FIG. 4

FIG. 5

FIG. 6

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ARC SUPPRESSING CIRCUITS


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4 Claims

ABSTRACT OF THE DISCLOSURE

An arc suppressing circuit for use with a mechanical switch which connects a source of alternating voltage to a load in its closed position. The circuit includes electronic switching means which can be set to a conducting state by the application of a signal to a control terminal. The power terminals of the electronic switch are connected to the contacts of the mechanical switch and a signal resulting from voltage transients generated when the switch is switched from the open to the closed position or from the closed to the open position is supplied to the control terminal of the switch. Once rendered conducting, the switch remains conducting until either the source voltage goes to zero or the switch is closed.

Our invention relates to arc suppressing circuits, and more particularly to novel electronic circuits for protecting the contacts of switching devices used to switch alternating current.

It is well known that the useful service life, as well as the usable current and voltage ratings, for contacts used to switch alternating currents are dependent on the degree of arcing which occurs when the contacts are opened while carrying current. The arcing problem is particularly severe in apparatus having contacts that are to be opened rather slowly, as in a switch which is responsive to temperature. As will be explained below, arcing can also occur on contact closure. It is a principal object of our invention to facilitate the suppression of arcing at switch contacts during the switching of alternating current.

When arcing is completely suppressed, a second problem may be encountered. Contaminants or contact reaction products may accumulate on the surfaces of the contacts. This accumulation may cause the contacts to exhibit a high resistance when closed. This condition does not occur with contacts that frequently pass arcing current, because the passage of the current cleans the surface of the contacts. Thus while it is desirable to suppress uncontrolled arcing, it is desirable to control the arcing that occurs during switching to make it possible to greatly increase the life of the contacts while yet maintaining them in a clean condition. It is accordingly another object of our invention to accomplish that purpose.

In the copending application of Eric I. Siwko, entitled "Arc Suppressing Circuit," Ser. No. 499,698 filed on Oct. 21, 1965, now Patent No. 3,389,301 which is also assigned to the assignee of the present invention, there is disclosed a circuit for the suppression of arcing at the contacts of a relay switch or like device where a set of single-pole double-throw contacts is available. However, many switches used to control power from an alternating voltage source to a load are not available with double-throw contacts. It is accordingly, a further object of our invention to provide an arc-suppression circuit which requires only a single-pole single-throw contact for operation.

In general, the electronic arc suppression circuits of our invention include an electronic switch connected in parallel with a pair of mechanical switch contacts. The mechanical contacts by opening and closing, control the supply of power from an alternating current source to a load. A control circuit for the electronic switch is provided to switch it to a conducting state shortly after the contacts have first engaged or first disengaged. The load current then flows in part through the electronic switch until the contacts become firmly engaged or completely separated. During the brief interval before the electronic switch goes into conduction, very slight arcing is permitted which makes the contact self-cleaning. By this arrangement, the life of the contacts can be greatly extended and yet the amount of maintenance required to keep them clean is greatly reduced.

The electronic circuit of our invention will best be understood in the light of the following detailed description, together with the accompanying drawings, showing various practical embodiments thereof. Other and further objects of our invention will in part be obvious and will in part appear in the following description.

In the drawings,

FIG. 1 is a graph of voltage versus time, useful in illustrating the operation of a conventional pair of unprotected contacts as they are being brought together to complete an electrical circuit;

FIG. 2 is a schematic wiring diagram of an electronic circuit embodying our invention;

FIGS. 3a and 3b are graphs similar to FIGURE 1 and useful in explaining the operation of the apparatus of FIG. 2;

FIG. 4 is a schematic wiring diagram of another embodiment of our invention;

FIG. 5 is a schematic wiring diagram of still another modification of the apparatus of our invention; and

FIG. 6 is a schematic wiring diagram of a fourth embodiment of our invention.

We have found that arcing at contacts supplied from an alternating voltage source can occur both when the contacts are opened when carrying current and also when closing, as will be explained below.

In FIG. 1, we have shown in dotted lines the waveform of a full cycle of alternating voltage appearing across the terminals of a voltage source. It is assumed that the source is connected through a suitable load impedance to a pair of contacts which when closed complete a circuit through the load and further that the contacts are brought together relatively slowly, as they would be for example, by the action of a temperature responsive element. Based on these assumptions, the full lines in FIG. 1 illustrate the voltage across the contacts as they are brought together. We have discovered that arcing does not normally occur between a pair of contacts as they are being brought together until contact is first actually made. However, when the contacts are very close together, for example about 0.00005 inch apart, the electrostatic force accompanying the voltage across the contacts becomes significant and pulls the contacts together rapidly. As indicated in FIG. 1, the voltage across the contacts from 0 to A will follow the
source voltage until the distance between the contacts is small enough and the voltage becomes large enough to cause them to pull together. When together, the voltage across the contacts is zero. Accordingly, the contacts are free to move apart a short distance and an arc is then drawn between them. We have found that with silver contact material on the switch contacts and with between 1 and 20 amperes of load current the arc between the points B and C on the graph of FIG. 1 will maintain about a 12 volt drop across the contacts. The electrostatic force from this voltage is not sufficient to pull the contacts together again. At about the point C indicated in FIG. 1, the supply voltage falls to a value insufficient to maintain the arc. The same cycle may then take place in reverse, but the indication is partially diminished because of the source as indicated by the full and dotted lines in FIG. 1. In practice a number of such half-cycles can occur in sequence before the contacts are fully closed. A similar action may take place as the contacts are opened.

FIG. 2 shows a circuit in accordance with one embodiment in which arcing at the control contacts is suppressed except for a small amount desirable for cleaning action. As shown, a switch S which includes a movable contact 1 and a fixed contact 2 is connected in series with a load impedance Z and a source of alternating voltage V. The switch S may be of any construction, but the indication is particularly useful when applied to switches which are slow to make and break, such as thermally actuated switches. In such a switch, the contact 1 might be a bimetallic element movable into or out of engagement with the terminal 2 in response to temperature. Connected between terminals 1 and 2 of the switch S are the power terminals 3 and 4 of a conventional solid state gate-controlled electronic A.C. switch Q1 such as the General Electric type SC40D silicon gate controlled A.C. switch or the type TIC20 made by Texas Instruments Incorporated. Electronic switches of this type are sometimes termed "triacs" and will conduct in either direction between their power terminals when appropriately triggered.

The electronic switch Q1 has a control terminal 5 and may be triggered from a blocking condition in which there is an effective open circuit between the terminals 3 and 4 to a conducting condition in which there is effectively a short circuit between the terminals 3 and 4 except for a saturation voltage gap of about 1.5 volts. Triggering is accomplished by applying a current signal of either polarity to the control terminal 5 with reference to the power terminals 3 and 4. The control terminal 5 is connected to the terminal 2 through a capacitor C1. The value of capacitor C1 is chosen so that the signal appearing on terminal 5 is the half-sine of the applied signal on switch Q1 when the switch S is open and equilibrium alternating voltage appears across the terminals 1 and 2 of the switch S. The value of capacitor C1 is chosen however to permit triggering of the A.C. switch Q1 in response to the voltage transient occurring when the switch S is first opened or closed. Once established, conduction in the switch Q1 will be maintained until the voltage falls below a value determined by the particular A.C. switch selected. This value is not particularly critical, as the voltage will always go through zero once every half-cycle and therefore conduction through the switch Q1 will be extinguished once each half-cycle.

Considering now FIG. 2 in conjunction with FIGS. 3a and 3b where the switch S is a slow make and break switch of the type described, the operation of the apparatus of FIG. 2 will be described. With the switch S open, the capacitor C1 will charge and discharge with the alternating currents supplied by the source voltage so that the currents passed by C1 are insufficient to trigger the A.C. switch Q1. As the switch contacts close, the waveform shown in FIG. 3a will appear across the contacts. FIG. 3a is similar to FIG. 1, showing the corresponding waveform when the contacts of the switch S are protected by the electronic switch Q1. Thus, as the contacts are closing the voltage across them follows the source voltage until at point A the contacts are sufficiently close and the source voltage sufficiently high that the contacts are brought together by the electrostatic force between them. The voltage across the contacts then goes to zero and the contacts are free to move apart. This they do at time B and a voltage corresponding to the sustained arc voltage then appears across the contacts. However, since both anode and triggering voltage (as will be explained below) are present for the switch Q1, it fires at time B' and drops the voltage across the switch contacts to about 0.5 volt. The time B' to B may be of the order of 1.5 microseconds and is not drawn to scale in FIG. 3a; rather, it is exaggerated for purposes of illustration. The transient signal which triggers the electronic switch Q1 may be either the sharp drop in voltage occurring at time A or the sharp rise at time B.

The time constant of the circuit formed by C1 and the gate circuit of Q1 is sufficiently long to maintain the switch Q1 in a triggered condition as a result of the transient at time A so that as soon as anode voltage is present, the electronic switch becomes conducting. At time C in FIG. 3a the applied source potential falls below the value necessary to maintain conduction of switch Q1 and the switch ceases to conduct. A similar indication may be drawn until the external force on the switch contacts finally causes them to fully close and they no longer can move apart. The voltage across the power terminals of the switch Q1 then zero and it is blocked.

FIG. 3b illustrates the operation of the circuit of FIG. 2 when the switch S has been closed and opens at a time B approximately in the middle of the half-cycle. When the switch first opens, an arc voltage may form and will persist for a short time until at time B' the switch Q1 is triggered and conducts. As noted above, at the present state of the art, an A.C. switch such as Q1 may be turned on about 1.5 microseconds after both anode voltage is available for it and a triggering signal is applied to its control terminal. With the switch Q1 conducting, the voltage across its power terminals 3 and 4 falls to a very low value in the neighborhood of 1.5 volts as described above, and no arcing current flows since the voltage is below the arc voltage of the contacts. At a time C when the line voltage falls to a value below which the switch Q1 cannot conduct, it will return to its blocked state. Assuming that the switch S is now fully open, the voltage across it will then follow the solid line in FIG. 3b, as shown by the last half-cycle in FIG. 3b. Depending on the magnitude of the alternating voltage, and on the mechanism employed to move the contact 1 of the switch S, several half-cycles such as the first half-cycle in FIG. 3a may occur, or the switch may open fully during the first half-cycle. While the operation of the circuit of FIG. 2 has been discussed with particular reference to slow make and break switches, it is also applicable to circuits utilizing relays or snap-action switches under conditions when the contacts are opened when carrying current.

Although the circuit of FIG. 2 is quite satisfactory for many purposes, it is subject to false operation by transients which may occur in the A.C. line when switch S is open. Such transients may be induced by other circuits connected to the same source such as a motor speed control or a light dimmer circuit. FIGS. 4, 5 and 6 show modifications of our invention which are not affected by line transients, thereby permitting their use in an environment in which line transients may occur and in which unintended switching is unacceptable.

In FIG. 4, we have shown a circuit for accomplishing the purpose of substantially suppressing arcs across the switch S while preventing line transients from triggering the circuit. As in the embodiment shown in FIG. 2,
a solid state gate-controlled A.C. switch Q1 has its power terminals 3 and 4 connected across the switch S, and the switch S is in series with a load impedance Z and a source V of alternating voltage. In the embodiment shown in FIG. 4, however, the gate terminal 5 of the A.C. switch Q1 is connected through a resistor R1 to the junction of the load Z and the source V.

In this embodiment, the switch Q1 is triggered by the voltage differential across the load. Thus, when the switch S is first closed, the switch Q1 will be triggered but will not conduct because the voltage across the terminals 3 and 4 will be zero. If the contacts 1 and 2 move apart in the manner described in connection with FIG. 1, however, the switch Q1 will conduct almost immediately, the only limitation being the turn on time of the switch, which is, as noted above, is of the order of 1.5 microseconds. The voltage across the contacts 1 and 2 will be held to about 1.5 volts for the rest of the half-cycle. If the switch S is fully closed by that time, the switch Q1 will remain in its blocked state. If the switch S is of the slow make and break type that requires several cycles to close, it will continue to be triggered on each half-cycle until the switch S is completely closed. When the switch S is opened at a later time, similar operation will take place until the contacts 1 and 2 are sufficiently separated. After a final half-cycle of conduction, the switch Q1 will remain in its blocked state because current will no longer flow in the load Z, and therefore no voltage will be present to gate the switch Q1. Line transients will not appear across the load Z with the switch S open since no load current can flow. The gate controlled A.C. switch requires some flow of load current before it will conduct. The switch S must, therefore, first be closed to cause load current to flow, and then opened, before the switch Q1 can be triggered.

FIGURE 5 shows an embodiment of our invention similar to that of FIG. 4, except that the resistor R1 of FIG. 4 is replaced by a capacitor C2. The operation of this embodiment is essentially the same as that of the FIG. 5 embodiment, but the use of the capacitor to complete the gating circuit makes it possible to save the power that would otherwise be lost in the resistor R1.

In FIG. 6, we have shown a modification of our invention which operates in the manner of the circuits of FIGS. 4 and 5, but which employs as the A.C. switch a two-state switch Q2 comprising two silicon-controlled rectifiers CR1 and CR2 connected across the contacts 1 and 2 of the switch S. As shown, the first controlled rectifier CR1 has its anode 6 connected to the terminal 2 and its cathode 7 connected to the terminal 1. The terminal 8 of the controlled rectifier is connected to the terminal 1 through winding L1 comprising one secondary winding of a pulse transformer connected in series with a capacitor C3 across a load represented by resistor R2 to form an effective load impedance Z. Capacitor C3 is a blocking capacitor and passes only transients to the winding L3 for use in triggering the switch CR1 and CR2.

The operation of the apparatus of FIG. 6 is similar to that of FIGS. 4 and 5. Thus, if the switch S has been fully opened for a sufficient period no current flows through the load and both controlled rectifiers in the switch Q2 are cut off. When the contacts of switch S are closed, and then momentarily move apart in the manner described in connection with FIG. 1, a voltage transient will be produced across resistor R2 which is sufficient to trigger the controlled rectifiers CR1 and CR2 by the currents induced in the windings L1 and L2, respectively. If the switch is closed during a positive half-cycle with respect to the terminal 1, the controlled rectifiers CR1 will begin conducting and will continue to conduct until the voltage across its terminals 6 and 7 falls below the value at which conduction can be sustained, either because the switch S is closed or because the end of the first half-cycle has been reached. On the following negative half-cycle, the controlled rectifiers CR2 will perform the function of carrying the current if the contacts of switch S are not yet fully closed. When the switch is finally completely closed, both controlled rectifiers will be cut off because they are shorted by the switch. When the switch S is opened while it is carrying current a similar operation will take place, with the rectifiers CR1 and CR2 conducting until the switch stays open. With the switch S fully opened, it will be apparent that line transients cannot trigger the switch Q2, because no load current can flow and therefore there can be no gating signal.

Thus we have provided improved arc suppression circuits using solid state controlled switches which, while suppressing the uncontrolled arc are usually associated with switching a load in an alternating current circuit, yet permit sufficient controlled arcing to occur to maintain clean contacts. The circuits of our invention require only the single make contact which is also provided for switching the load, and certain of the circuits, as more fully described above, are insensitive to line transients which may be generated by other equipment supplied from the same source.

While we have described our invention with reference to the details of various illustrative embodiments thereof, many changes and variations will occur to those skilled in the art upon reading our description, and such can obviously be made without departing from the scope of our invention.

Having thus described our invention, what we claim is:

1. In combination with a mechanical switch having an open position and a closed position and a circuit directly connecting said switch in its closed position, a source of alternating current and a load impedance in series, an arc suppressor for suppressing arcs at said switch contacts when said contacts are opened while carrying current comprising electronic switching means settable to a conducting state and a non-conducting state and connected in parallel with said mechanical switch, and means responsive to voltage transients produced when a mechanical switch is transferred from one position to the other for setting said electronic switching means to its conducting state, said switching means comprising a pair of controlled rectifiers having anode and cathode terminals oppositely connected in parallel with said switch and control terminals, and further comprising a capacitor and a pulse transformer having a primary winding and two secondary windings, said capacitor and the primary winding of said pulse transformer being connected in series across said load impedance, and said control terminals each being connected to a different side of said switch through a different one of said secondary windings.

2. In combination, a two-position switch adapted to close a circuit in a first position and to open the circuit in a second position, a solid state gate-controlled A.C. switch having first and second power terminals and a control terminal, said A.C. switch being triggerable from a blocked to a conducting state by a signal applied between its control terminal and said first power terminal, said power terminals being connected across said switch, a load impedance and a source of alternating voltage connected in series with said switch, and a control impedance connected between the junction of said load impedance and said source and said control terminal to supply a current to said control terminal triggering said A.C. switch to its
conducting state during transients occurring while said two-position switch is being opened or closed.

3. The combination of claim 2, in which said control impedance is a resistor.

4. The combination of claim 2, in which said control impedance is a capacitor.

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