May 23, 1967 E. S. BAKER 3,321,668

CURRENT CONTROL APPARATUS

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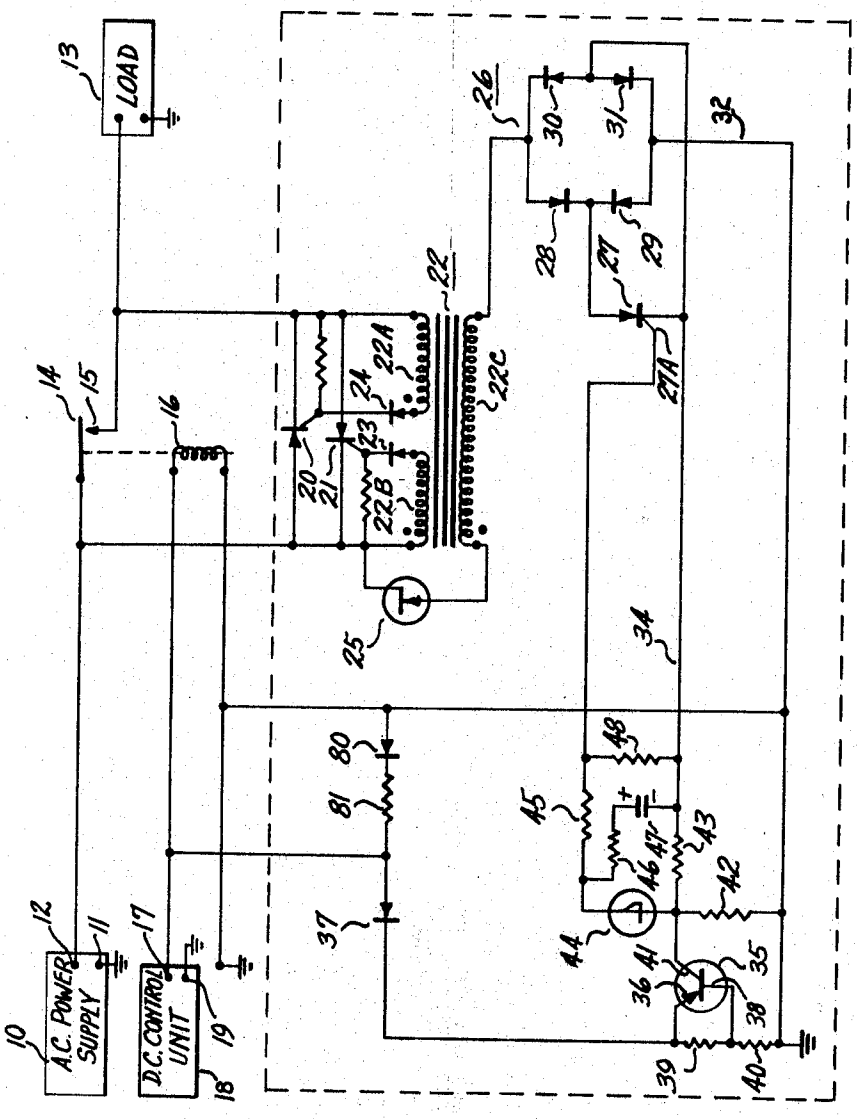


Fig. 1.

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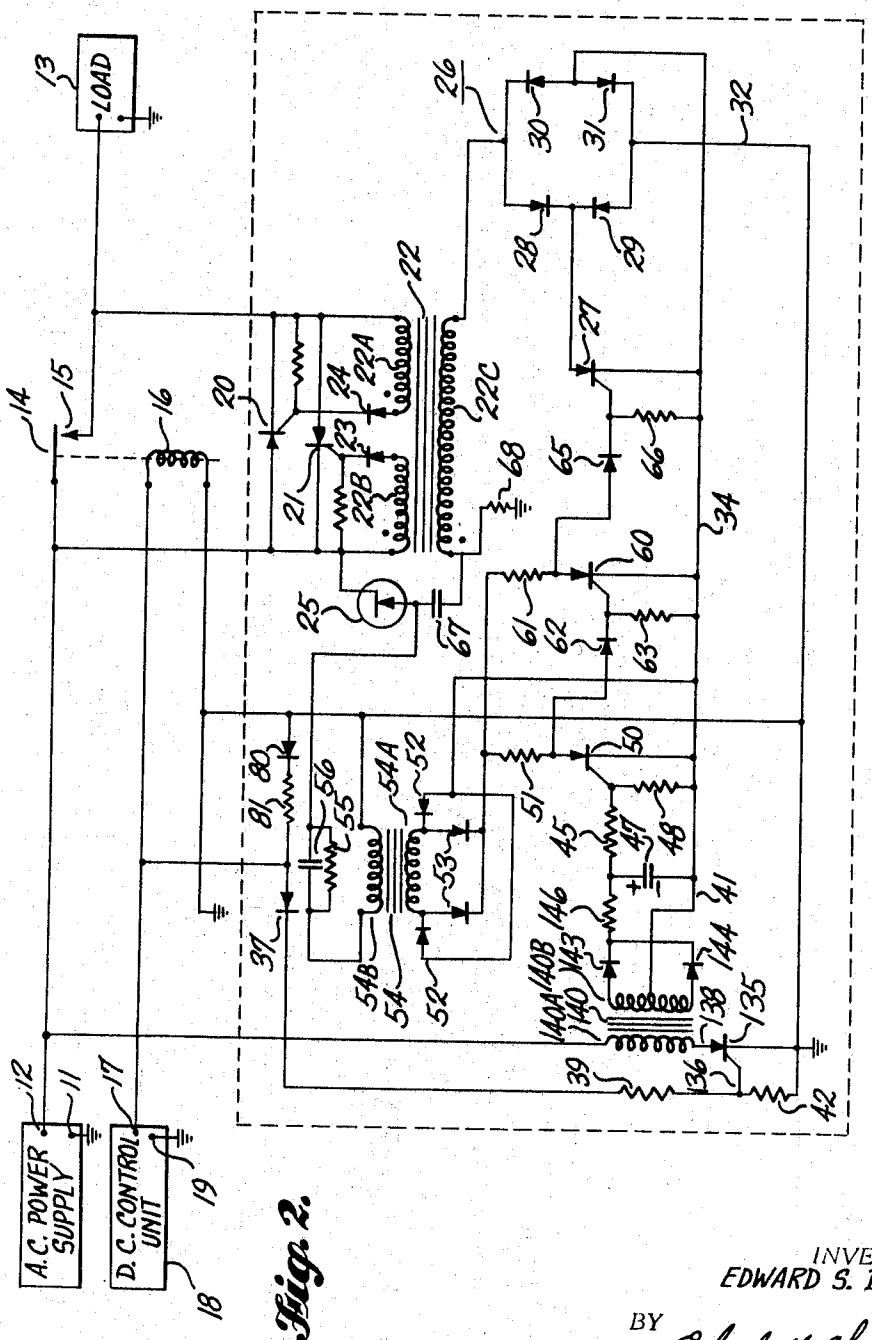


Fig. 2.

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CURRENT CONTROL APPARATUS

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6 Claims. (Cl. 317—11)

ABSTRACT OF THE DISCLOSURE

Systems are disclosed which include silicon controlled rectifiers in parallel with mechanical relay contacts. The gating circuits for the SCR's are such that isolation for a D.C. control unit is obtained and easy conversion of existing relays is possible. In one embodiment of Shockley diode is used in the gate control. Transformer coupling is used in the gate circuits.

This application is a continuation-in-part of U. S. patent application Ser. No. 416,310 filed Dec. 7, 1964, now abandoned, entitled, "Current Control Apparatus."

The present invention relates to current control systems and electro-mechanical relays, and more particularly to an improved current control system as well as apparatus for protecting the contacts of an electro-mechanical relay.

Electro-mechanical relays are widely used at the present time in the various applications wherein an electrical current must be switched on and off. Such relays have a control winding and a set of contacts which either make or break a circuit for the load. The repeated arcing which takes place when the contacts of the relay are making and breaking electrical circuits leads to deterioration of the contacts and hence requires eventual repair or replacement of the relay. Such wear is greatly accelerated when the relay is required to handle large currents. When the relay is used in a circuit which includes a transformer relatively large inductive currents often exist due to the transformer being energized during a portion of the applied sine wave voltage which is in opposition to the direction of pre-existing magnetization in the transformer when it was previously de-energized. Current controlling devices sometimes referred to as solid state relays have been devised for controlling the energization of various circuits, including transformers, so that the circuit is first energized at a selected point on the applied sine wave voltage to avoid large inductive current surges.

Since the current switching devices which make use of all semiconductor elements, such as silicon controlled rectifiers (SCR's), do not have moving mechanical contacts the problem of contact deterioration is eliminated. However when currents in the order of several tens of amperes must be handled, present day solid state semiconductor devices are not only found to be costly but, in addition, it has been found that the internal resistance of such devices is large in comparison to the resistance of a pair of closed mechanical contacts. Thus the solid state devices when used for carrying substantial current must be provided with suitable cooling to dissipate the heat generated by the current flowing therethrough. As a result many presently available semiconductor current switching devices referred to as solid state relays are heavier, more expensive, and occupy more space than their equivalent counterparts in the electro-mechanical relay art. Thus it has been found that while the solid state devices provide a distinct improvement in that they can be made to become conductive in a substantially noiseless manner, do not have contacts which deteriorate, and in general do not have other problems inherent in electro-mechanical relays, they have certain drawbacks when relied upon for switching relatively heavy currents.

It is therefore an object of the present invention to provide an improved current switching assembly which makes use of the advantageous features of electro-mechanical relays and of solid state current switching devices.

It is a further object of the present invention to provide an improved electric current switching assembly capable of switching large currents an making use of relatively low cost components.

A further object of the present invention is to provide an improved current switching apparatus which includes a conventional electro-mechanical relay in combination with solid state semiconductor devices adapted to substantially reduce the normal wear of the relay contacts and hence greatly increase the useful life of the current switching apparatus.

An additional object of the present invention is to provide an improved electronic circuit for protecting the contacts of a conventional relay and wherein semiconductor devices which have relatively low steady state current handling capabilities are utilized in combination with relays capable of switching large currents.

Another object of the present invention is to provide an improved and simplified relay contact protection circuit which includes a simplified control circuit making possible the ready application of the teachings of the present invention to various circuits now using electro-mechanical relays.

Another object of the present invention is to provide a protection circuit for the contacts of an electro-mechanical relay by making use of low cost silicon controlled rectifiers.

In accordance with the teachings of the present invention, a solid state semiconductor current control device such as a controlled rectifier is used in parallel with the contacts of an electro-mechanical relay so that during initial application of current to a load and during the time the relay contacts are moving toward each other the solid state semiconductor device carries the current. Thus there is little or no arcing across the relay contacts during the time that the contacts are being closed. Thereafter, once the mechanical contacts have been closed they in effect provide a short circuit path around the higher impedance of the solid state device. The steady state current is then primarily carried by the mechanical contacts. Thus the heat problem normally associated with heavy current flow through a solid state device such as an SCR is eliminated and simultaneously the excessive wear of relay contacts caused by arcing and pitting of the contacts during closing of the contacts is avoided. In a similar manner when the relay contacts are being separated the SCR carries the load current and again prevents the usual arc across the contacts. A pair of oppositely poled SCR's are preferably used across the relay contacts in an alternating current (A.C.) system.

An improved control circuit responsive to the signal applied to the winding of a relay is utilized for turning the SCR's on before the relay contacts move into engagement with each other or even close enough to each other to cause arcing thereacross. It is common in the art to use a relatively low level direct current (D.C.) control signal for energization of the relay control winding and therefore in order to permit ready adaptation of a given relay to the improvement of the present invention the control circuit includes means for isolating the D.C. source from the high voltage system and yet permit the use of a common signal ground for the control and power circuits. To this end, a transistor and a third controlled rectifier are coupled with the relay control circuit and with the gate electrodes of the contact shunting SCR's so that substantially complete isolation of the D.C. control

network from the power circuit is obtained. By thus providing a system in which the control unit and the main power supply are referenced to a common signal ground such as is presently the case with many A.C. relays, the present invention is readily usable with many existing relay control systems without extensive modification of the system.

To avoid the generation of radio frequency interference and also to avoid system disturbances which heretofore have been generated when a conventional electro-mechanical relay is energized, the system of the present invention in one embodiment thereof includes circuitry responsive to the application of an input signal to the relay control winding to cause the main power or contact shunting SCR's to become conductive at a time when the power supply voltage is near its zero reference axis. Thus power is initially applied to the load in a manner such that load disturbances are minimized. Since SCR's turn on well before the time when the relay contacts have approached each other to the point where arcing would occur the relay contacts are protected. The control circuit includes a timing network which serves to maintain the shunting SCR's conductive for a predetermined length of time after the relay control device de-energizes the relay winding. Said predetermined length of time is adjusted to be sufficiently long to insure conduction of the shunting SCR's until the relay contacts are completely opened. The shunting SCR's then become nonconductive when the power supply voltage is at its zero reference axis and thus there is no disturbance to the load as a result of opening the relay contacts.

It is well known that a semiconductor device such as an SCR can safely handle a current surge many times greater than the continuous current rating of the device. Since the shunting semiconductor devices which are in parallel with the relay contacts only carry the load current for the short time required for the contacts to open or close, the present invention makes possible the use of semiconductor devices having low continuous current ratings in protecting the contacts of a relay being used in control currents many times greater than said continuous current for which the semiconductor devices are rated. Thus even in those applications wherein a relay handling in excess of 50 amperes is to be protected, silicon controlled rectifiers having a surge current rating for one or two cycles of beyond 50 amperes and yet having a continuous current handling capability of only a few amperes can be used. The cost of the components required for providing protection for the electro-mechanical relay contacts is therefore substantially reduced, and in fact is found to be relatively low cost by comparison to the value added in terms of extended relay life.

The above as well as additional advantages and objects of the present invention will be more clearly understood from the following description when read with reference to the accompanying drawings and wherein,

FIGURE 1 is a schematic circuit diagram of a simplified embodiment of the present invention, and

FIGURE 2 is a schematic circuit diagram of a further embodiment of the present invention similar to that of FIGURE 1 but including circuit means for causing the main contact shunting power semiconductor devices to be turned on at a selected time in the cycle of the power supply.

Referring now to the drawings and in particular to FIGURE 1, there is shown for purpose of illustration a conventional alternating current (A.C.) power supply **10** having first and second terminals **11** and **12**. The terminal **11** is shown as connected to a point of reference potential referred to in the art, and herein, as common ground. The power supply is shown as adapted to supply A.C. power to a load **13**. A conventional electro-mechanical relay is shown schematically as including a movable contact **14**, a stationary contact **15**, and a control winding **16** which controls contact **14**. Control

winding **16** is connected to a control unit shown as the D.C. control unit **18** having one terminal **17** connected to one end of winding **16** and a second terminal **19** connected to common ground. One end of the winding **16** is connected to common ground. The parts thus far described form the conventional circuit arrangement for an A.C. relay adapted to be controlled by a low level signal from a control unit such as the D.C. control unit **18**. As is well known in the art, the movable contact **14** is yieldingly urged away from the stationary contact **15**. When the winding **16** is energized the contact **14** is pulled into engagement with the stationary contact **15** so that power is applied to the load **13**. The time required for the contact **14** to move into engagement with the stationary contact **15** varies in accordance with the type of relay, but for a typical 50 ampere relay the time is in the order of several milliseconds.

First and second semiconductor current control devices shown for purpose of illustration as silicon controlled rectifiers **20** and **21** are connected in parallel with the relay contacts **14** and **15** and thus may be referred to as shunting SCR's. To this end it will be seen that the anode of SCR **20** and the cathode of SCR **21** are connected to the contact **14** while the cathode of the SCR **20** and the anode of the SCR **21** are connected to the contact **15**. The secondary windings **22A** and **22B** of a transformer **22** are respectively connected through the diodes **24** and **23** to the gate electrodes of the SCR's **20** and **21**. The arrangement is such that when the primary winding **22C** of the transformer **22** is energized the appropriate one of the SCR's **20** or **21** will be provided with gating current for rendering the associated SCR conductive when the anode thereof is positive with respect to its cathode.

The primary winding **22C** for the gating transformer **22** is connected at one end through a thermal switch **25** to the power supply terminal **12** and is connected at its other end through a diode network **26** to the anode of a third silicon controlled rectifier **27**. It will be seen that the SCR **27** has its anode connected directly to the cathodes of the diodes **28** and **29** and has its cathode connected directly to the anodes of the diodes **30** and **31**. The anode of diode **29** and the cathode of diode **31** are connected by lead **32** to the point of reference potential referred to herein as common ground. The arrangement is such that as long as the SCR **27** is maintained nonconductive neither of the shunting SCR's **20** or **21** will be provided with sufficient gating current to be rendered conductive. When the SCR **27** is conductive the resulting current flow through the transformer primary winding **22C** will provide sufficient gating current for conduction of the SCR's **20** and **21** alternately. The SCR **27** is controlled by a control circuit responsive to the signal level on the output terminals of the D.C. control unit **18** and coupled with the gate electrode **27A** of SCR **27**.

The control circuit includes a semiconductor current switching device shown as a PNP transitsor **35** having an emitter **36** connected through the diode **37** to the non-grounded terminal **17** of the D.C. control unit **18**. To maintain the state of conduction of transistor **36** under the control of the D.C. control unit **18** the base electrode **38** of transistor **35** is connected to the center point of a voltage divider network provided by the resistors **39** and **40** connected in series circuit between the emitter **36** and common ground. The collector electrode **41** is connected through the resistor **24** to common ground and through the resistor **43** to the cathode of SCR **27**. The collector **41** is also coupled with the gate electrode **27A** of the SCR **27** through a Shockley diode **44** and a resistor **45** connected in series circuit therewith. A timing network described in greater detail hereinafter and including the resistor **46** and capacitor **47** (preferably a tantalum capacitor) are connected in series with the resistor **43** across the Shockley diode **44**.

As is well known in the art, a Shockley diode is a readily available solid state semiconductor device having

the characteristic that when subjected to a voltage in its forward direction which is lower than a predetermined threshold voltage, there is no current flow through the device. When the voltage across the device exceeds the pre-established threshold voltage the device breaks down and offers substantially no resistance to the flow of electrical current therethrough. The device then remains conductive as long as a minimum holding current is provided. When the current flow through the device is interrupted the device again becomes nonconductive and then thereafter resumes its conductive condition only when its pre-established threshold voltage is again reached or exceeded. When the circuit of FIGURE 1 is operated with a 115 volt power supply **10**, a Shockley diode or other device having a breakdown voltage of approximately 100 volts is preferable.

It will be seen that when the power supply terminal **12** goes positive with SCR **27** nonconductive the SCR **27** and diode **30** effectively block the flow of currents through the primary **22C**. When the power supply terminal **12** goes negative the cathode of diode **30** is made negative and thus the lead **34** connecting the anodes of diodes **30** and **31** to the collector **41** of transistor **35** through resistor **43** is negative with respect to signal ground. Since the transistor **35** when in a nonconducting condition acts as an infinite impedance it will be seen that there is no reflection of power supply voltages to the terminal **17** of the D.C. control unit **18**. The resistors **42** and **43** act as a voltage divider network which maintains the collector of the transistor **35** at a potential which goes negative to a value approximately equal to one-half of the power supply voltage when the value of the two resistors is equal. Since the anode of the Shockley diode **44** is also connected to the midpoint of resistors **42** and **43** and its cathode is connected through resistors **45** and **48** to lead **34**, the Shockley diode will be subjected to a forward bias of approximately one-half the peak voltage of the power supply **10** on negative half cycles of the power supply. The Shockley diode **44** is selected to have a threshold voltage greater than this intermittently applied voltage and therefore does not break down as long as the transistor **35** remains nonconductive.

When power is to be applied to the load **13** the terminal **17** of the D.C. control unit **18** is provided with a voltage which is positive with respect to common ground and therefore it will be seen that the voltage conditions exist for the transistor **35** to be rendered conductive. When the transistor **35** becomes conductive the collector electrode **41** is effectively placed at the voltage of the terminal **17** and hence the anode of the Shockley diode **44** is made positive with respect to ground. The amplitude of the voltage applied to terminal **17** and the breakdown voltage of the threshold device **44** are selected so that when the terminal **12** of power supply **10** reaches a given negative voltage the Shockley diode **44** will be subjected to a total bias sufficient to render it conductive. As soon as diode **44** becomes conductive capacitor **47** starts to charge and gating current is immediately provided to the gate of SCR **27**. Since the cathode of SCR **27** is negative with respect to its anode at this time the SCR **27** becomes conductive and current flows through the primary winding **22C** of transformer **22**. Gating current is thus induced in the secondary windings **22A** and SCR **21** is rendered conductive. Current is thus applied to the load **13** even though contacts **14** and **15** have not closed yet. It will be seen that the D.C. control unit **18** is directly connected to the control winding **16** and hence at the same instant that the transistor **35** is being rendered conductive the winding **16** is being energized. However, since the relay winding **16** must move the mass of the movable contact **14** it is found in practice that the SCR **21** is always rendered conductive before the contact **14** approaches the contact **15** by a distance sufficient to permit arcing thereacross regardless of when terminal **17** is made positive. As soon as the contact **14** engages the contact **15** the current for the load **13** will be carried primarily by the lower resistance path of the contacts with little or no current flowing through the SCR's **20** and **21**. In view of the low impedance path provided by the contacts **14** and **15** once they have closed, little or no heat is dissipated in the SCR's **20** and **21** and accordingly the usual large heat sinks needed for SCR's when carrying substantial currents is eliminated.

When the power being applied to the load **13** is to be interrupted it will be seen that one or the other of the SCR's **20** and **21** must be maintained conductive until the movable contact **14** has moved away from the stationary contact **15** if arcing therebetween is to be avoided. The time required for the movable contact of a relay to move away from the stationary contact is normally much less than the time required for pull-in of the movable contact. Since the D.C. control unit might have its output terminal **17** reduced to ground potential at any instant in time it will be seen that means must be provided for insuring continued conduction of the SCR **27** so that the SCR's **20** and **21** will be provided with gating current until the contact **14** has moved completely away from the contact **15**. That is, if adequate protection were not provided to insure such continued conduction of the SCR's **20** and **21** the removal of the positive voltage from the terminal **17** at a time when the power supply voltage was approaching its zero reference axis would result in the SCR **27** becoming nonconductive when the power supply voltage reached zero. Thus the SCR's **20** and **21** would remain nonconductive as the power supply voltage departed from zero. Accordingly, if the contact **14** had not departed completely from the contact **15** an arc would occur therebetween. To prevent this from happening the SCR **27** is provided with gating current after the positive voltage is removed from terminal **17**, said gating current being provided for a time interval longer than the maximum time required for the contact **14** to depart completely from the stationary contact **15** for the particular relay being used. To this end the timing network including capacitor **47** is adjusted to have a time constant greater than the time required for opening of the contacts **14** and **15**. It should be noted that when transistor **35** is rendered conductive the collector of the transistor **35** is effectively connected through the current limiting resistor **46** to one terminal of the capacitor **47** and through the resistor **43** to the other terminal of the capacitor, resistor **46** being small in resistance by comparison to the resistance of resistor **43**. As a result capacitor **47** charges very rapidly. Thereafter when the positive voltage is removed from terminal **17** of the control unit **18** and transistor **35** becomes nonconductive, the Shockley diode **44** becomes nonconductive and capacitor **47** will have as its discharge path the resistors **46**, **45** and **48**. Thus capacitor **47** is charged rapidly but discharged more slowly so that it provides gating current to SCR **27** for the desired time interval. As explained in greater detail hereinafter, when used in a 115 volt-60 cycle per second system with a 50 ampere relay having an opening of 6 milliseconds, a **10** microfarad capacitor in combination with resistors **46**, **45** and **48** having values of 2000, 1500, and 150 ohms, respectively, provided current for a time sufficient to assure conduction of SCR **27** until contacts **14** and **15** opened.

While the circuit illustrated in FIGURE 1 and described above works well and greatly increases the useful life of a relay, there are some situations wherein it is desirable to apply power to a load when the power supply voltage is crossing its zero axis and thus avoid disturbances to the load. The system of FIGURE 2 provides this advantage. Referring now to FIGURE 2, those elements corresponding to like elements in FIGURE 1 will bear the same reference numeral in FIGURE 2. The system of FIGURE 2 includes a fourth SCR **50** having its gate electrode connected to the resistors **45** and **48** which form part of a timing network similar to that described above. The

cathode of SCR 50 is connected to lead 34. The anode of the SCR 50 is connected through resistor 51 to the cathodes of the two diodes 52 connected to opposite ends of the secondary winding 54A of the transformer 54. The primary winding 54B is connected across the A.C. power supply 10 through the thermal switch 25. Diodes 53 have their cathodes connected to opposite ends of the secondary and their anodes connected to lead 34 so that a full wave rectifier circuit is provided for SCR 50. The transformer 54 is a step-down transformer and is adapted to provide a relatively low voltage across the SCR 50 via the full wave rectifier circuit. A fifth SCR 60 is connected in parallel with SCR 50 in that its cathode is connected to the cathode of SCR 50, its anode is connected through resistor 61 to the anode resistor 51 of SCR 50 and its gate electrode is connected through diode 62 to the anode of SCR 50. A bias resistor 63 connects the gate electrode of SCR 60 to the cathode thereof. A diode 65 and resistor 66 are similarly connected in series circuit between the anode and cathode of SCR 60 with the gate electrode of SCR 27 being connected to the junction point between the diode 65 and the resistor 66. To aid in rapid turn-on of SCR's 20 and 21 the primary winding of the transformer 22 is connected to the A.C. power supply through a capacitor 67. A resistor 68 of several thousand ohms may also be included between the capacitor 67 and ground so that a small amount of current is passed by the capacitor even though SCR 27 is nonconductive. The arrangement is such that the voltage applied to the anode of SCR 27 leads the power supply voltage by approximately 60 degrees and hence when SCR 27 conducts the gates of SCR's 20 and 21 are provided with current before their anodes become positive with respect to their cathodes.

In the circuit of FIGURE 2 a transformer 140 has one end of its primary winding 140A connected to the power supply terminal 12 and the other end connected through an SCR 135 to ground. The gate 136 of SCR 135 is connected to the control unit 18 through resistor 39 and diode 37, and is also connected to ground through resistor 42. The secondary winding 140B is center-tapped with diode 143 and 144 connecting opposite ends thereof to the gate of SCR 50 through resistors 146 and 45. The center tap is connected to the cathode of SCR 50. The arrangement is such that if SCR 135 is provided with a gate signal current will flow therethrough on alternate half cycles of the power supply and SCR 50 would be provided with a continuous gate signal due to the center-tapped secondary arrangement and capacitor 47.

The operation of the circuit of FIGURE 2 is similar to that of FIGURE 1. Assuming the relay contacts 14 and 15 are separated it will be seen that when power is provided by the A.C. power supply 10 with the SCR 135 nonconductive the SCR 50 will remain nonconductive since it has no gate signal. The SCR 60 however is properly biased for conduction and thus normally is conductive when SCR 50 is nonconductive. Such conduction of the SCR 60 in effect clamps the anode of diode 65 at the potential of the cathode of SCR 27 so that SCR 27 cannot become conductive.

When the control unit 18 provides a positive voltage on its output terminal 17 SCR 135 becomes conductive as terminal 12 of the power supply goes (or if it is at that time) positive. Thus the SCR 50 becomes conductive. When SCR 50 becomes conductive the anode of diode 62 is clamped to the potential of the cathode of SCR 60. However an SCR has the characteristic that it remains conductive until the anode thereof has its voltage reduced to that of its cathode and therefore even though SCR 50 becomes conductive SCR 60 will remain conductive until the voltage of power supply 10 reaches zero. When this occurs SCR 60 becomes nonconductive and remains nonconductive as long as SCR 50 is conductive. With SCR 60 nonconductive the gate electrode of SCR 27 is in a condition for conduction when the voltage of power supply 10 departs from zero and thus at that instant current starts to pass through the primary winding 22C of transformer 22. It should be noted that the voltage on the anode of SCR 27 leads the power supply voltage by approximately 60 degrees and therefore as soon as SCR 27 is provided with gating current, current flows through the primary winding 22C which in turn provides gating current to one of the SCR's 20 or 21. Thus current is initially provided to the load 13 by one of the SCR's 20 or 21 starting at a time when the voltage of the power supply 10 is passing through zero. Then thereafter the flow of current through the control winding 16 serves to pull contact 14 into engagement with contact 15 in the manner above described for FIGURE 1 and the SCR's 20 and 21 are shorted out by the mechanical contacts.

When the power being provided to the load 13 is to be interrupted the D.C. control unit 18 serves to remove the gate signal from SCR 135 and cause it to become nonconductive the next time the power supply voltage reaches zero. With the SCR 135 rendered nonconductive the capacitor 47 discharges through the resistors 45 and 48 causing the SCR 50 to remain conductive for a predetermined length of time regardless of when during the cycle the SCR 135 was rendered nonconductive. As a result thereof the SCR 50 remains conductive as does SCR 27 for a length of time sufficient to permit complete opening of the contacts 14 and 15, and during such time SCR's 20 and 21 carry current to the load as the contacts 14 and 15 are opening. When the capacitor 47 has been discharged it will be seen that the SCR 50 will again become nonconductive when the anode potential thereof next reaches zero. The SCR 60 therefore again becomes conductive and acts as a voltage clamp on the gate electrode of SCR 27 to maintain it nonconductive when its anode next becomes zero. Even though this would occur 60 degrees ahead of the time when the power supply voltage reaches zero it will be seen that the then conducting one of the SCR's 20 or 21 remains conductive until the end of the then existing half cycle of the power supply voltage. As a result it will be seen that regardless of when the D.C. control unit 18 provides an appropriate signal on its output terminal 17, power is initially provided and terminated for the load 13 when the voltage of power supply 10 is crossing the zero reference axis. Noise and disturbance to the load are accordingly minimized.

In one system constructed in accordance with FIGURE 1 a pair of low cost 3 ampere SCR's were used as the SCR's 20 and 21 for protecting the contacts of a 50 ampere Cutler-Hammer relay type 6042H165. When used with a 115 volt-60 cycle power supply a 100 volt 2N398B transistor was used in combination with a 4E100–8 Shockley diode. The resistors 42 and 43 were each 100,000 ohms, which was found to be sufficient to prevent substantial current flow in the primary winding 22C when the control unit 18 was in an off condition and yet provided the desired voltage divider action for operation of the Shockley diode 44. Resistors 45, 46 and 48 were 1500, 2000, and 150 ohms respectively and capacitor 47 was 10 mfd. A 28 volt D.C. control unit 18 was used. When used with relays which tend to have a substantial inductive kickback in the control winding 16 an additional diode 80 and resistor 81 are preferably connected across the winding 16 in the manner indicated in FIGURES 1 and 2 so that such energy is dissipated in the resistor 81. A resistor and capacitor 55 and 56 may also be used in the primary circuit of transformer 54 so somewhat advance the time of operation of SCR's 50, 60, and 27. While not essential, the thermal switch 25 is advantageously utilized in the circuit and placed adjacent to the SCR's 20 and 21 for disabling the entire circuit if the temperature of the SCR's 20 and 21 should rise above a preselected temperature.

There has thus been disclosed an improved current control system and including relay contact protection means which utilizes the advantages of electro-mechanical relays as well as the advantages of solid state semiconductor

current switching devices such as silicon controlled rectifiers. As shown by the dashed lines in the drawings, the protector circuit arrangement has four leads for connection to the usual four terminals of a relay, and thus the invention can be readily used in existing relay installations. The invention has been described with reference to specific embodiments only for purpose of teaching the invention, and it is intended that the following claims will encompass those modifications and changes which become obvious to a person skilled in the art as a result of the teachings hereof.

What is claimed is:

1. A protection circuit for the contacts of an electromechanical relay having a control winding comprising in combination: a silicon controlled rectifier having a main current carrying circuit connected in parallel with said contacts and having a control electrode; and control circuit means coupled with said control electrode and responsive to operation of said winding for closing said contacts to provide gating current to said control electrode, whereby said rectifier is rendered conductive prior to the time said contacts move into engagement with each other, said control circuit comprising a first transformer having a primary winding connected to one of said contacts and a secondary winding coupled with the control electrode of said first rectifier; a second controlled rectifier connected to said primary winding to control the flow of current therethrough and having a control electrode; a second transformer having a primary winding connected to one of said contacts and having a secondary winding; a third current control device connected to the primary winding of said second transformer and having a control electrode; means connecting said control electrode of said third device to said control winding; and circuit means connecting the control electrode of said second rectifier to the secondary winding of said second transformer.

2. A circuit as defined in claim 1 wherein said last-named circuit means includes means controlling the time of initial conduction of said second rectifier such that initial conduction of said first rectifier occurs at a time when the voltage across said contacts is substantially zero and is increasing in magnitude.

3. A current control system comprising in combination: a relay having first and second contacts and a control winding adapted to selectively open and close said contacts; a first semiconductor current control device connected in parallel with said contacts and having control electrode means; second semiconductor current control means coupled with said control electrode means and with said power supply to control the state of conduction of said first semiconductor current control device; a third

semiconductor current control device and an impedance element connected in series circuit across said control winding; a fourth semiconductor current control device having the characteristic of becoming conductive only when the voltage thereacross reaches a predetermined magnitude in a first direction and of blocking the flow of current in a direction opposite to said first direction; means connecting said fourth device between a control electrode of said second semiconductor current control means and the junction of said impedance element and said third semiconductor current control device; and circuit means connecting the junction of said impedance element and said third semiconductor current control means with said second semiconductor current control means.

4. A system as defined in claim 3 including a transformer having a primary winding connected to one of said contacts and a secondary winding connected to the control electrode of said first device.

5. A system as defined in claim 3 wherein said fourth device is a Shockley diode, said impedance element is a first resistor, and said last-named circuit means includes a second resistor connected to said first resistor.

6. A current control apparatus comprising in combination: a relay havinng first and second contacts and a control winding; a silicon controlled rectifier having an anode connected to said first contact, a cathode connected to said second contact, and a control electrode; a first impedance element; a second silicon controlled rectifier having an anode-cathode circuit and a control electrode; means connecting said anode-cathode circuit of said second rectifier and said element in series circuit to one of said contacts; circuit means coupled with said impedance element and with the control electrode of said first rectifier; a transistor coupled with said winding and with said second rectifier; a Shockley diode and a first resistor connected in circuit between said transistor and said control electrode of said second rectifier; a capacitor; and resistance means conencting said capacitor to said Shockley diode and to the anode-cathode circuit of said second rectifier defining a charging path for said capacitor through said Shockley diode and a discharge path through said first resistor.

References Cited by the Examiner

UNITED STATES PATENTS

2,789,253	4/1957	Vang	317—11
3,237,030	2/1966	Coburn	317—11 X

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