March 12, 1940. E. JANETSCHKE 2,193,421

CONVERSION OF CURRENTS OR VOLTAGES WITH THE AID OF PERIODICALLY ACTUATED BREAK CONTACTS

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Fig. 1

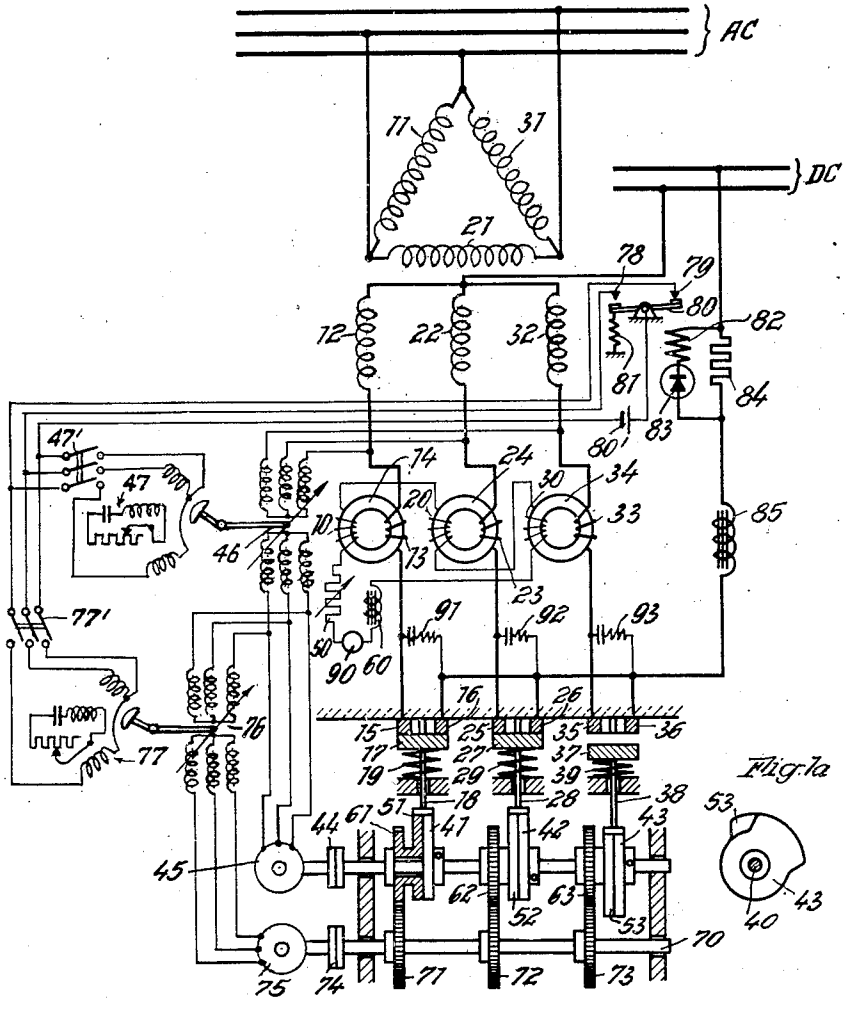

Fig. 1a

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Fig. 9

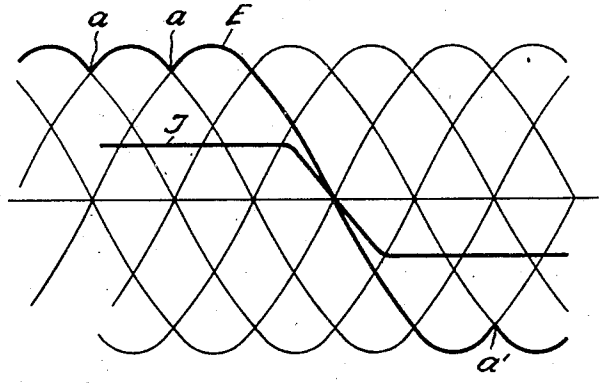
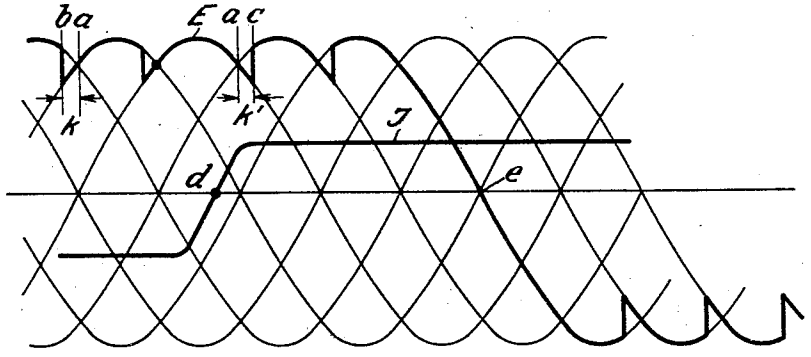


Fig. 10



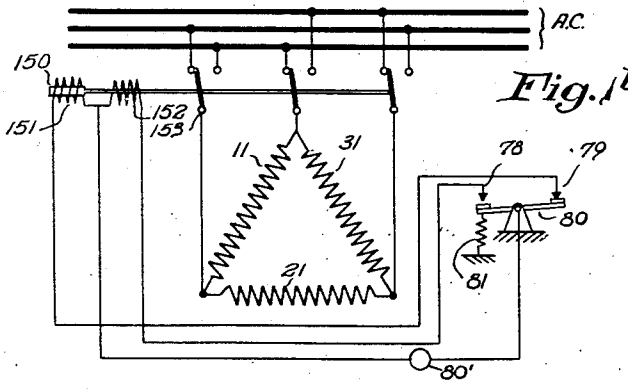


Fig. 1b

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Fig. 2

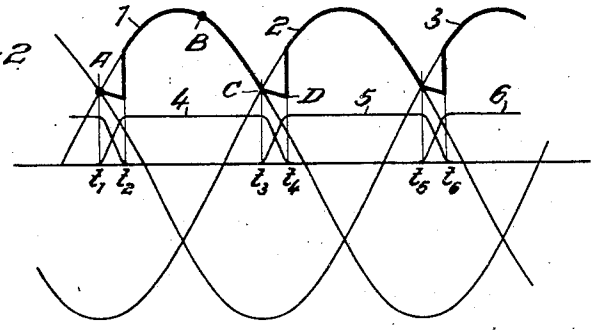


Fig. 3

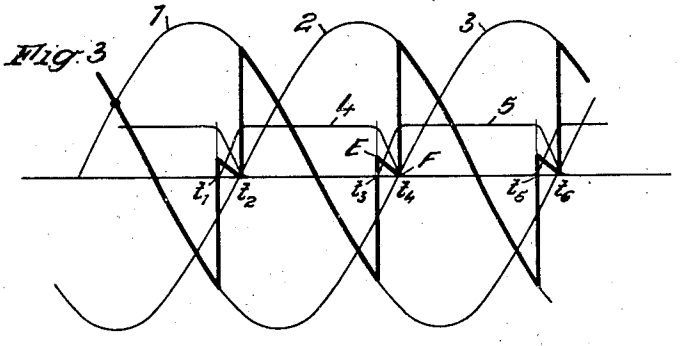


Fig. 4

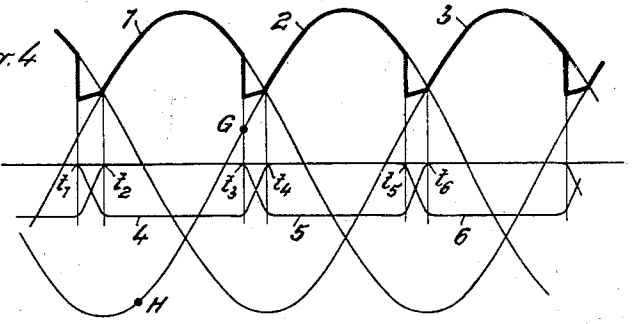
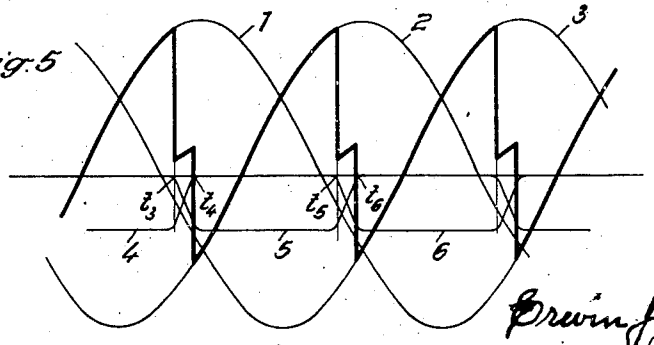


Fig. 5



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CONVERSION OF CURRENTS OR VOLTAGES WITH THE AID OF PERIODICALLY ACTUATED BREAK CONTACTS

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Fig. 8

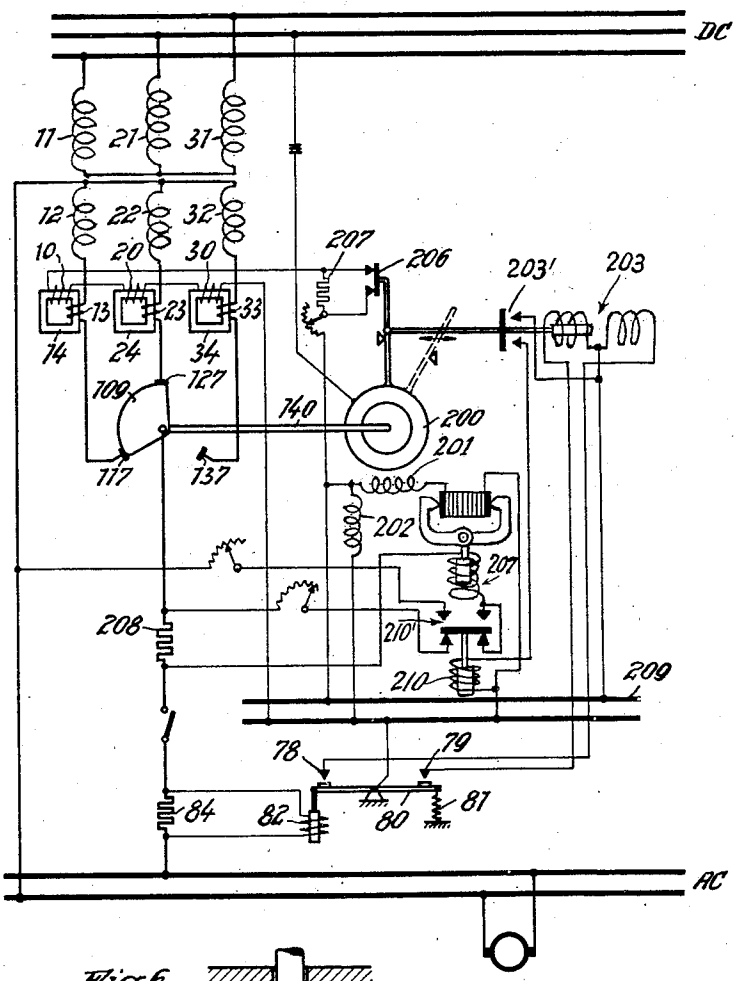
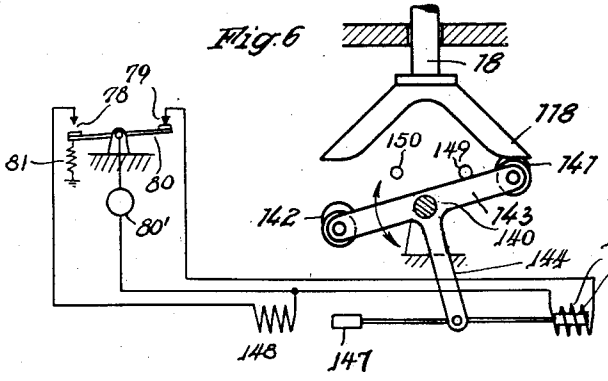


Fig. 6



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CONVERSION OF CURRENTS OR VOLTAGES WITH THE AID OF PERIODICALLY ACTUATED BREAK CONTACTS

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Fig. 7

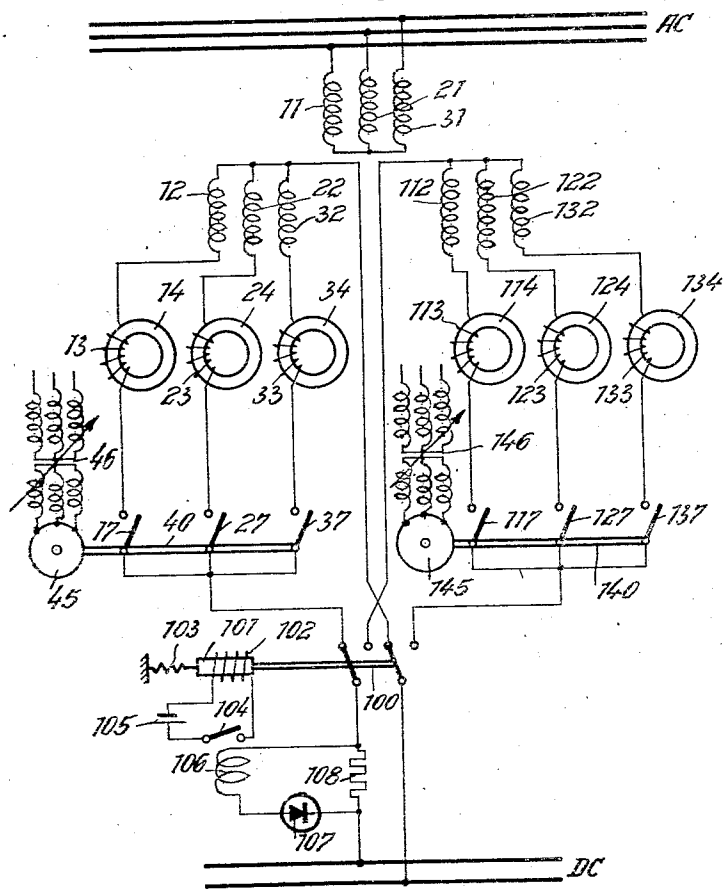

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Fig. 11

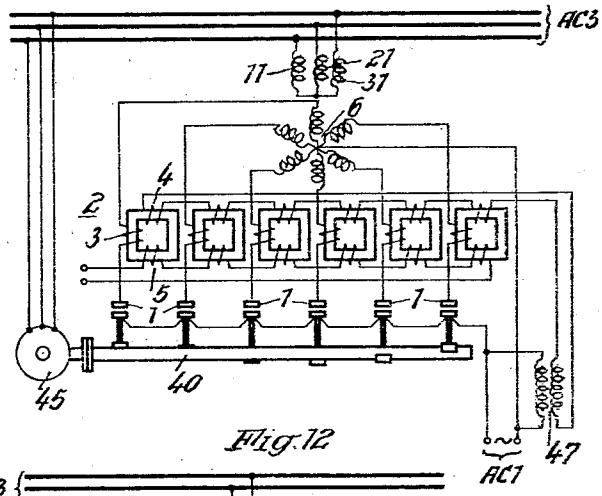
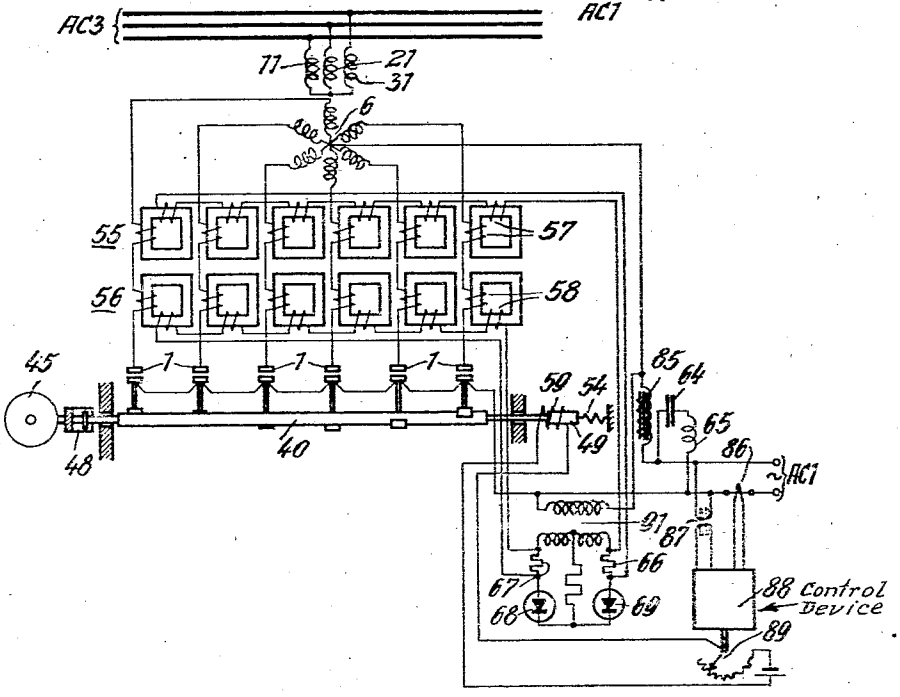


Fig. 12



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Patented Mar. 12, 1940 2,193,421

UNITED STATES PATENT OFFICE

2,193,421

CONVERSION OF CURRENTS OR VOLTAGES WITH THE AID OF PERIODICALLY ACTUATED BREAK CONTACTS

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Application February 27, 1937, Serial No. 128,185
In Germany March 2, 1936

24 Claims. (Cl. 175—364)

My invention relates to the conversion of currents or voltages with the aid of periodically actuated break contacts.

It has already been proposed to employ in converters variable resistances for improving the commutation, i. e., the flow of current from the break contact in one phase to the following contact in another phase, which resistances are connected in series with the break contacts and which considerably reduce the current in the contact to be opened at the moment of break. To this end, saturated inductances may, for instance, be employed which are desaturated if the current in the contact to be broken drops below a given value.

Further, it has already been proposed, with relation to the above-mentioned converters, to shift the moment at which the contacts are closed within the period of the current cycle in order to control the voltage.

The object of my invention is to ensure always a proper commutation in converters of the above-described character when the converter is used for exchanging energy between two current supply circuits with timely different current curves, i. e., between a direct-current supply circuit and an alternating-current supply circuit or between two alternating-current supply circuits with different frequency.

According to the invention the contact arrangement is designed in such a manner that upon a change of the direction of energy, a change in the synchronous position of the contact movement is effected, referred to the variations of the alternating voltage with respect to time.

Further details of my invention will be apparent from the following description taken in connection with the drawings and graphic representations of the relation between current and voltage.

Fig. 1 shows an embodiment of my invention in diagrammatic form. Fig. 1*a* shows a lateral view of a constructional detail of this embodiment. Fig. 1*b* illustrates a modification of a portion of the network shown in Fig. 1. Figs. 2, 3, 4 and 5 show graphic representations of the relation between current and voltage for different operating conditions of an arrangement according to the invention. Fig. 6 shows a modified mechanical design of a circuit breaker suitable for the invention. Figs. 7 and 8 show two other embodiments of arrangements according to the invention. Figs. 9 to 12 refer to converters which are employed for converting alternating current of one frequency to alternating current of another frequency, and more precisely Figs. 9 and 10 illustrate current and voltage curves, while Figs. 11 and 12 show two different embodiments of the total converter system.

The invention will be first described in connection with arrangements which serve to exchange energy between an alternating-current supply circuit and a direct-current supply circuit. In this case, the shifting of the moment at which the contact closes or opens with respect to the cycle of the alternating voltage is effected advantageously so that when passing from rectifier operation to inverter operation the flow of current from one contact to the following contact is shifted with respect to time from a moment which, depending upon the degree of control, more or less lags behind the moment of the voltage coincidence of the phases which are connected in succession, to a moment which leads the above-mentioned moment of the voltage coincidence. If during the reversal of current the voltage supplied by the converter should not vary, the time leading of the commutation process with respect to the moment of the voltage coincidence in the case of inverter operation must be approximately equal to the lagging of the commutation process in the case of rectifier operation.

The arrangement shown in Fig. 1 is designed in the manner just described.

AC is the alternating-current supply circuit and DC the direct-current supply circuit between which an exchange of energy is to be effected. The primary windings 11, 21, 31 of a main transformer are connected to the alternating-current supply circuit AC. The secondary windings 12, 22, 32 of this transformer are connected to each of the stationary contacts 15, 25, 35 of an interrupting device through each winding 13, 23, 33 of each reactor. The magnetic bodies 14, 24, 34 of the reactors are so designed that they are desaturated when the intensity of current decreases below a given value which lies below the average intensity of the alternating current. The magnetization curve of the material employed has a sharp saturation bend so that the inductance of the reactor greatly increases if the intensity of current drops below a given low value. Owing to this effect, the current curve is so distorted in the neighborhood of the time point at which the current passes the zero value that the intensity of current remains low during a given interval. Within this interval the contacts are broken. Consequently, the occurrence of an interrupting arc is avoided.

Each reactor is provided with an exciting wind-

ing 10, 20, 30. The windings are connected in series to a voltage source 90 through a reactance coil 60 and a resistance 50. By regulating the resistance 50, the magnetic bias of the reactors may be varied and, therefore, the interval within which the intensity of current is reduced may be shifted with respect to the cycle of the alternating current.

Each contact device of the switching gear is provided with a second stationary contact 16, 26, 36 as well as a movable contact 17, 27, 37 which in the switching-in position conductively connects the two stationary contacts, for instance 15 and 16, with each other. The stationary contacts 16, 26, 36 are electrically connected with one another and connected to a pole of the direct-current supply circuit DC through a reactance coil 85 and a resistance 84. The second pole of this direct-current supply circuit is connected to the neutral point of the secondary side of the main transformer.

A current path including an apparent resistance is arranged in parallel relation to each contact device. This apparent resistance is denoted by 91, 92, 93 and will be hereinafter more fully described.

For the drive of the movable contacts the following mechanical device is employed.

Each contact is arranged on a tappet 18, 28, 38 which is slidably mounted on the frame of the switching gear. A tension spring 19, 29, 39 has the tendency to bring the contacts 17, 27, 37 into the off-position. Further two shafts 40 and 70 are mounted on the frame of the interrupting device. On the shaft 40 is mounted for each contact device an eccentric 41, 42, 43 which is firmly secured to the shaft 40. The three eccentrics 41, 42, 43 are angularly spaced 120°. On the shaft 40 are mounted the eccentrics 51, 52, 53 immediately adjacent to each of the eccentrics 41, 42, 43. However, the eccentrics 51, 52, 53 may be rotated with respect to the shaft 40. Each of the eccentrics 51, 52, 53 is firmly connected to the gears 61, 62 and 63 respectively. Three gears 71, 72, 73 are firmly secured to the shaft 70. These gears mesh with the gears 61, 62, 63. The shaft 40 is connected to a synchronous motor 45 through a coupling 44 and the shaft 70 to a synchronous motor 75 through a coupling 74.

If the cams 41, 51 and 42, 52 and 43, 53 are so adjusted as to be in registry with each other the interval during which the movable contact is raised is shortest. If the corresponding eccentrics are, however, displaced with respect to one another as shown in Fig. 1*a*, the time at which the contacts close is increased. If both synchronous motors 45 and 75 rotate at the same speed, the relative position of both eccentrics remains the same during the rotation thereof. However, if the phase angles of both synchronous motors 45 and 75 are adjusted with respect to each other, the time at which the contacts close is thereby varied.

For regulating the synchronous motors, the following means are employed: Both motors are connected to the secondary windings 12, 22, 32 of the main transformer through a regulating transformer 46. With the aid of the transformer 46 both synchronous motors may be so controlled that the breaks take place at the time at which the intensity of current is reduced by the reactors 13, 23, 33. One of the synchronous motors is further so designed that its phase may be displaced with respect to that of the other motor. To this end, a second regulating transformer 76 is employed in the embodiment shown. By means of this transformer the interval may, consequently, be varied within which the contacts are closed.

The above-described controls are made conditional upon the direction of the energy flowing through the switching gear by the following means. Both regulating transformers 46 and 76 are provided each with a device 47 and 77 respectively for automatically adjusting the transformers. Both adjusting devices are each connected through a switch 47′ and 77′ to a relay which is actuated in response to the changes of direction of the energy in a conductor extending between both supply circuits AC and DC. The relay in the embodiment shown consists of a horizontal pendulum 80 which, depending upon the position thereof, brings about a contact between a power source 80′ and a stationary contact 78 or 79.

The horizontal pendulum 80 is under the action of a tension spring 81 which tends to hold the contact 79 in a closed position and, therefore, to bring either regulating transformer or also both in a certain regulating state depending upon the operating position of the switches 47′ and 77′. A field winding in series with a tube 83 is shunted to a resistance 84 lying between both supply circuits AC and DC. The field winding 82 works on the control member 80 of the relay. The field winding 82 is, however, only energized owing to the valve effect of the tube 83 if the current has a given direction in the resistance 84. If, therefore, the energy transmitted flows through the resistance 84 in a direction in which the field winding 82 is not energized the contact between the power source 80′ and the contact 79 is closed. Thereby at least one of the transformers 46 or 76 is adjusted in a definite manner which corresponds either to a certain position of phase of the cams of the interrupting device or to a certain duration of the contact making. If now the current changes its direction in the resistance 84, the winding 82 is energized, the relay 80 changed over, and at least one of the regulating transformers 46 or 76 is brought thereby into another position of phase. In this manner either the position of phase of the cams of the switching gear or the duration of the switching-in period is varied.

For a better understanding of the operation of the above-described arrangement, reference may be made to the graphs shown in Figs. 2 to 5. The curves 1, 2 and 3 in these graphs represent the three phases. The currents corresponding to the single phases are indicated by the curves 4, 5 and 6. The portions of the curves in full line represent the variations of the voltage across the direct-current terminals of the inverter with respect to time. Fig. 2 shows the conditions prevailing during rectifier operation for a full degree of control, i. e., for such a degree of control whereby the greatest possible value of the direct-current voltage is supplied. During the flow of current, the intervals of closure of the contacts which are closed and opened in succession (for instance 17 and 27 in Fig. 1) overlap one another by a certain time. During this time both contacts with the corresponding transformer phases (12 and 22) form a closed path of the short-circuit current. The current in the contact 17 to be opened is, therefore, composed of the load current and the current produced by the voltage effective in the path of the short-circuit current (12, 22, 23, 25, 27, 26, 16, 17, 15, 13, 12). In order to attain a proper commuta-

tion it is preferable to choose the moment at which the path of the short-circuit current closes, in such a manner that the short-circuit current in the contact 17 to be opened is in opposition to the current flowing into the current consuming device so that the resultant current in this contact is reduced. In rectifier operation, this condition is fulfilled if the voltage of the phase belonging to the following contact 27 is greater at the moment at which the contact closes than the phase voltage of the contact 17 to be broken or if the voltage at the closing contacts increases at least during the duration of the short-circuit to a greater amount than the phase voltage of the contact to be broken. The differential voltage between both phase voltages then acts in opposition to the load current in the contact to be opened. If, for instance, in rectifier operation shown graphically in Fig. 2 the following contact is closed at the moment t_1, t_3, t_5 etc., that is at the moment of the voltage coincidence of both contacts to be broken and opened in succession the voltage of the following contact 27 increases during the period of the short-circuit, whereas the voltage of the contact 17 to be broken decreases. If, for instance, the passage from phase 1 to phase 2 is considered, the voltage during the short-circuit varies in the direct-current circuit according to a middle curve C—D between the phase voltage 2 and the phase voltage 1. The difference between the phase voltage 2 and the phase voltage 1 is, however, effective in the path of the short-circuit current. The current increases in the following contact during the short-circuit interval t_3, t_4 in accordance with this difference to its normal value and reduces correspondingly the current in the contact 17 to be broken in such a manner that the sum of both currents at every moment is equal to the current flowing in the current consuming device. In this case, it is assumed that the current flowing in the current consuming device is completely smooth, i. e., remains always constant.

If now the direct-current voltage is to be reduced, the moment at which the contact closes may be retarded, whereby a state is finally attained in which the direct-current voltage supplied is equal to zero. This is attained, if the moment at which the contact closes lies approximately at B. Consequently, in rectifier operation, the interval A—B is available for the closure of the contact.

Fig. 3 also applies to rectifier operation and more precisely to a degree of control which is already extremely small. Also in this case, the curve of the direct-current voltage supplied is drawn in full line. As will be seen, the closure of the contacts is effected at a moment at which the phase voltage of the contact to be broken has already become negative. That the contact to be broken still carries current in the negative portion of its phase voltage curve is rendered possible by the smoothening means (85 in Fig. 1) provided in the direct-current circuit. If the flow of current from the contact 17 to the contact 27 is considered, it will be seen that in this case the direct-current voltage also varies from the moment at which the contact closes according to a middle curve E—F between the curves 2 and 3. Upon the opening of the contact to be broken the curve of the rectifier voltage is suddenly shifted to the corresponding point of the voltage of the following contact.

The inverter operation is characterized by the fact that the current is in opposition to the phase voltages. If, therefore, the differential voltage effective in the path of the short-circuit current is to be in opposition to the current during the short-circuit, the voltage of the following contact 27 must be greater than the voltage of the contact 17 to be broken. To fulfill this condition the closure of the contacts must be effected before the moment of the voltage coincidence.

Fig. 4 shows a graph for the inverter operation with full degree of control. The closure of the contacts takes place at the moments t_1, t_3, t_5, etc., and the break of the contacts takes place each time at the moment of the voltage coincidence, i. e., at the moments t_2, t_4, t_6, etc. In the same manner as in the above-mentioned instances the direct-current voltage varies during the short-circuit according to a middle curve between the corresponding phase voltages. If now the direct-current voltage is to be reduced, the time between the moment at which the closure of the contacts takes place and the moment of the voltage coincidence must be further increased. In this case, a point is finally obtained at which the direct-current voltage is again equal to zero. The moment of closing the contacts at which this is attained corresponds approximately to the point H; consequently, an interval of G—H is available for the control range in the case of inverter operation.

Fig. 5 is a graphic representation of the relation between voltages and currents in the case of an inverter operation and a partial degree of control.

According to the above explanation it is possible to operate the converter arrangement shown in Fig. 1 always under favorable commutating conditions both for rectifier and inverter operation if the synchronous position of the contact movement referred to the time variation of the alternating-current voltage is varied according to the invention upon the reversal of the current. This variation of the synchronous position is attained in the arrangement according to Fig. 1 by adjusting the synchronous position of the driving motor 75 by the device 77 and the relay 80 in accordance with the direction of current in the shunted resistance 84, or by simultaneously adjusting the synchronous position of both motors 45 and 75 and, therefore, of the driving cams 41, 51 and 42, 52 and 43, 53. However, the variation of the synchronous position of the contact movement may also be effected in another manner. The means employed for the particular purpose in question depend as a rule upon the type of the contact circuit breakers and on the type of their drive. If, for instance, a contact arrangement is employed in which a rotating contact and a plurality of stationary contacts are provided, the stationary contacts may, for instance, be rotated in the case of an unchanged synchronous position of the rotating contact or the rotating contact may be rotated with respect to the driving shaft. In a contact arrangement with reciprocating circuit breakers as shown in Fig. 1 also different cams for rectifier and inverter operation may be provided for each contact on the same shaft and may be displaced upon reversal of the current, for instance, by displacing the entire shaft. However, also an individual cam shaft for inverter operation and a second cam shaft for rectifier operation may be provided and the drive may be so designed as shown, for instance, in Fig. 6.

In Fig. 6, 18 represents the same tappet which is denoted by 18 in Fig. 1. Instead of the driving arrangement shown in Fig. 1 the following means as shown in Fig. 6 are employed for actuating the tappet 18. The tappet has a member 118 which may alternately cooperate with one of the cam shafts 141 and 142. Both cam shafts 141 and 142 are arranged on an oscillating lever 143 pivotally mounted as indicated at 140. Stops 149 and 150 serve to limit the movements of lever 143. Lever 143 has an actuating arm 144 which is connected with the armatures 145 and 147 of two magnet coils 146 and 148. If coil 146 is energized, lever 143 assumes the position illustrated. Upon demagnetization of coil 146 and energization of coil 148, lever 143 is rotated against stop 150 so that now cam shaft 142 comes into operation. A relay 78, 79, 80, 81 which corresponds to the relay designated in Fig. 1 by the same reference numerals, is connected with an auxiliary voltage source 80' and with the coils 146 and 148. As soon as the transfer of energy between the direct current supply circuit and the alternating current circuit changes its direction, the relay is actuated, coil 146 is deenergized while coil 148 now is connected to the voltage source 80'. Accordingly, lever 143 changes its position, thus bringing the cams of shaft 142 into operation. Shaft 142 and shaft 141 are continuously driven and so adjusted that the cams of one shaft show a given phase difference with respect to the cams of the other shaft. The change of the operating position of lever 143 thus results in the desired variation of the phase position with which tappet 18 is actuated.

Further, the synchronous position of the contact movement may be changed by changing in the case of the driving motor the synchronous position of the rotor with respect to the stator revolving three-phase field. To this end, for instance, the rotor is provided with two exciting windings each being capable of being regulated separately and lying in different axes. An extremely rapid adjustment may be, however, also attained if the stator of the motor is also so mounted as to be capable of being rotated a given angle. Embodiments of these two ways of varying the phase position of the contact movement will be described hereinafter with reference to Fig. 8. Another means for changing the synchronous position of the contact movement with respect to the feeding phase voltages consists in shifting the position of phase of the alternating-current voltage supplied to the contacts, for instance, by interchanging the connections of the contacts at the phases of the feeding three-phase current supply circuit. An example of such means is illustrated in Fig. 1*b*. 11, 21 and 31 designate the primary windings of the main transformer, as indicated in Fig. 1 by the same numerals. In departure from the arrangement of Fig. 1, a switch 153 is connected between the transformer and the A. C. circuit. The switch allows the interchanging of the connections of the three transformer phases in such a way that the voltages in the three phase windings of the transformer are phase shifted by 120°. The switch 153 is actuated by means of a magnet armature 150 and two magnet coils 151 and 152 which are connected to an auxiliary voltage source 80' and a relay 78, 79, 80, 81 which corresponds to the relay designated in Fig. 1 by the same numerals. It is to be understood that the relay circuit shown in Fig. 1*b* replaces the corresponding part circuit in Fig. 1. Accordingly, the relay shown in Fig. 1*b* is operated by the means 84, 82 and 83, illustrated in Fig. 1, in response to the reversal of the direction of the energy flow between the A. C. and the D. C. circuit so that the position of switch 153 also depends on this energy direction.

Finally, there is another possibility of changing the synchronous position of the contact movement which consists in providing two separate contact arrangements, one of which is always controlled as a rectifier and the other as an inverter. Upon the reversal of current the direct-current circuit is then changed over from one contact arrangement to the other. Both contact arrangements are preferably controlled in accordance with each other. This may be accomplished according to the embodiment shown in Fig. 7.

According to Fig. 7, two control arrangements connected with each other are employed for the exchange of energy between the alternating-current supply circuit AC and the direct-current supply circuit DC. The arrangement shown on the left-hand side is designed in a manner substantially similar to that shown in Fig. 1 as will be seen by the corresponding reference numerals indicating similar parts. The circuit breakers 17, 27, 37, however, may be driven by any other suitable drive which actuates the three contacts in succession and in synchronism with the voltage of the alternating-current supply circuit. The drive is indicated by the shaft 40, the synchronous motor 45 and the regulating transformer 46. The drive is so designed that the control device operates as a rectifier.

The arrangement shown on the right-hand side has substantially the same construction as will be seen by the reference numerals; the drive of this arrangement is, however, so designed that the latter operates as an inverter.

Both interrupting devices are driven simultaneously and are, therefore, always ready for operation. Both arrangements are connected to the direct-current supply circuit DC through a changeover switch 100, by means of which the supply circuit is connected to the rectifier or to the inverter depending upon the direction of current. The change-over is effected with the aid of a magnetic device represented in the drawing by the following parts. The switch is equipped with an armature 101 and a magnetic winding 102. A spring 103 tends to bring the switch into a given switching position. However, if the field winding 102 is energized, the switch is brought into the other operating position. The magnetic winding 102 is connected to the power source 105 through a relay contact 104. The relay winding 106 is connected to a resistance 108 through a tube 107. The tube causes an energization of the relay winding 106 and, therefore, also of the field winding 102 if the current in the resistance 108 has a given direction. Accordingly, an automatic change from the rectifier to the inverter is effected depending upon whether energy is transmitted from the alternating-current supply circuit to the direct-current supply circuit or in the reverse direction.

To maintain a proper commutation it is, however, in many cases not sufficient to vary only the synchronous position of the contact movement; it is then possible to influence simultaneously the periodical variations of the values of the series impedances with respect to time. If these impedances are inherent in saturated inductors, the latter may be provided with a biasing winding and

the magnetic bias of the magnetic cores of the inductors may be varied by varying simultaneously the synchronous position of the contacts. An arrangement of this kind is described above with reference to Fig. 1 where the magnetic bias of the inductances 13, 23 and 33 may be varied by adjusting the resistor 50. If resistor 50 is mechanically coupled with the phase shifting device for varying the phase adjustment of the interrupters, the adjustment is effected automatically. A similar connection between the magnetic bias and the phase shifting means is illustrated in Fig. 8.

Fig. 8 shows a wiring diagram in which a contact arrangement consisting of a rotating contact 109 and three stationary contacts 117, 127, 137 is employed for coupling the three-phase current supply circuit A. C. to the direct-current supply circuit D. C. The highly saturated reactors 13, 23, 33 which serve to limit the current during the commutation are arranged in series with the stationary contacts. A synchronous motor whose stator 200 is rotatably mounted and whose rotor is provided with two exciting windings 201 and 202 displaced 90° with respect to each other. The rotation of the stator 200 is effected by a particular device 203, for instance, an electromagnet, which is fed by an auxiliary direct-current supply circuit 209. For checking the occurrence of a reversal of current any suitable relays may be employed which operate in response to a change of direction of current or of power, or also an arrangement may be employed which compares the conditions of voltage of both supply circuits. In the embodiment of Fig. 8, the same relay 78, 79, 80, 81, 82 as in Fig. 1, is employed, the pendulum 80 of which oscillates as soon as the current in the resistance 84 changes its direction, so that the right- or the left-hand contact is closed, thus causing the electromagnet 203 to rotate the stator 200 of the motor a given angle limited by stops in either direction. Upon the rotation of the stator 200 a change of the magnetic bias of the reactors 13, 23, 33 is at the same time effected. The windings 10, 20 and 30 are connected to the direct-current supply circuit 209 through a contact pair 206 and a resistance arranged in parallel relation thereto. If the stator of the motor assumes the position shown in the embodiment, the contact pair 206 is closed and a comparatively large biasing current flows in the windings 10, 20, 30. If the motor stator is rotated to the right the contacts 206 are interrupted, the resistance 207 is connected in series with the windings 10, 20, 30 and, therefore, a smaller biasing current is adjusted.

To regulate the current in the exciting winding 201 of the synchronous motor an automatic regulator 207, for instance, a so-called Thoma regulator, is provided which in the embodiment shown serves to control the contact arrangement in accordance with the load current. To this end, the voltage present across the resistance 208 inserted in the direct-current conductor is supplied to the regulator. Under certain circumstances, the regulator may also be so connected that upon a reversal of current the regulating principle is changed, for instance, in such a manner that in the case of a rectifier operation the voltage and in the case of an inverter operation the current is regulated to a constant value. The latter case is, as a rule, desired if the inverter operation is utilized for the regenerative braking. The means for effecting the last-mentioned change may consist of a contact device 203' and a relay 210 with change-over contacts 210' as illustrated in Fig. 8.

In many cases it is preferable to combine various means for changing the synchronous position of the switching gear in one and the same system. For instance, one means may be then employed for the coarse adjustment and the other in addition thereto for the fine adjustment. If, for instance, the stator of the synchronous motor is rotated, this rotation is in general, as in the case of the arrangement of Fig. 8, effected within a given angle. This angle of rotation will not always be, however, convenient for every operating case, particularly if the zone of commutation is only narrow. The rotation of the stator need then be employed only for the coarse adjustment, while for the fine adjustment, i. e. for the adaptation to the corresponding degree of control, the rotor may additionally be rotated relatively to the rotating stator field.

Arrangements according to the invention may also be designed for converting alternating current of one frequency into alternating current of another frequency. For instance, with the aid of arrangements of the above-described type an alternating current may be first rectified and the direct current produced may be again converted to alternating current of the desired frequency. To this end, two separate contact arrangements may be employed, each of which comprises all auxiliary devices necessary therefor.

However, a considerably simple arrangement may be provided according to the invention by using one and the same group of contact devices for transmitting both the positive and the negative half waves of the converted alternating current.

If, for instance, a voltage of a polyphase system is to be converted to a monophase alternating-current voltage of lower frequency, the control of the contact arrangement must be effected in the following manner:

During the duration of a half cycle of the monophase voltage the contacts are closed or opened at such moments with respect to the polyphase voltage that the voltage across the output terminals has always the same sign. A change in the control of the contacts is then effected in such a manner that the sign of the voltage across the output terminals is reversed and the new direction is maintained during the duration of the next half wave.

For a better understanding of such a device reference may be first made to Figs. 9 and 10. It is assumed that the voltage of a six-phase system is to be converted to the voltage of a monophase system, for instance, with a frequency ratio of 60 to 16⅔ cycles. The figures show in which manner the curve of the converted voltage is formed of the voltage curves of the feeding alternating current system, the period being represented within which the passage of the converted voltage current from the positive to the negative half wave is effected. This passage from the positive to the negative half wave is effected in such a manner that that phase of the alternating-current voltage of higher frequency which forms the last portion of the positive half wave of the voltage curve of lower frequency, also forms the first portion of the following negative half wave. The contact belonging to this phase must, therefore, be closed for a correspondingly long time. In the case of the conversion process to which Figs. 9 and 10 refer, the moments at which all contacts belonging to the single phases of the

supply circuit of higher frequency are operated have approximately the same position of phase with respect to the alternating-current voltage of higher frequency within the positive and within the negative half wave of the converted alternating-current voltage of lower frequency. Thus, for instance, in Fig. 9 the passage from the voltage curve of one phase to the voltage curve of the following phase takes place at the moment of the voltage coincidence a or a'. The curve of the resulting voltage of lower frequency has the form of a trapezoid.

However, a passage from a phase voltage curve to the other phase voltage curve which takes place exactly at the moment of the voltage coincidence, as was assumed for the sake of simplicity in Fig. 9, is not always possible, since the commutation frequently entails that the moments at which the contacts are closed overlap each other by a certain amount, i. e., that the contact to be broken is opened a certain time after the following contact has been closed.

In Figs. 9 and 10 are, furthermore, plotted the curves for the alternating current J of the lower frequency, ohmic load being assumed in Fig. 9, so that the passages of the current and of the conversion voltage through the zero value take place simultaneously. Since the current has always the same direction as the voltage both in the positive and in the negative half wave, the converter operates continuously as a rectifier. In order to attain in the case of a rectifier operation favorable commutation conditions, the contacts must be closed at such a moment that upon a breaking of the contacts the voltage in the phase of the following contact is greater than the voltage in the phase of the contact to be opened. If, therefore, as assumed in Fig. 9 for the sake of simplicity, the maximum voltage is to be supplied—and this is the case if the passage takes place substantially at the moment of the voltage coincidence—the following contact must always be closed at the moment of the voltage coincidence and the contact to be broken must be opened a given interval later. If the full voltage should not be supplied but a smaller voltage the moment at which the commutation begins must be retarded so that a certain retardation of the closure of the following contact results, thereby obtaining a partial degree of control of the system. This applies also to the negative half wave. In this case the voltage of the following contact must have during the commutation a greater negative value than the voltage of the contact to be broken.

The magnetic bias of the inductors 13, 23, and 33 arranged in series with the break contacts is preferably so influenced that the moment at which the inductance increases to its maximum value, is varied during the passage from the negative to the positive half wave. To this end, the windings of the reactors are biased by a current component which when passing from the positive to the negative voltage half wave changes the state of magnetization of the inductors in such a manner that the moments at which the inductance attains the maximum values, are approximately shifted the same amount as the moments at which the corresponding contacts close. This may be attained in a simple manner by supplying an exciting current to the inductors which changes its sign approximately at the same time as the alternating-current voltage of low frequency produced.

By changing the control of the contacts, it is possible to change the alternating-current voltage curve produced in such a manner that the middle portion thereof approaches the sine shape. The individual break contacts should not have the same degree of control, but the moment at which the contacts are closed must be correspondingly shifted from phase to phase. Also in this conversion process the moments at which the maximum value of the inductance is attained in the individual inductors may be easily adapted to the voltage curve. This may, for instance, be accomplished by energizing the reactors by a sinusoidal current of the frequency of the original voltage. The moment at which the maximum value of the inductance is attained is then shifted continuously in the successive phases.

The above considerations are based on ohmic load. With converters according to the invention also pure wattless loads or a mixed load must, however, be transmitted. In this case, it is immaterial whether the flow of energy is directed from the supply circuit of high frequency to the supply circuit of low frequency or vice versa, that is to say, whether a reversal of current occurs. As soon as a wattless load is transmitted, the current curve is out of phase with respect to the curve of the converted voltage so that the passages of both curves through the zero value do not take place any longer at the same moment. This load condition is represented in Fig. 10. With this load both in the positive and in the negative half wave, there are not only periods during which the current flowing through the break contact has the same direction as the voltage (rectifier operation) but also periods during which current and voltage of the transformer phase in operation are in opposition (inverter operation). With a purely inductive load, the rectifier operation is changed over to the inverter operation after every quarter cycle. With a greater power factor, the times of the inverter operation become shorter, whereas the periods of the rectifier operation become correspondingly longer. In the case of the current flowing from the supply circuit of low frequency to the supply circuit of high frequency, the periods of the inverter operation will be longer than those of the rectifier operation. If this flowing back of the current is effected with a power factor equal to unity all tubes are operated as inverters during the entire period of low frequency.

In the case of an inverter operation the commutation process is preferably effected at such a moment at which the following contact has a lower voltage than the contact which is to supply the current. In the path of the short-circuit current which is formed by the overlapping contacts of different phases (i. e., by contact pairs which are simultaneously closed) a compensation current will then flow in such a direction that it weakens the current in the contact to be broken and supports the increase of the current in the following contact. If, therefore, a passage from one phase to the other phase is to be attained at the moment of the voltage coincidence (full degree of control), the commutation process must be initiated by closing the following contact a certain time before the moment at which voltage coincidence occurs.

In Fig. 10 at the left-hand side of the point a the current J is in opposition to the converted voltage during the positive half wave; that is to say, inverter operation prevails. Accordingly,

the commutation is initiated with the full degree of control as above assumed by the amount k (duration of commutation) before the point of intersection a of both phase voltages. At the point d the negative values of the current J become positive. At the right side of the point d the break contacts will, therefore, operate as rectifiers during the positive half wave and accordingly also the commutation process will be initiated at the moment of the voltage coincidence, so that the completion of the commutation process at the point c lies behind the point of voltage coincidence by the value k'. If the leading of the commutation point b before the point of the voltage coincidence a is chosen in the case of the inverter operation equal to the corresponding lagging of the point c behind the point a in the case of the rectifier operation, the mean value of the voltage for rectifier and inverter operation will be the same and the trapezoid curve produced will be a straight line in the horizontal portion thereof, provided a corresponding smoothening is effected. The commutation point is then shifted from b to c to the right by the value $2k$.

The moment at which the maximum value of inductance of the inductors 13, 23 and 33 is attained need not under circumstances be shifted when passing from inverter operation to rectifier operation, i. e., when the commutation point passes from b to c, since the time within which the inductors attain the maximum value of inductance may be chosen longer than the total shifting of the commutation period. If a shifting of the moment at which the maximum value of inductance is obtained is nevertheless desirable, this may be easily accomplished by influencing the excitation of the inductors by an additional component which changes its sign when the current passes through the zero value. In the negative voltage half wave the conditions are similar to those in the positive half wave.

In Figs. 11 and 12 are shown as embodiments the connections of two converters according to the invention which are adapted to fulfil the conditions above-described with reference to Figs. 9 and 10. The converters serve to exchange energy between a three-phase current supply circuit AC 3 and a single phase current supply circuit AC 1 and vice versa.

In the converter according to Fig. 11, the break contacts 1 are similar to those shown in Fig. 1. They are operated by the cam shaft 40 which in turn is driven by the synchronous motor 45. The windings 3 of the reactors 2 are series connected to the break contacts which are connected to the six-phase secondary winding 6 of the main transformer. Besides the series winding 3 each reactor is provided with two exciting windings 4 and 5. The exciting windings 4 are connected to a potential transformer 47 so that they are traversed by a current which is in phase with the voltage of the single phase current supply circuit. In this manner the moment at which the maximum value of inductance of the single reactors is attained, is shifted when passing from the positive to the negative half wave. In the case of an inductive load, in order to shift the moment at which the maximum value of inductance is attained in inverter operation, with respect to the moment of the maximum inductance in rectifier operation, it may be preferable not to energize the biasing windings 4 in response to the voltage of the single phase supply circuit, but in response to the single phase current. To this end, the windings must be connected to a current transformer arranged in series with the single phase supply circuit. The additional exciting windings 5 permit an additional influence of the preexcitation of the inductors which may be effected at will or in accordance with any operating magnitudes. The shifting of the switching-in and switching-out moments may be obtained in this arrangement by varying the phase position of the synchronous motor 45 in accordance with a control device which is influenced by the reversal of current.

In the arrangement shown in Fig. 12 two inductors, one of which is allotted to the positive whereas the other to the negative half wave of the single phase voltage, are connected in series with each break contact. During the positive half wave, the inductor relative to the negative half wave is then so highly preexcited that its inductance practically disappears. The same occurs during the positive half wave with the inductor allotted to the negative half wave. In this manner the inductors need not be alternately biased and may be tuned to the most favorable values for the half wave in question. In order to effect this magnetic bias so as to reduce the inductance, the biasing windings 57 and 58 are connected to the resistances 66 and 67 which are connected to the secondary side of the transformer 91 through the tubes 68 and 69 which transformer is connected on the primary side to the single phase voltage. The primary side of this current transformer is series connected to the single phase supply circuit. In case no single phase supply circuit is available, the transformer 21 is connected to a pilot time tapper whose frequency is constant with respect to the feeding primary frequency.

In the arrangement shown in Fig. 12, the shifting of the switching-in and switching-out moments in accordance with the reversal of current is effected in the following manner: The shaft 40 may be shifted in the longitudinal direction. The cams arranged on the shaft are so shaped that by displacing the shaft the switching-in and switching-out moments are shifted with respect to the cycle of the alternating-current voltage. Between the motor 45 and the shaft 40 is provided a coupling 48 which permits a shifting of the shaft 40 in the longitudinal direction.

The shifting is effected by means of a magnetic device indicated by a magnet armature 49, a spring 54 and a winding 59. The spring tends to pull the shaft 40 to the right. The winding 59 opposes more or less the action of the spring depending upon the intensity of the magnetic energization. A potential transformer 87 and a current transformer 86 are connected to the conductors leading to the single phase alternating-current supply circuit and to a magnetic adjusting device 88. This device 88 actuates the rheostat 89 in accordance with the direction of energy, thereby influencing the excitation of the winding 59.

I claim as my invention:

1. An arrangement for exchanging energy between two current supply circuits with different current curves, comprising a converter having mechanical contact interrupters, each of said interrupters being disposed in one of the phases connecting said two supply circuits, means for operating said interrupters in synchronism with the time variation of the current to be interrupted, a reactor of variable reactance arranged in each of said connecting phases in series with

the interrupter of said phase, means associated with said reactor for periodically effecting a sudden increase of said reactance within an interval including the moment of the opening of said interrupter, and means for varying the synchronous position of the operation of said interrupters upon the reversal of the current transmitted.

2. An arrangement for exchanging energy between two current supply circuits with different current curves, comprising a converter having mechanical contact interrupters, each of said interrupters being disposed in one of the phases connecting said two supply circuits, means for operating said interrupters in synchronism with the time variation of the current to be interrupted, an inductor connected in series with each of said interrupters, said inductor having a magnetic body designed to be saturated at low current intensities below the effective intensity of the alternating current so as to increase the inductance of said inductor at a time near the zero value of said current, and means for varying the synchronous position of the operation of said interrupters upon the reversal of the current transmitted.

3. An arrangement for exchanging energy between an alternating current supply circuit and a direct current supply circuit, comprising a converter having mechanical contact interrupters, each of said interrupters being disposed in one of the phases connecting said two supply circuits, means for operating said interrupters in synchronism with the time variation of the current to be interrupted, an inductor connected in series with each of said interrupters, said inductor having a magnetic body designed to be saturated at low current intensities below the effective intensity of the alternating current so as to increase the inductance of said inductor at a time near the zero value of said current, and means for varying the synchronous position of the operation of said interrupters upon the reversal of the current transmitted so as to shift the beginning of the commutations when passing from rectifier to inverter operation from a moment which, depending upon the degree of control, lies behind the moment of the voltage coincident to a moment which lies an equal amount before the moment of the voltage coincidence.

4. An arrangement for exchanging energy between two current supply circuits with different current curves, comprising a commutating device having interrupters with reciprocating contacts connected between said two supply circuits, a driving shaft provided with cams for operating said contacts, and means for driving said shaft so as to actuate said interrupters in synchronism with the current to be interrupted, a variable impedance series-connected to each of said interrupters, said impedance being adapted to periodically reduce the current intensity at a time in the neighborhood of the zero value of the current, and means for adjusting said cams upon the reversal of the current transmitted so as to vary the synchronous position of the operation of said interrupters.

5. An arrangement for exchanging energy between an alternating current supply circuit and a direct current supply circuit, comprising two converting systems, each of said systems having an interrupter allotted to each phase of said alternating current circuit, means for operating said interrupters in synchronism with the alternating current and variable impedances series-connected with said interrupters, said impedances being designed to periodically increase their impedance magnitude at a time near the zero value of the alternating current, one of said two systems being adjusted for rectifier operation, the other for inverter operation, electric connections between each of said two systems and said two supply circuits, said connections including a switch for switching-in either system, and means for operating said switch upon the reversal of the current transmitted.

6. An arrangement for exchanging energy between an alternating current supply circuit and a direct current supply circuit, comprising a converter having mechanical contact interrupters, each of said interrupters being disposed in one of the phases connecting said two supply circuits, means for operating said interrupters in synchronism with the time variation of the current to be interrupted, a variable impedance arranged in each of said connecting phases in series with the interrupter of said phase, said impedance being adapted to periodically increase its impedance magnitude within an interval including the moment of the opening of said interrupter, and means disposed in said connecting phases for interchanging in response to the reversal of the current transmitted the connections of said interrupters to said phases in order to vary the synchronous position of said interrupters with respect to the alternating current voltage.

7. An arrangement for exchanging energy between two current supply circuits with different current curves, comprising a converter having mechanical contact interrupters, each of said interrupters being disposed in one of the phases connecting said two supply circuits, means for operating said interrupters in synchronism with the time variation of the current to be interrupted, an inductor connected in series with each of said interrupters, said inductor having a magnetic body designed to be saturated at low current intensities below the effective intensity of the alternating current so as to increase the inductance of said inductor at a time near the zero value of said current, biasing windings provided on each of said magnetic bodies, an energizing circuit connected with said windings, controlling means disposed in said energizing circuits for varying the magnetic bias, and means for varying the synchronous position of the operation of said interrupters upon the reversal of the current transmitted, said controlling means of said energizing circuit being designed for being operated simultaneously with said means for varying the synchronous position of said interrupters.

8. An arrangement for exchanging energy between two supply circuits with different current curves, comprising a transformer having its primary windings connected with one of said supply circuits and the neutral point of its secondary windings connected to one phase of said second supply circuit, a set of contact interrupters, each having one contact series-connected to one of said secondary windings and a second contact pertaining to said first contact connected with another phase of said second supply circuit, means for actuating said interrupters in synchronism with the current of said first supply circuit so as to interrupt the current flowing through each interrupter at a time near the zero value of said current, an impedance series-connected to each of said interrupters, said impedance being adapted to periodically increase its magnitude at low currents near said zero value,

a control device disposed between said interrupter set and said second supply circuit, said device including a relay responsive to the direction of the current flowing between said set and said second supply circuit, variable means for adjusting the phase position of said interrupters with respect to the current to be interrupted, and an operative connection between said relay and said variable means for effecting said adjustment in response to the reversal of the current transmitted.

9. An arrangement for exchanging energy between two alternating current supply circuits of different frequencies, comprising a transformer having its primary windings connected with the supply circuit of the higher frequency and the neutral point of its secondary windings connected with one phase of the supply circuit of the lower frequency, a set of contact interrupters, each having one contact series-connected to one of said secondary windings and a second contact pertaining to said first contact connected with another phase of said second supply circuit, a driving device for actuating said interrupters in synchronism with said high frequency, variable means for adjusting the phase position of said interrupters with respect to the cycle of the current having the higher frequency, an impedance connected in series between each of said interrupters and said high frequency circuit, said impedance having a magnetic body designed to become unsaturated at low current intensities near the current zero value, additional biasing windings provided on said magnetic body, a second transformer having its primary windings connected with the supply circuit of lower frequency and its secondary windings coupled with said biasing windings in order to effect a magnetic bias in dependence upon the current in said low frequency supply circuit.

10. An arrangement for exchanging energy between two alternating current supply circuits of different frequencies, comprising a commutating converter disposed between said two supply circuits, said converter having a movable break contact connected to each phase of one of said supply circuits and driving means for operating said contacts in synchronism with the voltage of the supply circuit connected to said contacts, said converter being so adjusted that said contacts temporarily transmit both the positive and the negative half wave of the converted alternating current, inductors connected between said contacts and the supply circuit connected to said contacts, said inductors being designed to be periodically unsaturated at low current intensities and saturated at an intensity below the effective current intensity, and controlling means for varying the synchronous position of the operation of said contacts upon the reversal of the current transmitted.

11. An arrangement for exchanging energy between two alternating current supply circuits of different frequencies, comprising a commutating converter disposed between said two supply circuits, said converter having a movable break contact connected to each phase of one of said supply circuits and driving means for operating said contacts in synchronism with the voltage of the supply circuit connected to said contacts, inductors connected between said contacts and the supply circuit connected to said contacts, said inductors being designed to be periodically unsaturated at low current intensities and saturated at an intensity below the effective current intensity, and controlling means for varying the synchronous position of the operation of said contacts upon the reversal of the current transmitted, said controlling means being adjusted to cause at the time of said variation of phase position said contacts to transmit both a negative and a positive half wave, so that the phase of the voltage of the higher frequency which forms the last portion of a half wave of the voltage curve of the lower frequency also forms the first portion of the following half wave of the lower frequency.

12. An arrangement for exchanging energy between two alternating current supply circuits of different frequencies, comprising a commutating converter disposed between said two supply circuits, said converter having at least one interrupter allotted to each phase of the supply circuit having the high frequency and driving means for operating said interrupters in synchronism with said high frequency, said driving means being adjusted to have a phase position at which said interrupters are opened and closed at moments which, within a half wave of the inverted alternating voltage of low frequency, have approximately the same phase position with respect to the high frequency voltage, an inductor connected in series with each of said interrupters, said inductor having a magnetic body designed to be saturated at low current intensities below the effective intensity of the alternating current so as to increase the inductance of said inductor at a time near the zero value of said current, and means for varying the synchronous position of the operation of said interrupters upon the reversal of the current transmitted.

13. An arrangement for exchanging energy between two alternating current supply circuits of different frequencies, comprising a commutating converter disposed between said two supply circuits, said converter having at least one interrupter allotted to each phase of the supply circuit having the high frequency and driving means for operating said interrupters in synchronism with said high frequency, an inductor connected in series with each of said interrupters, said inductor having a magnetic body designed to be saturated at low current intensities below the effective intensity of the alternating current so as to increase the inductance of said inductor at a time near the zero value of said current, biasing windings provided on each of said magnetic bodies, an energizing circuit connected with said windings, and an electric coupling disposed between said energizing circuit and the low frequency supply circuit in order to bias said inductors by an energizing current which changes its sign at about the same time as the low frequency voltage.

14. An arrangement for exchanging energy between two alternating current supply circuits of different frequencies, comprising a commutating converter disposed between said two supply circuits, said converter having at least one interrupter allotted to each phase of the supply circuit having the high frequency and driving means for operating said interrupters in synchronism with said high frequency, at least two groups of inductors, each of said groups being allotted to one phase of the voltage of the low frequency supply circuit and comprising one inductor for each of said interrupters, each of said inductors being connected in series with an inductor of another group and having a magnetic

body designed to be desultorily saturated at a low periodical current below the effective current intensity and a winding provided on said body for preexciting said body, an energizing circuit disposed for each of said groups and connected to said windings of the inductors of said group, and electric coupling means disposed between said energizing circuits and said low frequency circuit for alternately biasing said inductor groups so as to periodically increase their inductances in rhythm with said low frequency voltage.

15. An arrangement for exchanging energy between two alternating current supply circuits of different frequencies, comprising a commutating converter disposed between said two supply circuits, said converter having at least one interrupter allotted to each phase of the supply circuit having the high frequency and driving means for operating said interrupters in synchronism with said high frequency, at least two groups of inductors, each of said groups being allotted to one phase of the voltage of the low frequency supply circuit and comprising one inductor for each of said interrupters, each of said inductors being connected in series with an inductor of another group and having a magnetic body designed to be desultorily saturated at a low periodical current below the effective current intensity and a winding provided on said body for preexciting said body, an energizing circuit disposed for each of said groups and connected to said windings of the inductors of said group, a transformer having its primary windings connected with said low frequency supply circuit and its secondary windings with said energizing circuits, and an electric valve series-connected in each of said energizing circuits so as to preexcite said inductor groups alternately in rhythm with said low frequency voltage and each of said groups only during a half wave of said voltage and always in the same direction.

16. An arrangement for exchanging energy between two alternating current supply circuits of different frequencies, comprising a commutating converter disposed between said two supply circuits, said converter having at least one interrupter allotted to each phase of the supply circuit having the high frequency and driving means for operating said interrupters in synchronism with said high frequency, an inductor connected in series with each of said interrupters, said inductor having a magnetic body designed to be saturated at low current intensities below the effective intensity of the alternating current so as to increase the inductance of said inductor at a time near the zero value of said current, controlling means for varying the synchronous position of the operation of said contacts in response to the reversal of the current transmitted, and variable means for adjusting the synchronous position of said contacts with respect to the cycle of said high frequency voltage within the half waves of the low frequency voltage so that the middle portion of the curve of said low frequency voltage is approximately sine shaped.

17. An arrangement for exchanging energy between two alternating current supply circuits of different frequencies, comprising a commutating converter disposed between said two supply circuits, said converter having at least one interrupter allotted to each phase of the supply circuit having the high frequency and driving means for operating said interrupters in synchronism with said high frequency, an inductor connected in series with each of said interrupters, said inductor having a magnetic body designed to be saturated at low current intensities below the effective intensity of the alternating current so as to increase the inductance of said inductor at a time near the zero value of said current, biasing windings provided on each of said magnetic bodies, an energizing circuit connected with said windings, and a current source connected with said circuit, said source being designed for producing an approximately sinusoidal energizing current having the frequency of the low frequency supply circuit, whereby the phase position of said interrupters is varied in response to the reversal of the current transmitted.

18. An arrangement for exchanging energy between two alternating current supply circuits of different frequencies, comprising a commutating converter disposed between said two supply circuits, said converter having a movable break contact connected to each phase of one of said supply circuits and driving means for operating said contacts in synchronism with the voltage of the supply circuit connected to said contacts, said converter being so adjusted that said contacts temporarily transmit both the positive and the negative half wave of the converted alternating current, inductors connected between said contacts and the supply circuit connected to said contacts, said inductors being designed to be periodically unsaturated at low current intensities and saturated at an intensity below the effective current intensity, controlling means for varying the synchronous position of the operation of said contacts upon the reversal of the current transmitted, and variable means for additionally adjusting the closing moments of said contacts in response to the wattless current transmitted.

19. An arrangement for exchanging energy between two alternating current supply circuits of different frequencies, comprising a commutating converter disposed between said two supply circuits, said converter having a movable break contact connected to each phase of one of said supply circuits and driving means for operating said contacts in synchronism with the voltage of the supply circuit connected to said contacts, said converter being so adjusted that said contacts temporarily transmit both the positive and the negative half wave of the converted alternating current, inductors connected between said contacts and the supply circuit connected to said contacts, said inductors being designed to be periodically unsaturated at low current intensities and saturated at an intensity below the effective current intensity, controlling means for varying the synchronous position of the operation of said contacts upon the reversal of the current transmitted, and means for varying the duration of the closing periods of said contacts in accordance with the wattless current transmitted.

20. An arrangement for exchanging energy between two alternating current supply circuits of different frequencies, comprising a commutating converter disposed between said two supply circuits, said converter having at least one interrupter allotted to each phase of the supply circuit having the high frequency and driving means for operating said interrupters in synchronism with said high frequency, an inductor connected in series with each of said interrupters, said inductor having a magnetic body designed to be saturated at low current intensities below

the effective intensity of the alternating current so as to increase the inductance of said inductor at a time near the zero value of said current, biasing windings provided on each of said magnetic bodies, an energizing circuit connected with said windings, and a current source connected with said circuit, said source being designed for producing an energizing current synchronously and in phase with the current of said low frequency, whereby the phase position of said interrupters is varied in response to the reversal of the current transmitted.

21. An arrangement for exchanging energy between two current supply circuits with different current curves, comprising a converter having mechanical contact interrupters, each of said interrupters being disposed in one of the phases connecting said two supply circuits, means for operating said interrupters in synchronism with the time variation of the current to be interrupted, reactive means for periodically distorting the curve of the current to be interrupted so as to decrease the current intensities in the neighborhood of the zero value of said current, and means operatively connected between said two supply circuits for varying the synchronous position of the operation of said interrupters responsive to the reversal of the current transmitted.

22. An arrangement for exchanging energy between two current supply circuits with different current curves, comprising a converter having mechanical contact interrupters, each of said interrupters being disposed in one of the phases connecting said two supply circuits, means for operating said interrupters in synchronism with the time variation of the current to be interrupted, an inductor connected in series with each of said interrupters, said inductor having a magnetic body designed to be saturated at low current intensities below the effective intensity of the alternating current so as to increase the inductance of said inductor at a time near the zero value of said current, an impedance connected in parellel to each of said contact interrupters for reducing the returning voltage between the contacts of said interrupter, and means for varying the synchronous position of the operation of said interrupters upon the reversal of the current transmitted.

23. An arrangement for exchanging energy between two supply circuits with different current curves, comprising a transformer having its primary windings connected with one of said supply circuits and the neutral point of its secondary windings connected to one phase of said second supply circuit, a set of contact interrupters, each having one contact series-connected to one of said secondary windings and a second contact pertaining to said first contact connected with another phase of said second supply circuit, a synchronous motor connected to said set for actuating said interrupters in synchronism with the current to be interrupted, said motor having a rotatably mounted stator, controlling means disposed between said interrupter set and said second supply current, said controlling means being responsive to the reversal of the current flowing between said set and said second supply current, and an operative connection between said controlling means and said stator, whereby the phase position of said interrupters is varied in accordance with the reversal of the current transmitted.

24. An arrangement for exchanging energy between two supply circuits with different current curves, comprising a transformer having its primary windings connected with one of said supply circuits and the neutral point of its secondary windings connected to one phase of said second supply circuit, a set of contact interrupters, each having one contact series-connected to one of said secondary windings and a second contact pertaining to said first contact connected with another phase of said second supply circuit, means for actuating said interrupters in synchronism with the current of said first supply circuit, phase adjusting means for varying the phase position of said interrupters with respect to the cycle of the current to be interrupted, a control device being connected between said interrupter set and said second supply circuit, said control device being responsive to the reversal of the current flowing in said element, an operative connection disposed between said control device and said phase adjusting means, and load responsive controlling means disposed between said interrupter set and said second supply circuit for additionally varying the phase position of said interrupters in accordance with the load of said arrangement.

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