

UNITED STATES PATENT OFFICE

2,290,683

CIRCUIT BREAKER CONTROL

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Application June 28, 1939, Serial No. 281,585
In Germany June 28, 1938

14 Claims. (Cl. 175—294)

This invention relates to improvements in control apparatus, and more particularly to a control arrangement for synchronously tripping circuit breakers.

In the interruption of high power electrical circuits by means of circuit breakers, it is desirable to initiate separation of the breaker contacts at a time sufficiently in advance of current zero in the current wave to enable the contacts to attain a given separation when the current passes through zero. During the interruption of normal currents it may be assumed that the wave form of the current in the half cycle in which interruption is to take place does not differ essentially from the wave form of preceding half cycles. In such cases, it is possible to select a current zero in the current wave form as a definite time point at which to initiate the control impulse and to give the circuit breaker an operating speed such that the desired contact separation is obtained after the lapse of a predetermined time period based upon the duration of a normal half cycle. However, in many cases, as for instance, during the interruption of overloads and short circuits, the assumption that the time period of the half wave in which circuit interruption is to take place is equal to the normal half period is not correct, since in a great number of instances particularly immediately following the instant at which the disturbance takes place, a more or less large deviation from the normal half wave value can appear. As a result of this deviation the breaker contacts do not separate at a point most favorable to arc extinction and consequently the full interrupting ability of the breaker is not utilized.

The object of this invention is to improve the accuracy with which a particular time point along a current wave in a circuit may be selected for the purpose of initiating a control impulse for controlling the circuit.

A further object of the invention is the provision of means for initiating a control impulse at a predetermined time point in the current wave of the circuit being controlled, which means act independently of the current magnitude in the circuit.

The improved results of the present invention are due to a utilization of the straight line portion of the current wave just preceding a current zero in selecting a predetermined time point at which to initiate the control impulse. More specifically, the invention utilizes means to initiate a control impulse that is responsive to a predetermined condition such as the ratio of the in-

stantaneous current i in the circuit to be controlled to the rate of change of instantaneous current

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of the circuit. This ratio is the same at a definite instant before current zero for all current values within the linear portion of the current wave.

A still further and more specific object of the invention is to provide a control device for delivering synchronized tripping impulses for tripping a circuit breaker whereby the tripping impulse is initiated at the instant at which the ratio of the current to the rate of change of the instantaneous current in the circuit to be interrupted has a predetermined value.

In accordance with the last-named object, a tripping impulse that is delivered in dependence upon the above-named ratio is initiated independently of the current magnitude and at the same time point before a current zero at which current interruption is desired. The probability that the current wave form under the influence of short circuit or overload will change substantially during the short time interval between initiating the impulse and current zero is small. A tripping control scheme for circuit breakers operative in dependence upon the ratio of the current to the rate of change of instantaneous current in the circuit therefore functions with greater precision than the devices heretofore proposed.

Other objects and advantages will appear more fully in the following description when taken in connection with the accompanying drawing in which:

Figure 1 is a diagrammatic illustration of the control system of my invention, and

Fig. 2 is a diagrammatic illustration of a modified form of control system.

Referring to the drawing, the reference number 1 designates a power circuit for carrying alternating current. Connected in the circuit 1 is a circuit breaker generally schematically shown at 3 and comprises a pair of fixed contacts 5 bridged by a movable contact member 7. The movable contact member 7 is actuated to the open and closed positions by a linkage mechanism composed of a lever 9 and bell crank 11. The upper end of the bell crank 11 engages a latching lever 13 for normally holding the breaker in the closed position against the bias of an operating spring 15. Associated with the latch

lever 13 is an electromagnetic trip device having an armature 17 and a trip coil 19. The trip coil 19, in this instance, is connected for energization from a suitable source of potential as the battery 21.

The flow of current from the battery 21 to the trip coil 19 for tripping the breaker 3 is controlled by a relay 23. The specific operation of the control relay 23 will appear more fully hereinafter. For the purpose of control, a current transformer 25 is connected to the power circuit 1 by means of its primary winding 27. The secondary winding 29 of the transformer 25 is connected by connections 31 and 33 to the relay 23. The secondary 29 of the transformer 25 is normally short circuited by magnetically actuated switch 35.

The relay 23 comprises a pair of U-shaped magnets 37 and 39 disposed in opposed spaced relation with respect to each other. The magnet 37 is energized by a coil 41 one end of which is connected to the terminal 43 of the connection 33, whereas the other end of the coil is connected to a reactance 45. The reactance 45 is connected at the terminal 47 to the connection 31. The magnet 39 is energized by a coil 49 which is serially connected with a resistance 51 between the terminals 43 and 47. It will be noted that the current flowing through the coil 41 will be directly proportional to and substantially in phase with the current flowing in the power circuit 1. The comparatively small amount of current flowing through the coil 49 is proportional to the voltage drop across the coil 41 and the reactance 45. Thus this voltage is proportional to the rate of change of the current in the main power circuit 1. The ohmic resistance 51 is utilized for the purpose of maintaining the small amount of current flowing through the coil 49 substantially in phase with the voltage across the coils 41 and 45. The coils 41 and 49 are so arranged that the respective magnetomotive forces produced thereby are equal and opposite at a predetermined time point in the current wave during each cycle.

Disposed between the magnets 37 and 39 is a pivotal armature 53 adapted to be moved a limited distance as defined by the stops 55 and 57. The free end of the armature 53 is provided with a switch arm 59 for carrying the movable contact support 61 of a control switch 63. A coil spring 65 attached to the switch arm 59 exerts just enough biasing action upon the arm 59 to overcome the weight of the armature 53 and its associated parts so as to normally hold the armature 53 against the stop 55.

The control switch 63 also includes two sets of stationary contacts 67-69 and 71-73. The support 61 carries bridging contact members 75 and 77, respectively, adapted to engage the two sets of stationary contacts 67-69 and 71-73. The bridging contacts 75 and 77 are mounted for limited relative movement with respect to the support 61 and are biased by springs, as shown, to one of their limiting positions. Contacts 69 and 73 are connected by a conductor 79. A conductor 81 joins the contact 71 with one terminal of the battery 21. The contact 67 of the switch 63 is connected by a conductor 83 to the coil 85 of a relay 87. The coil 85 is also connected in series with a relay 89 which, in turn, is connected to the trip coil 19. The trip coil 19 is connected to the other terminal of the battery 21 through a conductor 91. The contacts of relay 87 are connected by conductors 93 and 95 to the con-

ductors 81 and 83 to provide a shunt circuit across the control switch 63. The coil of the relay 89 is connected by conductors 97 to the conductors 31 and 33 leading from the secondary winding 29 of the current transformer 25.

The operation of the control system, as shown in Fig. 1, is as follows: Upon the occurrence of a predetermined overload, the switch 35, having its operating coil in series with the conductor 31, is caused to open thereby removing the short circuit across the secondary winding 29 of the current transformer 25. Upon the opening of the switch 35 current in proportion to the overload in the main circuit 1 and substantially in phase therewith is delivered through the line connections 31-33 to the relay 23. More specifically, current will flow from the secondary 29 through the line connection 33, terminal 43, coil 41, coil 45, terminal 47 and line 31 back to the secondary 29. Following the subsidence of the initial transient, the current flowing through the coil 41 is proportional to the current flowing in the main power circuit 1 and substantially in phase therewith and causes the magnet 37 to be magnetized so that it attracts the pivoted armature 53 and holds it against the stop 55. A much smaller current will also flow from the terminal 43 through the resistance 51, coil 49 to the terminal 47. This current is proportional to the voltage drop between the terminals 43 and 47, and since this drop is reactive in nature, the current flowing through the coil 49 is substantially proportional to the rate of change of current in the main circuit 1 and leads said line current by substantially 90 electrical degrees. The winding 49 is so arranged that when it is energized the magnet 39 exerts a pull upon the pivoted armature 53 opposite to that exerted by the magnet 37.

It is to be noted, however, that since the circuit through coil 49 is predominantly pure resistance, whereas the circuit through coil 41 is predominantly reactive, the coil 49 will be energized prior to the energization of coil 41, irrespective of the phase conditions at the time of opening of the switch 35. It, therefore, would follow that upon each opening of the switch 35, the coil 49 would be energized prior to energization of the coil 41 and cause the armature 53 to be moved downwardly to actuate the control switch 63. In order to avoid such a false tripping operation, the relay 89 is connected in series with the trip coil 19. The relay 89, which is actuated in response to opening of the switch 35, has a predetermined time delay so that it will remain open and prevent energization of the trip coil 19 until after the currents through the coils 41 and 49 have reached a condition which is truly representative of the instantaneous current in the main circuit and the rate of change of current in that circuit.

The magnets 37 and 39 and their respective windings 41 and 49 are so arranged with respect to the armature 53 that the respective attractive forces exerted thereby are equal to each other at a predetermined time point along the current wave preceding a current zero. In other words, the relay 23 is preferably so constructed that the ratio

$$\frac{i}{di/dt}$$

is equal to a constant at a definite time point before current zero. It is a known fact that the instantaneous value of current i reaches a maxi-

imum value at or near the quarter periods of its cyclic wave form. At maximum current the rate of change of current is zero. As the instantaneous current decreases from its maximum value, the rate of change of current increases. It is, therefore, evident that a time point occurring at a definite instant prior to a current zero may be selected at which the pull exerted by magnet 37 is equal to that exerted by the magnet 39. Following this time point, as the current decreases, the pull of the magnet 37 will decrease and the pull of magnet 39 which is proportional to the rate of change of current will increase, thereby causing armature 53 to be moved against the stop 57 carrying with it the switch arm 59 and the movable contact support 61 of the control switch 63.

During the initial part of the downward movement of the contact support 61, the bridging contact 75 remains in engagement with the contacts 67—69. Shortly before the bridging contact 75 breaks connection with the contacts 67 and 69, the lower bridging contact 77 engages the contacts 71 and 73 so as to close the circuit from the battery 21 to the trip coil 19. Current then flows from the battery 21 through the conductor 81, contacts 71, 77, 73, conductor 79, contacts 69, 75, 67, conductor 83, coil 85, contact members of relay 89, trip coil 19, and through the conductor 91 back to the battery. Further downward movement of the support member 61, that is, to its lowermost limit, causes the bridging contact 75 to break connection with the contacts 67 and 69. The battery 21 at this instant is not disconnected from the trip coil 19, since the initial current impulse through the trip coil energized the coil 85 of the relay 87 causing the latter to establish a shunt circuit through the conductors 93 and 95 around the control switch 63.

Energization of the trip coil 19 initiates a mechanical tripping impulse upon the armature 17 which, in turn, actuates the latch lever 13 to trip the breaker 3 to the open circuit position. In practice, the breaker 3 is so designed that it has a high speed operating mechanism so that the bridging member 7 will have separated from the stationary contacts 5 the desired distance upon the occurrence of the first current zero following the initiation of the tripping impulse. Upon the interruption of the main circuit 1 by the breaker 3, the current transformer 25 is de-energized causing relay 89 to break the circuit from the battery 21 to the trip coil 19.

From the foregoing, it will be noted that the control switch 63 is capable of initiating a tripping impulse only during the downward movement of the armature 53 and that when the armature 53 is held against the stop 57, the bridging contact 75 is out of engagement with the stationary contact 67 and 69. This arrangement is essential to guard against false operations which may occur as follows: During each cycle of current flow in the main circuit 1, there is at least one-quarter cycle during which the current in the coil 41 is aiding the current in the coil 49 of the relay 23 so as to maintain the armature 53 against the stop 57. Thus, if the control switch 63 were allowed to be closed during this interval and an overload occurred so that switch 35 were opened at about the beginning of the interval, the control switch 63 would still be closed following closure of the relay 89 which places the trip coil circuit in operative condition. Under these conditions, a tripping

operation would take place without reference to a predetermined time period preceding current zero.

Furthermore, in order to prevent the introduction of a tripping impulse by the control switch 63 when the armature 53 is moved from its lower position to the upper position in response to the periodic attraction of the magnets 37 and 39, the bridging contact 77 is provided with a dashpot 94. The dashpot 94 retards relative motion between the contact 77 and the movable contact support 61 to such an extent that the connection between the bridging contact 77 and the stationary contacts 71 and 73 is broken immediately upon the upward movement of the support 61. Relative movement does not take place until the support 61 has moved upwardly a distance to normally carry the contact 77 out of range of the contacts 71 and 73. The control arrangement, therefore, selects one predetermined time point in each cycle at which to initiate a tripping impulse to the breaker operating mechanism.

The control arrangement shown in Fig. 2 is similar to that shown in Fig. 1 with the exception that the relay 23 is of modified form. The magnets 37 and 39 in this instance are spaced somewhat farther apart and have disposed therebetween a pair of spaced field pole members 98. Pivotaly mounted armature 53 is replaced by a shorter armature 99 which is also pivotaly mounted and is normally biased away from the field poles 98 by a spring 101 and is adapted to be attracted to the field poles when the latter are magnetized to a predetermined degree.

The armature 99 carries the switch arm 59 which, in turn, carries the movable contact support 61 of the switch 63. In all other respects, the system of Fig. 2 is the same as that shown in Fig. 1.

The operation of the apparatus of Fig. 2 is as follows: As previously described, magnet 37 is energized by current flowing through the coil 41 which is proportional to the flow of current in the main circuit 1. The coil 41 being energized, sets up a magnetic field through the field poles 98 which attract the armature 99 holding it in bridging relation with the field poles 98 and thus moves the movable contact support 61 of the control switch 63 to its upper position, placing it in readiness to close the trip coil circuit. Also, as previously described, the coil 49 is energized by a current which is proportional to the rate of change of instantaneous current in the main power circuit 1, to establish a magnetomotive force in the magnet 39 which at a given instant equals the magnetomotive force set up in the magnet 37.

The magnets 37 and 39 and their respective windings 41 and 49 are so arranged that the resultant magnetic flux set up in the field poles 98 is zero at a predetermined instant preceding a current zero. When the flux in the field poles 98 becomes zero, the magnetic attraction for the armature 99 ceases and the spring 101 moves the switch arm 59 downwardly to cause the switch 63 to close, thereby establishing a current conducting circuit from the battery 21 to the trip coil 19 which causes the breaker 3 to open in a manner previously described. Inasmuch as the tripping impulse occurs at a time point which is dependent upon the ratio of the current i to the rate of change of current

$$\frac{di}{dt}$$

the tripping impulse will always occur at the same time point preceding a current zero irrespective of the current magnitude in the power circuit.

From a consideration of Fig. 2, it will also be apparent that the flux in the field poles 93 becomes zero when the magnetomotive force of the coils 41 and 49 are equal. The fact that flux in the field poles 93 becomes zero may be used as the basis for a modified form of control.

It will be apparent to those skilled in the art that the resistor 51 and the coil 43 can be connected across the reactance 45 only instead of the reactance 45 and the coil 41 in series. Furthermore, if the coil 41 is constructed as a low power factor circuit of adequate reactance, the reactance 45 can be eliminated.

From the foregoing description it will also be apparent that armatures 53 and 99, as shown in Figs. 1 and 2, may be utilized to directly actuate the latch mechanisms of certain circuit breakers without resorting to the use of an electrical trip circuit.

It will also be understood that although I have shown and described specific embodiments of my invention, the same is for the purpose of illustrating the invention, and that changes and modifications may be made by those skilled in the art without departing from the spirit and scope of the appended claims.

I claim as my invention:

1. In combination, an electric circuit for carrying an alternating current, a control device therefor and means operative independently of the magnitude of current above a predetermined value in said circuit and responsive to a predetermined ratio of current to the rate of change of instantaneous current in said alternating current circuit for producing a control impulse to actuate said control device.

2. In combination, an electric circuit for carrying an alternating current, an electro-responsive control device, means for energizing said control device in accordance with the current in said alternating current circuit, and means for energizing said control device in accordance with the rate of change of instantaneous current in said alternating current circuit, said electro-responsive control device including means operative independently of the current magnitude above a predetermined value in said circuit and responsive to a predetermined ratio of the current to the rate of change of instantaneous current in said alternating current circuit for producing a control impulse.

3. In combination, a circuit for carrying an alternating current, a device for delivering synchronized control impulses of definite phase position with reference to the alternating current in said circuit, and means for energizing said device in accordance with both the current and the rate of change of instantaneous current in said alternating current circuit for causing said device to deliver a control impulse at substantially the instant at which the ratio of the instantaneous current to the rate of change of instantaneous current in said alternating current circuit has a predetermined value.

4. In an electrical control system for an alternating current circuit, a circuit for carrying an alternating current, electroresponsive means having at least two coils, means for energizing one of said coils with a current proportional to the current in said circuit, means for energizing the other of said coils with a current proportional

to the rate of change of instantaneous current in said circuit, and means operative independently of the magnitude of current in said circuit above a predetermined value and in response to energization of said coils to produce a control impulse at an instant when the ratio of the current to the rate of change of instantaneous current in said circuit is of a predetermined value.

5. In an electrical control system for an alternating current circuit, a circuit for carrying alternating current, relay means having at least two electromagnets, means for energizing one of said electromagnets with a current proportional to the instantaneous current in said circuit, means for energizing the other of said electromagnets with a current proportional to the rate of change of instantaneous current in said circuit, and an armature operatively associated with said electromagnets and movable in response to energization of said electromagnets to institute a control impulse at an instant when the ratio of the instantaneous current to the rate of change of instantaneous current in said circuit is of a predetermined value.

6. The combination with a circuit breaker for interrupting an alternating current circuit having latch means for holding the breaker in the closed position, of means for tripping said latch means to cause said breaker to open, and means responsive to the current and the rate of change of the instantaneous current in the circuit to be interrupted for actuating said tripping means at a definite phase position with respect to the alternating current in the circuit being interrupted.

7. The combination with a circuit breaker for interrupting an alternating current circuit having a trip coil, of means for energizing said trip coil to cause said breaker to open, and means operative independently of the current magnitude above a predetermined value for controlling said energizing means and to initiate the flow of current through said trip coil at such time when the ratio of the current to the rate of change of instantaneous current in the circuit to be interrupted is of a predetermined value.

8. The combination with a circuit breaker for interrupting an alternating current circuit having latch means for holding the breaker in the closed position, of means for tripping said latch means to cause said breaker to open, and electro-responsive means operative independently of the current magnitude above a predetermined value for causing said tripping means to deliver a tripping impulse at the instant when the ratio of the current to the rate of change of instantaneous current in the circuit to be interrupted is of a predetermined value.

9. The combination with a circuit breaker for interrupting an alternating current circuit having latch means for holding the breaker in the closed position, of means for tripping said latch means to cause said breaker to open, said tripping means including a relay for initiating the tripping impulse, and means for energizing said relay with alternating currents proportional respectively to the instantaneous current and the rate of instantaneous change of current in the circuit to be interrupted to cause said tripping impulse to occur at a predetermined time point in the current wave of the circuit to be interrupted.

10. The combination with a circuit breaker for interrupting an alternating current circuit having a trip coil, of means for energizing said trip

coil to cause said breaker to open, said energizing means comprising a source of power for delivering tripping current to said trip coil, and a relay responsive to the current and the rate of change of instantaneous current in the circuit to be interrupted for controlling the flow of current to said trip coil, said relay initiating the flow of current to said trip coil at a predetermined time point in the current wave and at an instant when the ratio of the current to the rate of change of instantaneous current in the circuit to be interrupted is of a predetermined value.

11. The combination with a circuit breaker for interrupting an alternating current circuit having latch means for holding the breaker in the closed position, of means for tripping said latch means to cause said breaker to open, said tripping means including a relay for initiating the tripping impulse, said relay having two electromagnets, means for deriving a current proportional to the current in the circuit to be interrupted for energizing one of said electromagnets, means for deriving a current proportional to the rate of change of instantaneous current in the circuit to be interrupted for energizing the other of said electromagnets, and an armature movable in response to the joint influence of said electromagnets for initiating the tripping impulse.

12. In a control device for an alternating current circuit, means for delivering a synchronized control impulse of definite phase position with respect to the current in said circuit, said means comprising a pair of electromagnets, means for energizing one of said electromagnets with a current proportional to the current in said circuit, means for energizing the other of said electromagnets with a current proportional to the rate of change of instantaneous current in said circuit, fixed armature means disposed within the resultant magnetic field of said electromagnets, a movable armature normally held in a predetermined position by the magnetic attraction of said fixed armature means, and biasing means for moving said movable armature to a second position to initiate a control impulse in response

to predetermined flux conditions in said fixed armature means as determined by said electromagnets.

13. In a control device for an alternating current circuit, means for delivering a synchronized control impulse of definite phase position with respect to the current in said circuit, said means comprising a pair of spaced electromagnets disposed in opposed relation, means for energizing one of said electromagnets with a current proportional to the current in said circuit, means for energizing the other of said electromagnets with a current proportional to the rate of change of instantaneous current in said circuit, a pair of spaced field poles disposed between said electromagnets, a movable armature normally held in bridging relation with respect to said field poles by the magnetic attraction thereof, and biasing means for moving said armature away from said field poles to initiate a control impulse in response to predetermined flux conditions in said field poles as determined by said electromagnets.

14. The combination with a circuit breaker for interrupting an alternating current circuit having latch means for holding the breaker in the closed position, of means for tripping said latch means to cause said breaker to open, said tripping means including two electromagnets disposed in magnetically opposed relation, means for energizing one of said electromagnets with a current proportional to the current in the circuit to be interrupted, means for energizing the other of said electromagnets with a current proportional to the rate of change of instantaneous current in the circuit to be interrupted, stationary armature means disposed within the resultant magnetic field of said electromagnets, a movable armature normally held in a predetermined position by the magnetic attraction of said stationary armature means, and biasing means for moving said movable armature away from said stationary armature means in response to predetermined flux conditions in said stationary armature means for initiating the tripping action.

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