutated, said breaker having pressure contacts designed to retain the same mutual position of the contact surfaces of its stationary and its movable contact elements when said elements contact each other during the contact closing period, means for operating said movable contact element in synchronism with said current, means for adjusting the phase position of the movement of said movable contact ele-

ment with respect to the time at which the current to be commutated passes through its zero value, means for periodically flattening the current curve in the neighborhood of said zero value, and impedances connected to said contact elements in parallel to the break for reducing the periodic voltage recurring between the contacts when opening.

22. In combination with a commutating apparatus according to claim 21, said contact elements of said circuit breaker having circular contact surfaces, the movable contact element being designed to move on a straight line axially with respect to said circular surfaces.

23. In combination, a contact apparatus for the periodic interruption of alternating current having a contact breaker comprising a pusher rod for each phase to be interrupted, a movable contact coaxially mounted on said pusher rod, a stationary seat carrying a stationary contact and being disposed coaxially with respect to said pusher rod and said movable contact so as to have said stationary contact engaged and disengaged by said movable contact during the operation of said pusher rod, and drive means for imparting to said pusher rod a reciprocatory movement, said movable contact and said stationary contact of said circuit breaker forming at least part of a ring, respectively, and being reciprocable with respect to each other in the direction of the geometric axis of the ring form, and means for rotating one of said contacts about said geometric axis during the interrupting period of said breaker.

24. A periodically operating switching apparatus particularly for rectifying alternating current, comprising a circuit breaker in each phase of the alternating current, a common synchronous motor operatively connected with said circuit breakers so as to effect the opening of said breakers at a time in the neighborhood of the zero value of the current, means for periodically reducing the current intensity in the neighborhood of said zero value of the current by distorting the current curve, said means including impedances series connected to said circuit breakers, voltage-biasing impedances connected in parallel to said breakers and electrically operated means for periodically increasing the contact pressure acting between the contacts of said circuit breakers during the contact period.

25. In a switching apparatus as set forth in claim 24, said means for periodically increasing the contact pressure comprising a pressure exerting magnet coil disposed to be energized in response to the load current intensity of the apparatus.

26. A two- or multi-phase commutating apparatus for interrupting, converting or rectifying alternating current, comprising a circuit breaker in each phase of the circuit of the alternating current, a driving device for operating said circuit breakers sequentially in synchronism with said current, means for periodically reducing the current intensities in the neighborhood of the zero value of said current by distorting the current curve, said means including impedances in series connection to said breakers, voltage-biasing impedances connected in parallel to the break of said breakers, current responsive means for increasing the contact pressure of said circuit breakers, said latter means and said driving device being adapted to one another so as to open said breakers only below a predetermined cur-

rent intensity not damaging to the breaker contacts.

27. In a commutating apparatus according to claim 21, said circuit breakers forming a valve, the contacts of the circuit breakers forming the seat and the disc of said valve, a conduit for the supply of compressed gas to said valve, the valve being adapted to cause the compressed gas to be blown over the contact surfaces upon the opening of the contacts.

28. An apparatus for interrupting or rectifying alternating current or converting direct current into alternating current, comprising mechanical circuit breakers, a common synchronous motor connected with said breakers so as to open said breakers in the neighborhood of the zero value of the current, alternating current resistors parallel connected to the breaks of said circuit breakers, means for reducing the current intensities in the neighborhood of the zero value of the current by distorting the current curve, said circuit breakers comprising main contacts with large contact surfaces and auxiliary contacts with small contact surfaces, said auxiliary contacts being disposed to close sooner and to open later than the main contacts and being equipped with contact surfaces of a material more resistant to arcs than the material of said main contacts.

29. A commutating device for rectifying or converting alternating current, comprising a mechanical interrupter for each phase of said current, a drive for actuating said interrupter in synchronism with said current, means for adjusting the phase position of each interrupter in order to effect the opening of said interrupter at a time near the zero value of the current to be interrupted, a variable alternating current resistance means allotted to each alternating current phase and series-connected to said interrupter, said resistance means being designed to periodically increase its impedance so as to reduce the current intensities in the neighborhood of said zero value, load responsive means designed to control the impedance of said resistance means in accordance with variations of the load of said device, and at least one impedance device connected in parallel to the break of each interrupter for reducing the initial magnitude of the normal operating voltage recurring across the interrupter when starting its interrupting operation.

30. A commutating device for rectifying or converting alternating current, comprising a mechanical interrupter for each phase of said current, a drive for actuating said interrupter in synchronism with said current, means for adjusting the phase position of each interrupter in order to effect the opening of said interrupter at a time near the zero value of the current to be interrupted, a variable inductance means allotted to each alternating current phase and series-connected to the interrupter of said phase, means for biasing said inductance means periodically so as to increase the impedance of said inductance means during the commutation period of said interrupter, and load responsive means designed to additionally bias said impedance in accordance with variations of the load of said device.

31. A commutating device for connecting an alternating current circuit with a direct current circuit for rectifying and other converting purposes, comprising a mechanical interrupter in each phase of said alternating current circuit, a drive for actuating said interrupter in synchronism with the alternating current adapted to open the break of said interrupter at a time

near the zero value of the current, an inductance in each phase of said alternating current circuit series-connected to said interrupter, said inductance having a ferromagnetic body, and two auxiliary windings, an auxiliary circuit connected to one of said auxiliary windings of each interrupter in order to pre-excite said body so as to increase the impedance value of said inductance at a time near said zero value, load responsive means in said direct current circuit connected to said other auxiliary winding of each interrupter in order to superimpose a pre-excitation of said magnetic body in accordance with the load of said device.

32. A commutating device for connecting an alternating current circuit with a direct current circuit for rectifying and other converting purposes, comprising a mechanical interrupter in each phase of said alternating current circuit, a drive for actuating said interrupter in synchronism with the alternating current adapted to open the break of said interrupter at a time near the zero value of the current, an inductance in each phase of said alternating current circuit series-connected to said interrupter, said inductance having a ferromagnetic body, means for pre-exciting said body, said means being connected to an alternating current circuit designed to increase by said pre-excitation the impedance value of said inductance during the commutation period of each interrupter, load responsive means for superimposing another pre-excitation of said magnetic body, said load responsive means being connected to said direct current circuit, and at least one impedance connected in parallel to the break of each interrupter for controlling the initial operating voltage effective across the break.

33. A multi-phase commutating device for alternating current, comprising a mechanical interrupter in each phase of the alternating current circuit, each interrupter having a stationary and a movable contact member, common driving means for successively actuating said movable contact members in synchronism with said current so as to open each interrupter at a time in the neighborhood of the zero value of the current to be interrupted, an inductance in each phase series-connected to said interrupter, said inductance being designed to increase its impedance value at small current intensities so as to reduce the current intensities in the neighborhood of the zero value, an impedance disposed in parallel to said interrupter in order to reduce the intensities of the returning voltage between the opening contacts of said interrupter, and magnetic means arranged on each interrupter and designed to prevent said movable member of the interrupter from opening in response to irregularly high currents occurring at the regular opening moment, said magnetic means having an operating coil series-connected with said interrupter and being disposed to act independently of said common driving means of said interrupters.

34. An apparatus for interrupting or rectifying alternating current or converting direct current into alternating current, comprising mechanical circuit breakers, a common synchronous motor connected with said breakers so as to open said breakers in the neighborhood of the zero value of the current, alternating current resistors parallel connected to the breaks of said circuit breakers, means for reducing the current intensities in the neighborhood of the zero value of the current by distorting the current curve, said circuit breakers comprising main contacts and auxiliary contacts,

said auxiliary contacts being disposed to close sooner and to open later than the main contacts and being equipped with contact surfaces of a material more resistant to arcs than the material of said main contacts, and means for rotating said main contacts with respect to the other main contact of each circuit breaker about the axis of its breaking movement, the auxiliary contact allotted to said rotatable main contact being attached to said rotatable contact and disposed to allow free rotations of said main contact.

35. In a switching apparatus as set forth in claim 21, said means for increasing the contact pressure comprising a magnetic core disposed on each circuit breaker in order to exert said increased pressure, and a winding arranged on said core and connected in series with the break of said circuit breaker.

36. A commutating device for connecting an alternating current circuit with a load circuit of different current characteristic, comprising a circuit breaker in each of the connecting phases between said two circuits, means for periodically actuating said breakers in synchronism with said alternating current, an inductance series connected with each of said breakers, said inductance having a magnetic body designed to be unsaturated at low current intensities near the zero value of the current and to be saturated at a higher current intensity but below the average intensity, a voltage-biasing impedance path connected in parallel to each of said breakers to reduce the initial magnitude of the operating voltage recurring across the breaker when opening the circuit, and means for preventing sudden changes of the load in said load circuit.

37. A commutating device for connecting an alternating current circuit with a load circuit of different current characteristic, comprising a circuit breaker in each of the connecting phases between said two circuits, means for periodically actuating said breakers in synchronism with said alternating current, an inductance series connected with each of said breakers, said inductance having a magnetic body designed to be unsaturated at low current intensities near the zero value of the current and to be saturated at a higher current intensity but below the average intensity, impedance means connected in parallel to each of said breakers for reducing the recurrent voltage during the opening period of said breaker, and an interrupter responsive to sudden excessive changes of the load in said load circuit and arranged in said connecting phases so as to disconnect said circuit breaker upon occurrence of such change.

38. A commutating device for connecting an alternating current circuit with a load circuit of different current characteristic, comprising a circuit breaker in each of the connecting phases between said two circuits, means for periodically actuating said breakers in synchronism with said alternating current, an inductance series connected with each of said breakers, said inductance having a magnetic body designed to be unsaturated at low current intensities near the zero value of the current and to be saturated at a higher current intensity but below the average intensity, impedance means connected in parallel to each of said breakers for reducing the recurrent voltage during the opening period of said breaker, and means responsive to changes of the load in said load circuit for switching in an additional load when said first load drops below a given value.

39. In combination, an alternating current cir-

cult, a load circuit, an electric translating system connected therebetween and including a circuit interrupting means connected therein and arranged to conduct current during predetermined intervals and arranged to interrupt the associated circuit during other predetermined intervals, and means for decreasing the current and the rate of change of the current to provide an interval of time sufficient to permit opening of said circuit interrupting means and comprising a saturable reactor including a core member, a winding connected in series relation with said circuit interrupting means and a control winding for controlling the magnetic condition of said core member, said control winding being energized to establish in said core member at the beginning of each conducting interval a flux in the same direction as that established by said first mentioned winding and tending to establish in said core member at the end of each conducting interval a flux which opposes the flux established by said first mentioned winding.

40. Switching means for periodically interrupting an alternating current circuit, comprising separable contacts in said circuit, current-limiting resistance means bridging said contacts and having a resistance smaller than the impedance of the alternating current circuit to be interrupted at substantially current zero in the current wave of said circuit, and periodically operating means for opening said contacts at substantially current zero.

41. Switching means for periodically interrupting alternating current, comprising separable contacts, a reactance device connected in series with said contacts, said reactance device being variable so as to be effective only during a predetermined time interval in the region of the zero value of the current wave to be interrupted for controlling the rate of change of said current in said region, a resistance bridging said contacts and having a resistance value smaller than the reactance of said device during said region, and periodically operating means for opening said contacts during said region.

42. With a multi-phase arrangement for transferring energy between an alternating current circuit and a direct current circuit, the combination of mechanical contact circuit breakers disposed between said alternating current circuit and said direct current circuit, each of said breakers being connected in a respective phase of said alternating current circuit, a device for periodically operating said breakers in synchronism with the frequency of said alternating current circuit, said device being designed to actuate said breakers in succession with overlapping closing periods, so that temporary short circuits including the simultaneously closed breakers are closed periodically, impedance devices designed to increase their impedance magnitude abruptly at current values below a certain periodical low value so as to periodically flatten the curve of the current to be controlled by said breakers, said impedance devices being series connected with said breakers so as to form part of said periodically closed short circuits, and load-responsive means for varying the time interval between the periodical operation of said breakers and the beginning of said flattening of the current curve, whereby the opening of each breaker is effected within an interval during which at least one of the impedance devices being series connected with said breaker in a common short circuit has an increased impedance magnitude and the absolute

intensity of the current to be interrupted is below a critical value.

43. With a multi-phase arrangement for transferring energy between an alternating current circuit and a direct current circuit, the combination of mechanical contact circuit breakers disposed between said alternating current circuit and said direct current circuit, each of said breakers being connected in a respective phase of said alternating current circuit, a periodically operating device for sequentially actuating said breakers in synchronism with the frequency of said alternating current circuit and with overlapping closing periods so that temporary short circuits including the simultaneously closed breakers are closed periodically, impedance devices designed to increase their impedance magnitude abruptly at current intensities below a certain periodical low value so as to periodically flatten the curve of the current to be controlled by said breakers, said impedance devices being series connected with said breakers so as to form part of said periodically closed short circuits, and load-responsive means for shifting the opening moments of said breakers with respect to the voltage cycle of said alternating current circuit, said means being designed to delay said opening moments at increasing intensity of the load current.

44. With a multi-phase arrangement for transferring energy between an alternating current circuit and a direct current circuit, the combination of mechanical contact circuit breakers disposed between said alternating current circuit and said direct current circuit, each of said breakers being connected in a respective phase of said alternating current circuit, a periodically operating device for sequentially actuating said breakers in synchronism with the frequency of said alternating current circuit and with overlapping closing periods so that temporary short circuits including the simultaneously closed breakers are closed periodically, impedance devices designed to increase their impedance magnitude abruptly at current intensities below a certain periodical low value so as to periodically flatten the curve of the current to be controlled by said breakers, said impedance devices being series connected with said breakers so as to form part of said periodically closed short circuits, load-responsive means for varying the time interval between the periodical operation of said breakers and the beginning of said flattening of the current curve whereby the opening of each breaker is effected within an interval during which at least one of the impedance devices then being series connected with said breaker in a common short circuit has an increased impedance magnitude and the absolute intensity of the current to be interrupted is below a critical value, an additional circuit containing an auxiliary load, and a load-responsive switching device disposed to connect said additional circuit to said arrangement upon a decrease of the load current of said arrangement below a predetermined value.

45. With a multi-phase arrangement for transferring energy between an alternating current circuit and a direct current circuit, the combination of mechanical contact circuit breakers disposed between said alternating current circuit and said direct current circuit, each of said breakers being connected in a respective phase of said alternating current circuit, a periodically operating device for actuating said breakers in synchronism with the frequency of said alternating current circuit and with overlapping closing

periods so that temporary short circuits including the simultaneously closed breakers are closed periodically, reactors having a magnetic core abruptly desaturating at low periodical current intensities so as to increase the effective reactance in order to periodically flatten the curve of the current to be controlled by said breakers, said reactors being series connected with said breakers so as to form part of said temporary short circuits, a pre-exciting winding arranged on the magnetic core of each of said reactors, a pre-exciting circuit connected with said windings, variable means disposed in said pre-exciting circuit for controlling the current flowing in said windings, and load-responsive means for varying the time interval between the periodical operation of said breakers and the beginning of said flattening of the current curve whereby the opening of each breaker is effected within an interval during which at least one of the reactors then being series connected with said breaker in a short circuit has an increased reactance and the absolute value of the current to be interrupted is below a critical value.

46. With a multi-phase arrangement for transferring energy between an alternating current circuit and a direct current circuit, the combination of mechanical contact circuit breakers disposed between said alternating current circuit and said direct current circuit, each of said breakers being connected in a respective phase of said alternating current circuit, a periodically operating device for actuating said breakers in synchronism with the frequency of said alternating current circuit and with overlapping closing periods so that temporary short circuits including the simultaneously closed breakers are closed periodically, reactors having a magnetic core designed to become abruptly desaturated and to thereby increase the reactance at low periodical current values so as to periodically flatten the curve of the current to be controlled by said breakers, said reactors being series connected with said breakers so as to form part of said periodically closed short circuits, a pre-exciting winding arranged on the magnetic core of each of said inductances, a pre-exciting circuit connected with said windings, and variable circuit means connected in said latter circuit to supply said windings with a pre-exciting current varying within each voltage cycle of said alternating current circuit.

47. With a multi-phase arrangement for transferring energy between an alternating current circuit and a direct current circuit, the combination of mechanical contact circuit breakers disposed between said alternating current circuit and said direct current circuit, each of said breakers being connected in a respective phase of said alternating current circuit, a device for periodically operating said breakers in synchronism with the frequency of said alternating current circuit, said device being designed to actuate said breakers sequentially with overlapping closing periods so that temporary short circuits including the simultaneously closed breakers are closed periodically, a voltage-biasing impedance device connected in parallel to the interrupting gap of each of said breakers for reducing the initial magnitude of the normal operating voltage recurring across the gap during the initial opening period of the breaker, inductive reactors connected in series with said breakers so as to be included in said periodically closed short cir-

uits, said reactors having a magnetic core of a ferromagnetic material having a magnetization curve with a sharp saturation bend to become abruptly desaturated, thereby increasing the inductivity at low periodical current values in order to periodically flatten the curve of the current to be controlled by said breakers, a pre-exciting winding arranged on the magnetic core of each of said reactors, and circuit means connected with each of said windings for energizing said winding by an auxiliary current synchronous with that of said alternating current circuit and having a phase position different from that of the energizing currents in the other windings and from that of the current flowing in the reactor associated with said winding.

48. With a multi-phase arrangement for transferring energy between an alternating current circuit and a direct current circuit, the combination of mechanical contact circuit breakers disposed between said alternating current circuit and said direct current circuit, each of said breakers being connected in a respective phase of said alternating current circuit, a periodically operating device for sequentially actuating said breakers in synchronism with the frequency of said alternating current circuit and with overlapping closing periods so as to periodically establish temporary short circuits including the simultaneously closed breakers, variable impedance means having an increased impedance at current intensities below a given low value so as to periodically flatten the curve of the current to be controlled by said breakers, said impedance means being series connected with said breakers so as to form part of said temporary short circuits, load-responsive means for varying the time interval between the periodical operation of said breakers and the beginning of said flattening of the current curve, whereby the opening of each breaker is effected within an interval during which at least one of the impedance means being series connected with said breaker in a common short circuit has an increased impedance and the intensity of the current to be interrupted is below a critical value, and means for periodically distorting the curve of the alternating voltage to be interrupted so as to reduce the normal operating voltage recurring between the separating contacts of each breaker.

49. A translating device for converting electric current of given characteristic into current of different characteristic, comprising mechanical contact interrupters each having a movable contact and a countercontact, a motor for periodically actuating said interrupters, means for transmitting the movement from said motor to said movable contacts, and individual controlling means allotted to each of said interrupters for displacing the opening moments of said interrupter with respect to the movement of said transmitting means, said controlling means being electrically coupled with said circuit phase containing said interrupter so as to be actuated in response to load variations of the current passing said interrupter and being adjusted to open said interrupter at a time before said current passes its zero value so that at the time of said zero value the break distance between said movable and said countercontact of said interrupter has attained a length at which the flow of current in the reverse direction is prevented with certainty.

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