March 20, 1945. R. C. VAN SICKLE 2,372,139

SYNCHRONOUSLY TRIPPED CIRCUIT BREAKER

Filed June 12, 1942 2 Sheets-Sheet 1

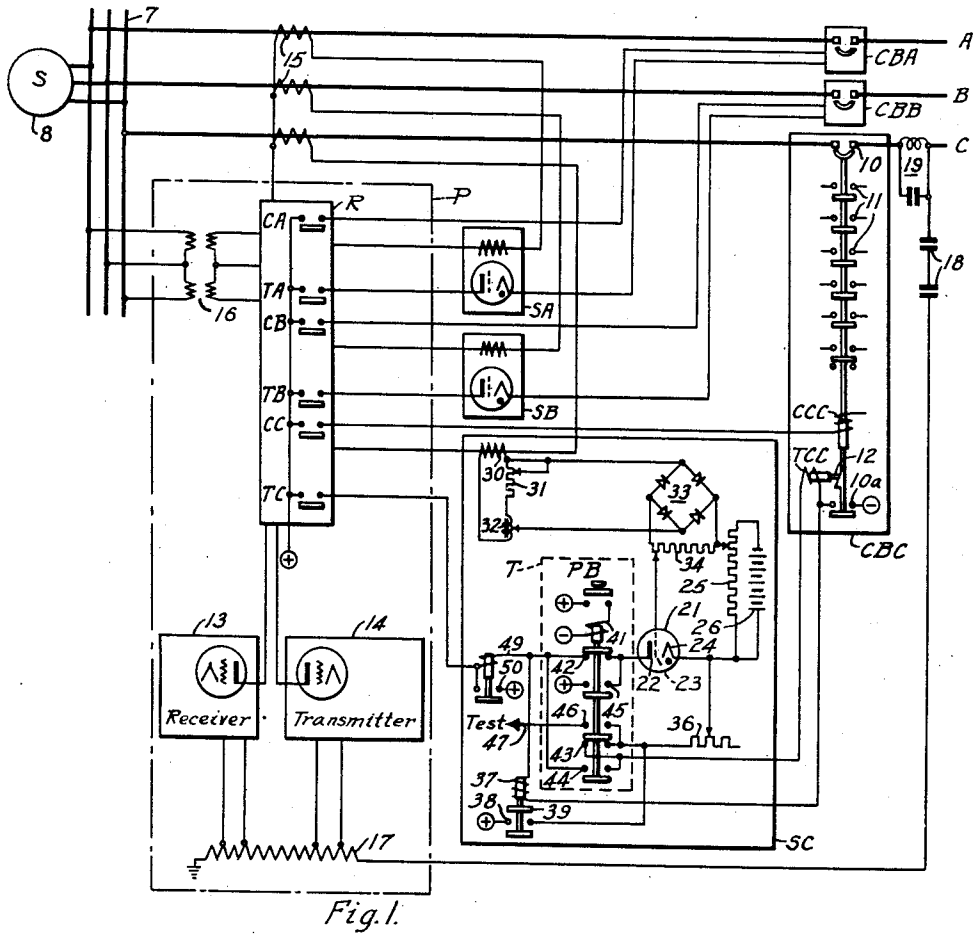


Fig. 1.

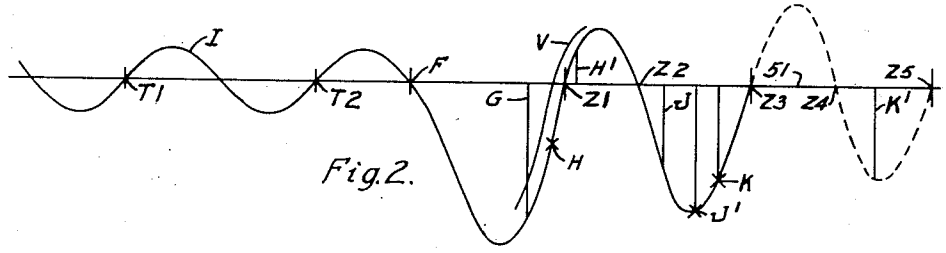


Fig. 2.

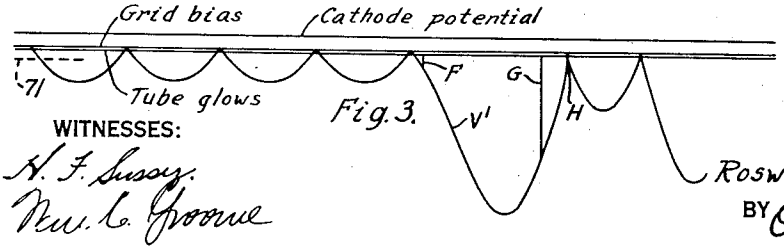


Fig. 3.

WITNESSES:

N. F. Sussoy.

Mw. C. Groome

INVENTOR

Roswell C. Van Sickle.

BY O. B. Buchanan

ATTORNEY

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SYNCHRONOUSLY TRIPPED CIRCUIT BREAKER

Filed June 12, 1942 2 Sheets-Sheet 2

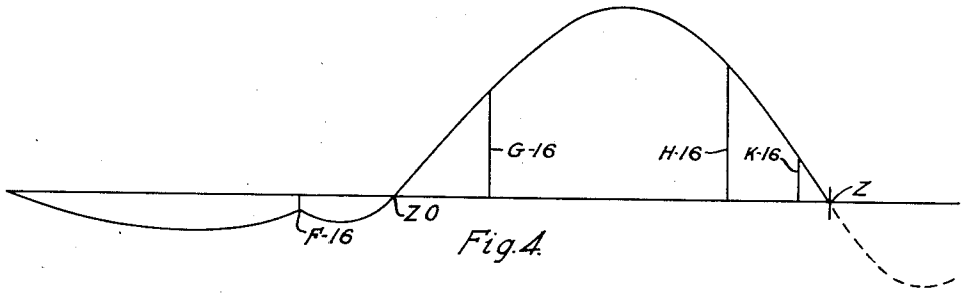


Fig. 4.

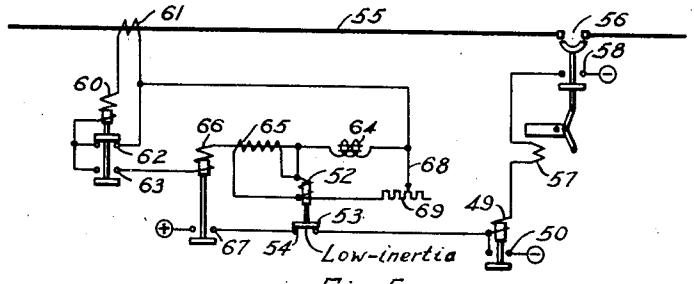


Fig. 5.

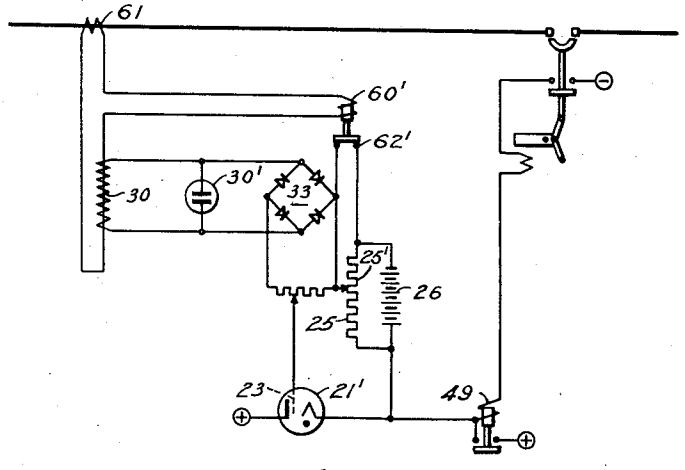


Fig. 6.

WITNESSES:

N. F. Lisser.

Wm. C. Groome

INVENTOR

Roswell C. Van Sickle.

BY O. B. Buchanan

ATTORNEY

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2,372,139

UNITED STATES PATENT OFFICE

2,372,139

SYNCHRONOUSLY TRIPPED CIRCUIT BREAKER

Roswell C. Van Sickle, Wilkinsburg, Pa., assignor to Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., a corporation of Pennsylvania

Application June 12, 1942, Serial No. 446,720

15 Claims. (Cl. 175—294)

My invention relates to circuit breakers of the type in which the moment of energizing the trip-coil is synchronized with reference to the wave-form of the line-current. Heretofore, particularly in Europe, where there are more 16⅔-cycle systems, such circuit breakers have been utilized, with means purporting to anticipate the first current-zero, or the end of the first half-cycle having current of fault-magnitude, so as to provide a supposedly fixed time-period within which it was possible to trip the breaker and separate the contacts far enough to enable the breaker to interrupt its arc at the first current-zero.

So far as I am aware, however, no attempt has been made to apply the synchronous-trip circuit-breaker idea to 60-cycle lines, because of the utter impossibility of detecting the fault, unlatching the breaker, and separating the contacts far enough to interrupt the arc at the end of the first half-cycle in which the line-current is of fault-magnitude, and also because of the known variation in the lengths of the successive half-cycles, because of the asymmetrical nature of most fault-currents, whereby the first long half-cycle is always of the highest current-magnitude, followed by a smaller and shorter half-cycle of the opposite polarity, followed by a long half-cycle of the first polarity but of slightly decreased magnitude, followed by a short half-cycle of the second polarity but of a slightly increased magnitude, and so on until, after a number of cycles, the fault-current becomes symmetrical, with opposite half-cycles of the same magnitude and duration. The asymmetrical nature of the fault-current is a random phenomenon, starting on either the positive or negative half-wave, and at various points in the cycle, and under various conditions respecting the phase-relationships between line-current and line-voltage both before and after the occurrence of the fault.

As a result of these conditions, no serious attempt has heretofore been made, so far as I am aware, to predict current-zeros, during a fault, other than to anticipate the first current-zero by a small fraction of a cycle, in a system of such low frequency, however, that said small fraction of a cycle involved sufficient time to effect a breaker-operation resulting in a current-interruption at the first current-zero.

The object of my invention is two-fold. Primarily, it is to provide a circuit-breaker system in which it is possible to predict a current-zero at least two half-cycles subsequent to the end of the first half-cycle in which fault-current occurs or is detected. In my system, the operating-times of the breaker are coordinated with the predicted time-period, so that the breaker-contacts may be separated by a predetermined amount by the end of that predicted time-period. Secondarily, it is an object of my invention to provide a specific detecting-means which is novel and which, in some respects, has certain advantages, although my invention, in its broader aspect, is not limited to any particular time-detecting or synchronizing means.

Examples of the previous low-frequency synchronous-breaker ideas, such as are useful in 16⅔-cycle systems, are to be found in the Bayha Patent No. 2,225,763, December 24, 1940, the Kesselring Patent No. 2,261,686, November 4, 1941, and the Gieffers application, Serial No. 281,585, filed June 28, 1939, patented July 21, 1942, No. 2,290,683, all assigned to the Westinghouse Electric & Manufacturing Company. In each of these cases, the fundamental idea was to retard the beginning of the separation of the breaker-contacts until considerably after the peak-value of the first half-cycle of fault-current, so that the breaker-arc would not be called upon to carry the peak-current of fault-magnitude, the contact-separation being effected later in the half-cycle while the current was approaching its zero-value, thus easing the burden on the circuit-breaker, and permitting the use of breakers having an interrupting-rating considerably lower than the expectable peak-magnitude of the fault-currents.

In the case of 60-cycle circuit-breakers, however, the situation is somewhat different, because of the considerably shortened time-period of each half-cycle. My experience, and the experience of my associates in the Westinghouse Electric & Manufacturing Company, in connection with 60-cycle breakers, indicates that the destructive effect of the current in the breaker is not primarily a function of current-magnitude, at all, but it is a function of arcing-current, times arcing-voltage, times time. In other words, the destructive power of the current in the breaker is proportional primarily to the kva.-seconds or total amount of energy consumed in the breaker during the arcing period, regardless of the maximum instantaneous value of the current. Heavy instantaneous current-values are particularly innocuous at the very beginning of the arcing-period, when the breaker-contacts are separated only a very small amount, so that very little voltage is consumed in the arc.

Experience with 60-cycle breakers has also demonstrated that it is necessary to effect a cer-

tain minimum distance of separation of the arcing-contacts in order to enable the breaker to resist or prevent a restriking of the arc after a current-zero, this separation-distance being of the order of ¼", in breakers of the lower voltage-ratings, to ½" or more, in breakers of the higher voltage-ratings. The exact magnitude of the requisite separation-distance to avoid restriking of the arc after a current-zero is variable, of course, depending upon the line-voltage, the quantity of ionized gases generated in the arc prior to the current-zero, and the intensity or effectiveness of the deionizing means which are available in the breaker for rendering the arc-path non-conducting, so that the dielectric strength of the arc-space at all times exceeds the transient recovery-voltage after the current-zero.

An important feature of my invention, as applied to 60-cycle breakers, is the recognition of the fact that, while successive half-cycles, particularly the first two or three half-cycles after the occurrence of current of fault-magnitude, are of widely varying and quite unpredictable time-periods, because of the randomly occurring asymmetrical nature of most fault-currents, as well as the randomly occurring variations in phase-relationships with respect to the line-voltage, nevertheless, if the total time of two successive half-cycles is considered, that time is fairly constant and predictable, being practically equal to the time-period of one full cycle of the line-current, or usually a trifle more or less than this amount, because of the decrease in the direct-current component. In any event, any departure of the full-cycle period of the fault-current from the normal 60-cycle period is sufficiently small to be unimportant from the standpoint of arc-interruption, which is by no means the case with respect to the time-periods for successive half-cycles of an unsymmetrical current-wave.

My invention, as applied to a 60-cycle breaker, therefore, aims to determine, first, the instant of time at which the first current-zero occurs, or this instant may be anticipated or predicted in advance, by a small amount of time, amounting to a small fraction of a half-cycle, thus providing a little more time for the breaker-operation, but by no means providing anything approaching the amount of time which is actually required for the breaker-operation. I then utilize a breaker which is chosen and adjusted so that it consumes precisely one cycle, or one cycle plus the very brief anticipatory-time just mentioned, or in the case of the largest breakers, two cycles, in which the magnetic flux is built up in the tripping mechanism, the latching-mechanism is unlatched, the contacts are given their preliminary movement during which they are in wiping engagement proior to actual contact-separation, and the contact-separation is increased to a predetermined distance which is safe from the standpoint of enabling the breaker to resist or prevent a restriking of the arc as the current subsides to zero and the line-voltage applied to the arc-terminals begins to build up again, in the reverse polarity.

In some cases of rapidly decaying direct-current components, as in the case of circuits having relatively high power-factors under short-circuit conditions, it might be possible to utilize an interrupting-time of ½ cycle or preferably 1½ cycles or 2½ cycles, subsequent to the first current-zero after the fault, because, by that time, the dissymmetry of the current-wave would have materially subsided, so that the times of completion of these odd half-cycles (1st, 3rd and 5th, respectively) might be predictable with sufficient accuracy in some cases. As I at present view my invention, however, I believe that it will have its principal 60-cycle application in breakers in which the operating-time terminates within an even number of half-cycles after the current-zero with respect to which the trip-circuit was initially energized by the synchronizing means responsive to the current wave-form.

With the foregoing and other objects in view, my invention consists in the circuits, systems, combinations, apparatus, methods and parts, hereinafter described and claimed, and illustrated in the accompanying drawings wherein:

Figure 1 is a diagrammatic view of circuits and apparatus illustrating my invention in a preferred form of embodiment;

Fig. 2 is a curve-diagram showing an illustrative current wave-form, with indications of an illustrative subdivision of the operating-time of the synchronizing device and of the various steps in the breaker-operation in connection with a 60-cycle system;

Fig. 3 is a curve-diagram illustrative of the operation of the synchronizing tube which is illustrated in Fig. 1, in connection with the current wave-form shown in Fig. 2;

Fig. 4 is a view similar to Fig. 2, except that it is illustrative of conditions such as might prevail on a 16⅔-cycle system; and

Figs. 5 and 6 are diagrammatic views of circuits and apparatus illustrating two different alternative forms of the synchronizing device, in connection with synchronously operated circuit-breakers.

In Fig. 1, I have illustrated my invention in connection with a three-phase synchronous transmission-system. Since both ends of such a transmission-line are, or may be, more or less similar, I have illustrated only one end of the line, with the understanding that the other end of the line may have similar equipment.

The line is indicated by three line-conductors A, B and C, corresponding to the three phases. This line is connected to a three-phase bus **7**, to which is also connected a synchronous machine **8**, which may be a generator, motor, or a synchronous-condenser, or any combination of these three, in addition to any other types of load-devices or sources which might be applicable thereto. Each line-conductor A, B and C is provided with its own single-pole or single-phase circuit-breaker mechanism, indicated at CBA, CBB and CBC, and since these mechanisms are identical, only the mechanism CBC is indicated in any detail, the same comprising a circuit breaker having main contacts **10**, a plurality of auxiliary switches **11** for various control-purposes, including an auxiliary switch **10***a* in the trip-circuit, a closing-coil CCC, and operating-means for effecting an opening-operation of the main contacts **10** of the breaker, said operating-means comprising a tripping-coil TCC for releasing the latching mechanism **12**.

In any circuit-breaker system, suitable means must be provided for suitably responding to a fault-condition for the purpose of determining that a breaker-opening operation is desirable, and for controlling the tripping-circuit of the breaker; and in Fig. 1, I have diagrammatically indicated such means as mounted on a panel P and comprising a relay-assembly R, and a carrier-current receiver and transmitter **13** and **14**. The relay-assembly R is energized from the line-

current and line-voltage, by means of the current-transformers 15 and the potential-transformers 16. This relaying-equipment R may take any one of a number of different forms, known in the art, and so far as my present invention is concerned, any suitable fault-detecting relaying-means may be utilized. In the usual case, the relaying equipment will include means responsive both to the current-magnitude, or the line-impedance or reactance, and to the direction of the line-current, and in many cases, as illustrated, it will also include means for checking against the current-direction or other conditions at the other end of the line-section, as is indicated by the use of the carrier-current equipment 13 and 14.

The relaying equipment R will often utilize a plurality of tripping-contacts in series, for instance, separate contacts responsive to impedance, direction, and carrier. In more modern relaying-systems, there may be also contacts or means for selecting the particular phase or phases which are affected by the fault, so that only one or two of the three circuit-breakers CBA, CBB and CBC, is or are operated. For simplicity of illustration, I have symbolically illustrated the tripping-contacts of the relaying-equipment R as being, in effect, a single contact, for each of the three phases, as indicated by the contacts TA, TB and TC of the relay. These contacts, so far as my present invention is concerned, may operate either individually, in response to single-phase arcing-ground faults, or in pairs, in response to phase-to-phase faults, or gang-operated with all three tripping-contacts TA, TB and TC closed substantially simultaneously. I have also illustrated the relaying-equipment R as comprising three closing-contacts CA, CB and CC for energizing the closing-coils of the respective circuit-breakers, such as the phase-C closing-coil CCC.

The carrier-current equipment 13—14 is coupled to the line in any suitable manner, as by means of a coupling-transformer 17, and coupling-capacitors 18, in conjunction with a carrier-current wave-trap 19 in the phase-C conductor to which the carrier-equipment is connected.

In accordance with my present invention, the tripping-circuit for each phase includes a synchronizing device, which is indicated at SA, SB and SC, for the respective phases. Since these synchronizing equipments are all similar, only the phase-C synchronizing equipment SC is indicated in detail.

The synchronizing equipment SC of Fig. 1 comprises essentially a grid-glow tube 21 which is serially connected in the tripping-circuit. This tripping-circuit may be traced, starting at the relaying-panel R, with the positive bus-terminal (+), and including the phase-C fault-responsive tripping-contact TC, the anode-cathode circuit of the tube 21, the phase-C trip-coil TCC, and the auxiliary breaker-switch 10*a* which opens when the breaker opens, the trip-circuit being completed at the negative bus terminal (—) of the tripping-bus.

The synchronizer-tube 21, in Fig. 1, is illustrated as being of the gas-filled, hot-cathode, grid-glow type, having an anode 22, a grid 23 and a cathode 24. Such a tube has the characteristic of remaining non-conducting as long as the grid 23 is sufficiently negative with respect to the cathode 24, the value of this critical negative grid-voltage depending upon the amount of voltage applied to the plate-circuit, in this case, the value of the voltage of the tripping-bus which is indicated at (+) and (—). The tube 21 has the property of glowing or arcing over, between its anode 22 and its cathode 24, practically instantaneously as soon as its grid-potential becomes more positive than the critical grid-voltage just mentioned, and after the tube has once become conducting, it will remain conducting, independently of the grid-voltage, as long as the anode-circuit voltage continues to be applied to the tube, or until this anode-circuit voltage, or plate-voltage, is reduced substantially to zero, or to a very small value.

In accordance with my invention, as illustrated in Fig. 1, I control the grid-voltage of the synchronizer-tube 21 in accordance with the line-current in the particular phase-conductor C for which the synchronizer-tube 21 is operative, and I adjust the tube and the control-circuit so that the tube is ready to become conductive at the very end of each half-cycle of the line-current, or just as the current approaches zero in either polarity, provided that the plate-voltage is applied to the anode-cathode circuit 22—24 of the tube. In the particular embodiment illustrated in Fig. 1, the plate-voltage is normally kept off of the tube 21 by the open relay-contact TC, but when the TC-contact is closed, in response to a fault-detecting operation of the relay R, the tube 21 will be put in readiness to become operative at the next current-zero of its current-responsive circuit, as will be subsequently described.

The synchronizer-tube 21 of Fig. 1 is provided with a grid-biasing voltage, which may be derived from a potentiometer 25 energized from a biasing-battery 26, so adjusted that the potentiometer delivers a negative voltage which is just not quite enough negative to prevent the tube from glowing, when impressed with its rated plate-voltage, such as the voltage of the tripping-bus (+) and (—). I then provide additional means for supplying a rectified alternating-current voltage-wave for making the grid-voltage more negative than the grid-bias supplied by the potentiometer 25, so that the actual grid-voltage is so strongly negative as to block or prevent the glowing of the tube, except at, or substantially at, the points where the rectified alternating-current voltage-wave becomes zero.

The alternating-current control of the grid-voltage of the synchronizer-tube 21, in Fig. 1, is obtained by means of an auxiliary current-transformer 30, which is connected in the phase-C circuit of the line-current transformer-bank 15. The auxiliary current-transformer 30 supplies a very small amount of current, at a high voltage, to an impedance-device comprising a resistance 31 and an inductance or other reactance 32, either one or both of which may be adjustable, as indicated. The voltage-drop across the combined impedance 31—32 is rectified in a full-wave rectifier-bridge 33, and applied to a potentiometer 34 which is connected in circuit with the grid 23 of the tube 21, in such polarity as to make the grid 23 more negative, with respect to the cathode, in accordance with the instantaneous values of the voltage-drop in the impedance 31—32.

The resistance 31 and inductance 32 of the impedance which provides the alternating-current biasing-voltage are so related that the unrectified biasing voltage leads the line-current in the associated phase-C by an angle which is preferably sufficiently small so that the slope of the wave-form of current, or the differential of the

current with respect to time, will be substantially rectilinear or constant within the range of this time of phase-advance ahead of the zero-point of the current-wave. This would be an angle of about 10°, although larger angles of 20°, and even more, might be tolerated, at more and more sacrifice of independence of the magnitude of the peak-value of the current, as the angle gets much larger than 10°. This relationship is chosen so that the current, divided by the rate of change of current with respect to time, shall provide a value which is equal or proportional to the time, which is true, provided that the rate of change does not vary materially within the limits over which the current is to be integrated, that is, within the angle of phase-advance which is effected by the reactance component of the impedance 31—32. In this manner, I am able to obtain or determine a small amount of additional time which is available for circuit-breaker operation, while still being able to select the time at which the leading voltage-wave becomes zero, without having that selection or determination vitiated by the magnitude of the fault-current.

An important feature of my invention, as applied to a 60-cycle system, resides in the fact that the circuit breaker, such as the circuit breaker CBC, requires a certain operating-time which is predeterminable within sufficiently close limits to make sure that the main breaker-contacts 10 shall achieve a certain amount of separation, or a separation within a predetermined range of maximum and minimum values, at the time of a predictable subsequent current-zero of the line-current in the phase in which the breaker is associated. This operating-time of the breaker is preferably controllable, within certain limits, at least limits adequate to make minor field-adjustments, and to that end it is desirable that certain means should be provided for controlling or adjusting the operating-time of the breaker. One means for controlling the breaker-time is to control the magnitude of the tripping-current, which may be done by means of a variable resistance 36 which I have illustrated as being connected in series with the trip-coil TCC. The breaker-time might also be controlled by other obvious means, such as adjustment of the tension of the opening-spring, the amount of wiping action of the contacts, and other means, not illustrated, the variable resistance 36 being intended to be symbolic of any means for adjusting the operating-time of the breaker.

It will be noted that my synchronizing-means SA, SB and SC is so designed that it may be added to any existent circuit-breaker system, or it may be removed from a new circuit-breaker system which originally had this feature, by the simple expedient of connecting or disconnecting the tripping-circuit of the selector-mechanism in series with the trip-coil circuit. The selector-means thus operates as an instrumentality which makes it possible to utilize a relaying-equipment R which detects and analyzes the fault to a degree sufficient to determine that a trip-circuit energization is required, before the close of the first half-cycle of current of fault-magnitude, the exact time of relay-operation within this half-cycle being variable in accordance with the location and kind and intensity of the fault and the various operating-conditions of the transmission system, as effected by such variable factors as the value and location of the grounding-impedances, and the number and disposition and size of the synchronous generators and other equipment connected to the system at any particular time.

The addition of the synchronizer-means, such as SC, makes it possible to predetermine the time, with reference to the current-zero which terminates this first half-cycle of fault-current, and to always energize the trip-circuit of the breaker at that predetermined time in relation to, or in synchronism with, said first zero-current point. In this manner, the breaker is called upon to carry an arc only long enough to separate its contacts by a physical separation which is the amount necessary to insure no restriking of the arc thereafter. This shortens the arcing-time by the time from the moment of relay-response to the tripping-moment selected by the synchronizing device SC. Since the voltage of the arc increases with time, the destructive action of my short-time arc is thus very considerably reduced. In some extreme cases, the additional quantities of highly ionized arcing-gases, which would have been produced by the additional arcing-time without my synchronizing-device, might be of such magnitude or intensity that the deionizing means of the circuit breaker would be unable to cope with it, so that a circuit breaker, which began its arcing too early in a cycle, and continued arcing too long, with the contacts getting further apart than the optimum separation, might find itself unable to interrupt the arc at the following current-zero, but would restrike during the next succeeding half-cycle, thus still further prolonging the arcing-time of the breaker. All such disadvantages are avoided, and the destructive power of the arcing is held down to a minimum value, by the addition of the synchronizing means which preselects the point in the current-cycle at which the tripping circuit is first energized, in accordance with my invention.

In order to be able to utilize my synchronized time-selector SC in the tripping circuit of a breaker, it is necessary, of course, that that timing-device shall have a high order of reliability, or that means be otherwise provided so that a failure of the synchronized timing-device shall not result in a failure of tripping. With this thought in mind, I have indicated diagrammatically, in Fig. 1, two different means for safeguarding the tripping-circuit against possible defects or deficiencies or shortcoming of the timing-device.

As shown in Fig. 1, I provide a half-cycle, delayed-action tripping-relay 37, which is energized whenever the fault-responsive tripping-relay R closes its part of the trip-circuit (at TC, for example). The circuit of the operating-coil of the auxiliary relay 37 can thus be traced from the TC-contact, the 37-coil, and the breaker-switch 10*a*. The auxiliary switch 37 has a make-contact 38 which directly energizes the trip-coil TCC, so that, if the synchronizer-tube 21 has not already actuated the trip-circuit by the time the auxiliary relay-contact 38 closes, the trip-circuit will then be energized, regardless of the portion of the half-cycle within which such energization takes place, and the only disadvantage thereby resulting would be a delay of about one-half of a cycle, and an increased amount of damage suffered by the breaker during that tripping-operation.

Any suitable time-delay means may be utilized for making the auxiliary relay 37 have the desired time of action. By way of symbolic representation, intended to indicate any suitable time-delay means, I have illustrated the auxiliary

relay 37 as being provided with a lag-ring 39 for causing it to require about a cycle, or other suitable time, to operate, or about the time-period of the longest expectable half-cycle of an asymmetrical fault-current, or other operating-time adequate to give the synchronously timed tube 21 a chance to operate first, if it is going to operate properly.

A second means which I have provided, for safe-guarding the tripping-circuit against possible defective operation of, or trouble in, the synchronous timing-tube 21, consists in a test-panel T which I have symbolically indicated in Fig. 1. The test-panel may take any one of a number of different forms, for cutting the timing-tube 21 out of service, and testing it, in such a manner that tripping-circuit is left intact during said testing, so that, if a fault should occur while the timer is being tested, tripping will be effected instantaneously, without waiting to preselect an optimum point in the cycle at which to energize the trip-circuit. I have illustrated a suitable test-circuit T, by way of example, as comprising a push button PB for energizing a test-relay 41, having two normally closed, main-circuit, back-contacts 42 and 43, which are connected in the tripping-circuit, one on each side of the timer-tube 21. The test-relay 41 also has a main-circuit make-contact 44 which is utilized to bypass the anode-cathode circuit 22—24 of the tube 21, so as to maintain the intactness of the tripping-circuit during the testing-period. The testing relay 41 is illustrated as having two other make-contacts 45 and 46, which are utilized to connect the tube 21 to a suitable testing-apparatus, indicated as comprising the positive battery-terminal (+) and a test-circuit terminal 47, respectively.

In Fig. 1, I have also shown the tripping-circuit as including a contactor-switch 49, having an operating-coil which is connected in series with the tripping-coil TCC, and also in series with the operating-coil of the auxiliary relay 37, so that the contactor-switch 49 will instantly pick up as soon as the TC relay-contact closes, thus closing the contactor-switch make-contact 50, which bypasses the TC-contact and maintains the integrity of the tripping-circuit until the circuit breaker opens its auxiliary switch 10a.

The operation of the apparatus shown in Fig. 1 will be better understood with the aid of Figs. 2 and 3. In Fig. 2 I have shown an illustrative current wave-form, and illustrative timing, which will serve as a basis for explaining the operation, it being understood that the figure is only illustrative.

In Fig. 2, the curve I represents the line-current in the phase-conductor in which the circuit-breaker in question is connected. It is here assumed that this is a 60-cycle current. A portion of the corresponding voltage-drop across the grid-biasing current-responsive impedance 31—32 is indicated at V in Fig. 2, this voltage-curve leading the current-curve by a small angle, as indicated. The voltage-scale is so chosen that the current and voltage-curves have the same amplitude.

It is assumed that a fault occurs on the transmission-line at the point marked F in Fig. 2. This fault may occur at any point in the current-cycle, during either a positive or negative half-wave of current, and there is also considerable variation in the phase of the line-voltage (not the grid-biasing voltage V) at the moment of fault, and also in the amount of asymmetry of the fault-current which begins to flow, starting with the point F in Fig. 2. It requires a certain variable time, such as the time F—G, for the fault-responsive relaying-equipment R to determine the exact location of the fault, and, if the fault is in the protected line-section, to close its portion of the tripping circuit, as indicated at TC in Fig. 1. The point G may be indicated, therefore, as a reasonable point to assume that the relay-contact TC closes, this point being usually well within the first half-cycle of current of fault-magnitude, that is, the half-cycle which terminates at the first current zero Z1 in Fig. 2. It will be noted that the voltage-wave V for the alternating-current part of the grid-biasing voltage passes through zero at a time H in advance of the first current-zero Z1, and the time indicated at H may be regarded as the instant at which the synchronizing response is obtained in the tube 21, and the instant at which the trip-coil of the breaker is energized.

The fault-current curve depicted in Fig. 2 is fairly typical of fault-currents, showing the asymetrical nature of these currents, in general. Thus, the first large half-cycle, such as F—Z1, is not only large in amplitude but long in time-period; the second half-cycle Z1—Z2, of opposite polarity, is both small in magnitude and short in time-duration; and the third half-cycle Z2—Z3, of the same polarity as the first half-cycle, is of somewhat shortened magnitude and time-period as compared with said first half-cycle. After the point Z3, if the circuit-breaker does not then interrupt the fault-current, the fault-current continues, as indicated by dotted lines in Fig. 2, it being noted that the next two successive half-cycles, namely, from Z3 to Z4, and from Z4 to Z5, are much more nearly symmetrical with respect to each other, the fault-current approaching closer and closer to symmetry as time goes on, not always as rapidly as indicated in Fig. 2.

Because of the inequality in the time-periods of successive half-cycles, and because of the unpredictable nature of this inequality, some fault-currents being much more asymmetrical than others, and also because of the impossibility of obtaining a circuit-breaker operation within the small time H—Z1, or even within the time G—Z1 which is available during the first half-cycle of fault-current, I have provided a breaker-system in which I take advantage of the fact that it is possible to predict, within very close limits, the time-duration of two half-cycles after any given current-zero such as Z1, it being noted that the full-cycle time-periods Z1—Z3 and Z3—Z5 are substantially equal to the time period of a complete cycle of the line-current prior to the occurrence of the fault.

In the case illustrated in Fig. 2, the lengths of the time periods Z1—Z3 and Z3—Z5 are somewhat smaller than the one-cycle time-period T1—T2 prior to the fault. The amount of shortening of successive one-cycle periods, under fault-conditions, is not, in any event, a very large proportion of the total one-cycle time-period, and usually the amount of period-shortening is predictable, for the average prevailing conditions of any circuit, so that proper allowances may be made. It will be noted that I define a half-cycle as the time period from one current-zero to the next, or a cycle as the time period from one current-zero to the second current-zero thereafter.

In accordance with my invention, I prefer to avail myself of the predictable time-periods such as H—Z3 or H—Z5 for obtaining the circuit-

breaker interrupting-operation, the circuit-breaker being designed, as previously explained, to consume the specified time-period in bringing about the necessary separation of its contacts, although, as will be seen from Fig. 2, it would be possible, at least in some cases, to avail oneself of the time-period H—Z4, including an odd number of half-cycles greater than two, or even a single half-cycle after the current-zero selected by the synchronizer, for obtaining a predictable amount, or range, of contact-separation in the circuit-breaker at the time of this fourth current-zero Z4 after the occurrence of current of fault-magnitude. In other words, the breaker, such as CBC, has a predetermined opening-operation time requiring until exactly the end of a predetermined even number of complete half-cycles, or a predetermined plurality of half-cycles, or a single complete full cycle, after the first current-zero Z1 after the fault-determination G in Fig. 2, for bringing about a degree of separation of the main contacts 10 by approximately the exact amount necessary to insure circuit-interruption at that current-zero, at the end of the predetermined opening-operation time, with a reasonable margin of safety.

Assuming, first, that the circuit breaker CBC in Fig. 1 requires the one-cycle time H—Z3, in Fig. 2, to operate, this operating-time of the circuit-breaker may be broken down, or analyzed, in a typical case, by noting the instant J at which the unlatching might be completed and at which the moving contact of the breaker begins to move, and the instant K at which the moving contact stops wiping over the stationary contact, and the contacts part and begin to actually separate from each other, so that an arc is produced during the period K—Z3, or until the next current-zero Z3, and this arcing-time K—Z3, or the entire contact-moving time J—Z3, is so chosen that the contacts will achieve a certain predetermined separation, such as ½ inch, or other value required by the particular breaker and the particular rating as to current and voltage. If the arc does not restrike after the current-zero Z3, the line-current remains at zero, as indicated at 51 in Fig. 2.

My invention is also applicable to other circuit-breakers which cannot interrupt the arc within a time such as that indicated at H—Z3. Fig. 2 also indicates the conditions which might exist, for example, with a circuit breaker of the very largest current and voltage-ratings, which might require over one cycle total tripping-time, necessitating an adjustment for a two-cycle time H—Z5 in Fig. 2. In such a case, the unlatching might be completed at a time such as J', and the contacts might begin to part at a time such as K', the arcing continuing during the period K'—Z5, after which the current is interrupted.

In Fig. 3, I have shown the manner in which the synchronized timing-tube 21 operates. In Fig. 3, the first horizontal line indicates the cathode-potential, as indicated; the second horizontal line indicates the negative grid-bias which is provided by the potentiometer 25; and the lower horizontal line indicates the grid-potential below which (or more negative than which) the tube cannot commence to glow, with a predetermined plate-voltage applied thereto, as in the case of the bus-terminals (+) and (—). The rectified voltage-wave V of Fig. 2 is indicated in Fig. 3 at V', this voltage being added to unidirectional biasing-voltage, to give the total grid-potential with respect to the cathode.

In order that no substantial error shall be introduced, as to the exact point in the successive half-cycles at which the grid-potential becomes more positive than the critical grid-voltage at which the tube glows, it is desirable that the unidirectional grid-bias and the critical tube-glowing voltage be as close together as is compatible with satisfactory maintenance problems; and it is further desirable that the voltage V' should be quite large, compared to this slight voltage-difference between the grid-bias line and the tube-glowing line, so that the precise point at which the rectified grid-voltage curve V' crosses the line representing the critical grid-voltage of tube-glowing shall not be materially affected by the magnitude of the fault-current, being, for all magnitudes, practically at the point H where the voltage-curve V becomes zero in Fig. 2. In other words, the voltage-drop across the impedance 31—32 in Fig. 1 should be large.

Prior to the relay-response-time G in Fig. 3, the plate-voltage is not applied to the glow-tube 21 in Fig. 1, and hence the tube is not responsive to the grid-voltage changes. After the application of the plate-voltage to the tube at the instant G, in Fig. 3, the tube is ready to begin to glow as soon as its grid-voltage V' becomes less negative, with respect to the cathode, than the critical-voltage-line at which the tube begins to glow. This point is substantially the point H, as marked on the drawings, and as previously explained. Thereafter, the tube continues to glow, even though the grid subsequently becomes more negative, as indicated by the continuation of the grid-potential line after the point H in Fig. 3, the operation of the tube being finally interrupted by the removal of its plate-voltage, upon the opening of the auxiliary breaker-switch 10*a* in Fig. 1.

While I have so far discussed my invention in its application to what seems to be the more important type of system, in this country, namely, the 60-cycle system, my invention is not limited to 60-cycle systems, and I have shown, by way of example, in Fig. 4, the conditions illustrative of what might occur on a system having a frequency of 16⅔ cycles. In Fig. 4, it is assumed that the fault occurs at a time F—16, which is so close toward the end of a half-cycle that the first half-period of the fault-current does not attain fault-magnitude, so that the current passes through a primary current-zero-point ZO prior to the beginning of the half-cycle ZO—Z during which the current first attains fault-magnitude. Because of the extreme length of this half-cycle, as compared to a 60-cycle half-cycle, it is possible, as shown in Fig. 4, to achieve a complete operation of relaying and breaker-operation within a single half-cycle, the instant of relay-response being indicated, by way of example, at G—16, in Fig. 4, while H—16 indicates the synchronizing response at a more or less predetermined time-interval prior to the current-zero Z. The trip-coil is energized at the moment H—16, the contacts part at a moment such as K—16, and the circuit is interrupted at the current-zero Z.

The times indicated in Fig. 4 are quite short, and the circuit-breaker requires all of the indicated time, from H—16 to Z, in order to complete its operation after the energization of its trip-coil. It is necessary, therefore, in a system such as is depicted in Fig. 4, to so choose the relative values of resistance and reactance, in the impedance 31—32 of Fig. 1, that the phase-angle of advance of the grid-biasing voltage-drop 31—32,

with respect to the phase-angle of the line-current, is considerably more than 10° of the 16⅔-cycle current, which means that it becomes practically necessary to abandon the idea of making the synchronizing response H—16 altogether independent of the current-magnitude, which could be achieved only during phase-advances of not greatly more than 10°. In a 60-cycle system, however, where the breaker-operating time is approximately a cycle, rather than a fraction of a half-cycle, the amount of error introduced by making the phase-advance angle as much as 30° may not be significant.

While I have illustrated my invention in one form of embodiment, in Fig. 1, I do not desire to be limited to this particular form of embodiment, particularly in the broader aspects of my invention, relating to its 60-cycle application, which I consider quite novel and quite important. For this purpose, I desire Fig. 1 to be regarded as symbolically illustrative of a complete 60-cycle system, in which the essential idea is to achieve tripping at the third or fifth current-zero Z3 or Z5 after the attainment of current of fault-magnitude, or after the closure of the fault-responsive relay-contact TC (Fig. 1) at the time indicated at G in Fig. 2. In some cases, the breaker-operating time might possibly be at the end of the third or the fifth half-cycle after the predicted or time-selected current-zero Z1, although I at present prefer to limit my operations to an even number of half-cycles, as indicated by the points Z3 and Z5 in Fig. 2.

So far as the broader aspects of my 60-cycle invention are concerned, I am not limited to the utilization of a phase-advanced voltage-curve V in Fig. 2; but the voltage-curve V could be in phase with the line-current I, which would bring the synchronizing point H into coincidence with the current-zero Z1; or the voltage-wave could even lag behind the current-wave I, which would bring the synchronizing response after the selected zero-current point Z1, as indicated at H' in Fig. 2, which would mean that the circuit-breaker would have a slightly shorter time within which to operate.

Also, in accordance with the broad 60-cycle phase of my invention, I am not limited to any particular means, or kind of means, for selecting, or responding to, the first current-zero Z1 following the relay operation G in Fig. 2. Thus, my invention might utilize any one of several other types of means for responding adequately to the first current-zero Z1, or for selecting an instant of time bearing a predetermined relation to the first current-zero of the line-current which traverses the main contacts 10 of the breaker after the relay-response at G, or for selecting an instant of time approximately coincident with the first current-zero Z1, the time-interval of the phase-advance H—Z1 being only a very small part of the breaker-time H—Z3, in any event.

Two alternative forms of such synchronized timing-means are shown in Figs. 5 and 6, for responding to said first current-zero after the relay-response, either with, or without, an anticipation of the current-zero time Z1 by a time-interval such as the interval from H to Z1 in Fig. 2, or the interval from H—16 to Z in Fig. 4.

In Fig. 5, I show a mechanically movable relay 52 for responding to a zero-point in a voltage-drop which is equivalent to the voltage-drop in the impedance 31—32 in Fig. 1. This time-selecting relay 52 has a low-inertia moving element 53, which is of such light weight, and is so lightly biased as compared to the electromagnetic forces operative thereon, that it is capable of dropping out, and bridging its back-contacts 54, at each zero-point in the magnetizing-current which energizes the relay, so that this time-selecting relay 52 can be utilized to close the tripping-circuit at 54, at a selected point in the current-cycle.

In Fig. 5, the power-line is shown at 55, only a single phase or line-conductor being shown; the circuit-breaker is indicated at 56, its trip-coil at 57, and its auxiliary switch at 58. The fault-responsive tripping-relay is indicated, in Fig. 5, at 60, simply in the form of an over-current relay energized from a line-current transformer 61, although it will be understood that any convenient type of fault-responsive relay may be utilized.

In Fig. 5, a timing-circuit, for energizing the timing-relay 52, is shown, as being energized from the same current-transformer 61. The fault-responsive relay 60 is shown as having a back-contact 62 for short-circuiting this timing-circuit, and a make-contact 63, for then open-circuiting said timing-circuit, so as to make sure that no current is supplied to the timing-circuit prior to the occurrence of a fault. The timing-circuit in Fig. 5, is illustrated as an inductive reactance or choke-coil 64, a step-up or high-voltage current-transformer 65, and the operating-coil of an auxiliary relay 66. The auxiliary relay 66 is of ordinary speed, so that it will pick up, in response to current flowing through its operating coil, and will close its make-contacts 67 more sluggishly or slowly than the time necessary for the low-inertia timing-relay 52 to open its back-contact 53—54 upon the application of energy thereto. The two contacts 67 and 54 are serially connected in the tripping-circuit of the trip-coil 57, so that the trip-coil 57 is not energized until the low-inertia timing-relay 52 drops out at the first current-zero of its magnetizing current. The auxiliary relay 66 does not drop out at each current-zero.

The particular means utilized for energizing the low-inertia timing-relay 52 in Fig. 5 is novel in that the operating coil of this relay 52 is energized from the vectorial sum of two voltages, one of which is proportional to, and in phase with, the line-current, while the other voltage is proportional to, but approximately 90° in advance of, the line-current, these two voltages being at first in opposition to each other. The voltage which is in phase with the line-current is obtained from the secondary terminals of the high-voltage auxiliary current-transformer 65, which supplies a very small current, at high voltage, to the operating coil of the timer-relay 52. The voltage leading the line-current is obtained from the voltage-drop in the impedance 64, by means of a shunt-circuit 68 including an adjustable resistance 69, the resistance 69 being sufficiently large so that the impedance of the coil 52 plus the resistance 69 is practically pure resistance, so that the current flowing in the shunting circuit 68—69—52 is practically in phase with the voltage-drop across the coil 64.

In the operation of the system shown in Fig. 5, when a fault occurs, the fault-relay 60 responds, and permits the line-current from the current-transformer 61 to be supplied to the timing-circuit 64—65—66. At the first instant of current in-rush, the choke-coil 64 interposes a high impedance, so that practically all of the first in-rush of the current passes through the shunting

circuit 68—69—52, thus energizing the timer-relay with a strong leading current which is at its maximum value, because the choke-coil 64 immediately begins to carry current and to decrease the voltage-drop thereacross. Although the leading current which is supplied to the coil 52 through the inductance-shunting circuit 68—69 is opposed by the in-phase current supplied by the auxiliary current-transformer 65, the relationships between these two energizing currents (or voltages) are such that the leading current is much larger, until a point corresponding to the point H prior to the current-zero Z1 in Fig. 2.

In this manner, the low-inertia timing-relay 52 very quickly picks up its movable element 53, and opens its back-contact 54, much more quickly than the ordinary-inertia relay 66 can pick up its make-contact 67, so that the tripping circuit is opened at 54 before it can be closed at 67. The tripping circuit is thereupon not completed until the point H (see Fig. 2) of the cycle at which the decreasing leading-current in the inductor-shunting circuit 68—69 becomes substantially equal to, or less than, the in-phase current supplied by the current-transformer 65, during the last portion of the half-cycle wherein the line-current is approaching its current-zero Z1 of Fig. 2. When the low-inertia timing-relay 52 drops out, at approximately the instant of equality between its two energizing-currents, the trip circuit is energized, sealing itself in at the contactor-switch contacts 50, as previously described, thus keeping the trip-coil 57 energized until its circuit is finally opened by the auxiliary breaker-switch 58.

In Fig. 6, I have shown a different form of embodiment of a timing-circuit, embodying a grid-glow tube 21' in which the phase-shifting impedance 31—32 of Fig. 1 is omitted, and the rectifier 33 is energized directly across the terminals of the auxiliary current-transformer 30, so that the synchronizing response-point H is moved over to the current-zero Z1, in Fig. 2.

In Fig. 6, also, a different type of utilization of the fault-responsive relay is shown, whereby the fault-responsive relay controls the grid-potential of the tube 21', instead of opening and closing the plate-circuit of the tube, as in Fig. 1. In Fig. 6, the fault-responsive relay is shown as a simple overcurrent relay 60', which is intended to be symbolic of any suitable fault-responsive relay, whether or not it is overcurrent, impedance-responsive, reactance-responsive, directionally-responsive, or pilot-channel responsive.

By way of illustration, also, in Fig. 6, the fault-responsive relay 60' is utilized to have its back-contacts 62' control the control-circuit or grid-circuit of the tube 21', rather than utilizing a tripping-contact, such as TC of Fig. 1, in series with the trip-circuit itself. In Fig. 6, the back-contact 62' of the fault-responsive relay normally short-circuits a portion 25' of the potentiometer 25, so that, as long as the back-contact 62' is closed, the grid 23 is impressed with the full voltage of the biasing battery 26, so that the unidirectional grid-bias is moved down to a point indicated at 71, in Fig. 3, below, or more negative than, the critical grid-voltage at which the tube will begin to glow. When a fault occurs, the relay-contact 62' opens and changes the grid-bias to the conditions depicted by the full-line curves in Fig. 3, so that thereafter the tube will glow at the first current-zero of the alternating-current voltage-wave which is supplied through the rectifier 33, as depicted at H in Fig. 3, except that the point H is moved over into coincidence with the line-current zero-point Z1 in Fig. 2, because of the omission of the phase-advancing impedance 31—32 of Fig. 1.

In Fig. 6, as in Figs. 1 and 5, the important part of the cycle of the wave-form controlling the synchronizing timer is the current-zero part, and the maximum-current part or peak of the wave-form (such as the wave-form V' in Fig. 3) is unimportant. Hence, in Fig. 6, I have indicated the possibility of utilizing a voltage-limiting grid-glow tube 30' connected across the terminals of the current-transformer 30, or any other non-linear means for cutting off the peaks of the alternating-current part of the rectified grid-biasing voltage, while linearly responding to the line-current near the current-zero parts of the voltage-curve V.

In all the forms of my invention, I have achieved the important result of responding to the phase of the line-current traversing the main contacts of the breaker after the determination that a breaker-opening operation is desired, independently of the phase of the line-voltage, and independently of the phase of the previously flowing line-current.

It will be understood that the various alternative features which I have shown and described, in the various figures of my drawings, are to be utilized, wherever applicable and wherever desirable, in all of the figures, with these and other additions, omissions, and substitutions, made in accordance with the skill of the skilled workers of the art. And while I have described by invention, and explained its operation, in accordance with certain illustrative assumptions and proportions, I wish it to be understood that these matters are purely illustrative in nature, and are not intended by way of absolute limitations upon my invention, as will be obvious to those skilled in the art. I desire, therefore, that the appended claims shall be accorded the broadest construction consistent with their language.

I claim as my invention:

1. An alternating-current circuit-breaker system for operation on an alternating-current line which is subject to asymmetrical fault-currents, comprising the combination, with such a line, of a single-phase circuit-breaker having an operating-means for effecting an opening-operation of the main contacts of the breaker, means for determining that a breaker-opening operation is desirable, current-responsive synchronized timer-means having a selective action with respect to the line-current conditions which obtain after the occurrence of a fault, for quickly selecting an instant of time approximately coincident with a current-zero of the line-current traversing the main contacts of the breaker after said determination that a breaker-opening operation is desirable, and means responsive to the operation of said timer-means for energizing the operating-means of the breaker, characterized by said breaker having a predetermined interrupting time requiring until exactly the end of a predetermined even number of substantially complete half-cycles after said first current-zero for bringing about a degree of separation of the main contacts by approximately the exact amount necessary to insure circuit-interruption at the current-zero at the conclusion of the predetermined interrupting-time, with a reasonable margin of safety, defining a half-cycle as the time-period from one current-zero to the next.

2. An alternating-current circuit-breaker system for operation on an alternating-current line which is subject to asymmetrical fault-currents, comprising the combination, with such a line, of a single-phase circuit-breaker having an operating-means for effecting an opening-operation of the main contacts of the breaker, means for determining that a breaker-opening operation is desirable, current-responsive synchronized timer-means having a selective action with respect to the line-current conditions which obtain after the occurrence of a fault, for quickly selecting an instant of time approximately coincident with a current-zero of the line-current traversing the main contacts of the breaker after said determination that a breaker-opening operation is desirable, and means responsive to the operation of said timer-means for energizing the operating-means of the breaker, characterized by said breaker having a predetermined interrupting-time requiring until exactly the end of substantially a single complete full cycle after said first current-zero for bringing about a degree of separation of the main contacts by approximately the exact amount necessary to insure circuit-interruption at the current-zero at the conclusion of the predetermined interrupting-time, with a reasonable margin of safety, defining a cycle as the time-period from one current-zero to the second current-zero thereafter.

3. The invention as defined in claim 1, in combination with testing-means for checking the operative condition of said synchronized timer-means and for meanwhile causing the energization of the operating-means to be immediately responsive to said determination that a breaker-opening operation is desirable during the period in which said test is in progress.

4. The invention as defined in claim 1, in combination with an auxiliary delayed-action means having a delay of at least approximately the longest expectable half-cycle for responding to said determination that a breaker-opening operation is desirable and for thereupon energizing the operating-means of the breaker without waiting any longer for the instant-selecting operation of the timer-means.

5. An alternating-current circuit-breaker system for operation on an alternating-current line which is subject to asymmetrical fault-currents, comprising the combination, with such a line, of a single-phase circuit-breaker having an operating-means for effecting an opening-operation of the main contacts of the breaker, means for determining that a breaker-opening operation is desirable, current-responsive synchronized timer-means having a selective action with respect to the line-current conditions which obtain after the occurrence of a fault, for quickly selecting an instant of time bearing a predetermined relation to a current-zero of the line-current traversing the main contacts of the breaker after said determination that a breaker-opening operation is desirable, and means responsive to the operation of said timer-means for energizing the operating-means of the breaker, characterized by said breaker having a predetermined interrupting-time requiring until exactly the end of a predetermined even number of substantially complete half-cycles after said first current-zero for bringing about a degree of separation of the main contacts by approximately the exact amount necessary to insure circuit-interruption at the current-zero at the conclusion of the predetermined interrupting-time, with a reasonable margin of safety, defining a half-cycle as the time-period from one current-zero to the next.

6. An alternating-current circuit-breaker system for operation on an alternating-current line which is subject to asymmetrical fault-currents, comprising the combination, with such a line, of a single-phase circuit-breaker having an operating-means for effecting an opening-operation of the main contacts of the breaker, means for determining that a breaker-opening operation is desirable, current-responsive synchronized timer-means having a selective action with respect to the line-current conditions which obtain after the occurrence of a fault, for quickly selecting an instant of time bearing a predetermined relation to a current-zero of the line-current traversing the main contacts of the breaker after said determination that a breaker-opening operation is desirable, and means responsive to the operation of said timer-means for energizing the operating-means of the breaker, characterized by said breaker having a predetermined interrupting-time requiring until exactly the end of substantially a single complete full cycle after said first current-zero for bringing about a degree of separation of the main contacts by approximately the exact amount necessary to insure circuit-interruption at the current-zero at the conclusion of the predetermined interrupting-time, with a reasonable margin of safety, defining a cycle as the time-period from one current-zero to the second current-zero thereafter.

7. The invention as defined in claim 5, in combination with testing-means for checking the operative condition of said synchronized timer-means and for meanwhile causing the energization of the operating-means to be immediately responsive to said determination that a breaker-opening operation is desirable during the period in which said test is in progress.

8. The invention as defined in claim 5, in combination with an auxiliary delayed-action means, having a delay of at least approximately the longest expectable operating-time of the synchronized timer-means, for responding to said determination that a breaker-opening operation is desirable and for thereupon energizing the operating-means of the breaker without waiting any longer for the instant-selecting operation of the timer-means.

9. An alternating-current circuit-breaker system, comprising a single-phase circuit-breaker having an operating-means for effecting an opening-operation of the main contacts of the breaker, means for determining that a breaker-opening operation is desirable, current-responsive synchronized timer-means having a selective action with respect to the line-current conditions which obtain after the occurrence of a fault, for selecting an instant of time bearing a predetermined relation to a current-zero of the line-current traversing the main contacts of the breaker after said determination that a breaker-opening operation is desirable, and means responsive to the operation of said timer-means for energizing the operating-means of the breaker, characterized by said timer-means comprising a means responsive to substantially a current-zero effect, and energizing-means therefor, including current-responsive impedance-means for obtaining the effect of a current-zero at a predetermined phase-angle in advance of the current-zero in the current traversing the main contacts of the breaker, said predetermined phase-angle being sufficiently small so that the slope of the

current wave-form remains substantially constant between the instant of timer-response and the instant of current-zero in the current traversing the breaker-contacts.

10. An alternating-current circuit-breaker system, comprising a single-phase circuit-breaker having an operating-means for effecting an opening-operation of the main contacts of the breaker, means for determining that a breaker-opening operation is desirable, current-responsive synchronized timer-means having a selective action with respect to the line-current conditions which obtain after the occurrence of a fault, for selecting an instant of time bearing a predetermined relation to a current-zero of the line-current traversing the main contacts of the breaker after said determination that a breaker-opening operation is desirable, and means responsive to the operation of said timer-means for energizing the operating-means of the breaker, characterterized by said timer-means comprising means responsive to the current traversing the main contacts of the breaker for deriving a single leading alternating-current electrical quantity which leads said breaker-current by a predetermined phase-angle, and a single means for making a response at approximately a current-zero point in said derived electrical quantity.

11. The invention as defined in claim 10, characterized by said single means being a single grid-controlled tube.

12. The invention as defined in claim 10, characterized by said single means being a single, mechanically moving, low-inertia relay.

13. An alternating-current circuit-breaker system, comprising a single-phase circuit-breaker having an operating-means for effecting an opening-operation of the main contacts of the breaker, means for determining that a breaker-opening operation is desirable, current, responsive synchronized timer-means having a selective action with respect to the line-current conditions which obtain after the occurrence of a fault, for selecting an instant of time bearing a predetermined relation to a current-zero of the line-current traversing the main contacts of the breaker after said determination that a breaker-opening operation is desirable, and means responsive to the operation of said timer-means for energizing the operating-means of the breaker, characterized by said timer-means comprising an electrical relay having a magnetic operating-means and a low-inertia moving element which drops out substantially at the zero-points in the magnetic energization, energizing-means therefor, and means for energizing said relay from said energizing-means in response to said determination that a breaker-opening operation is desirable, said energizing-means comprising means responsive to the current traversing the main contacts of the breaker for deriving two opposed currents, one of said derived currents being substantially in phase with the breaker-current, and the other derived current being substantially 90° out of phase therewith.

14. An alternating-current circuit-breaker system, comprising a single-phase circuit-breaker having an operating-means for effecting an opening-operation of the main contacts of the breaker, means for determining that a breaker-opening operation is desirable, current-responsive synchronized timer-means having a selective action with respect to the line-current conditions which obtain after the occurrence of a fault, for selecting an instant of time bearing a predetermined relation to a current-zero of the line-current traversing the main contacts of the breaker after said determination that a breaker-opening operation is desirable, and means responsive to the operation of said timer-means for energizing the operating-means of the breaker, characterized by said timer-means comprising means responsive to the current traversing the main contacts of the breaker for deriving a single leading alternating-current electrical quantity which leads said breaker-current by a predetermined phase-angle, and grid-controlled tube-means having unidirectional biasing-means for predisposing said tube-means to respond at approximately a current-zero point in said derived electrical quantity.

15. An alternating-current circuit-breaker system, comprising a single-phase circuit-breaker having an operating-means for effecting an opening-operation of the main contacts of the breaker, means for determining that a breaker-opening operation is desirable, current-responsive synchronized timer-means having a selective action with respect to the line-current conditions which obtain after the occurrence of a fault, for selecting an instant of time bearing a predetermined relation to a current-zero of the line-current traversing the main contacts of the breaker after said determination that a breaker-opening operation is desirable, and means responsive to the operation of said timer-means for energizing the operating-means of the breaker, characterized by said timer-means comprising means responsive to the current traversing the main contacts of the breaker for deriving a single leading alternating-current electrical quantity which leads said breaker-current by a predetermined phase-angle, double-wave rectifier-means for rectifying said derived electrical quantity, and means for responding at approximately a current-zero point in said rectified quantity.

ROSWELL C. VAN SICKLE.