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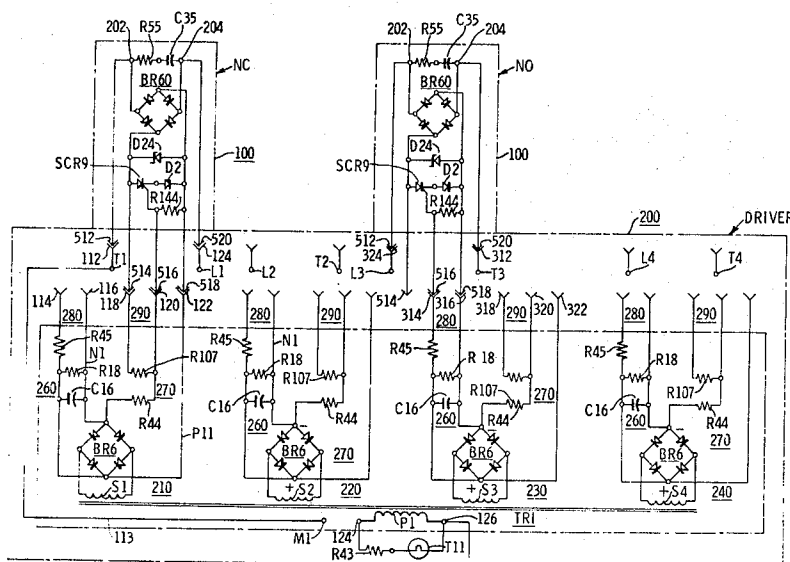
ABSTRACT: A static control relay comprising a base unit adapted to removably receive a plurality of pole units each including a semiconductor switching means actuatable between substantially nonconducting and conducting conditions or states. The base unit includes first and second control circuits corresponding to each associated pole unit and is adapted to selectively receive and operatively connect each pole unit to one of said control circuits. The semiconductor switching means of each pole unit is normally substantially nonconducting when the pole unit is operatively connected to the first control circuit through a plurality of contacts on said pole unit and a first set of terminals on the base unit and normally conducting when the pole unit is operatively connected to the second control circuit through a plurality of contacts on the pole unit and a second set of terminals on the base unit which are adapted to selectively receive said pole unit. When the base unit is energized, each pole unit associated therewith is actuated from the normal operating condition or state to the opposite operating condition or state.

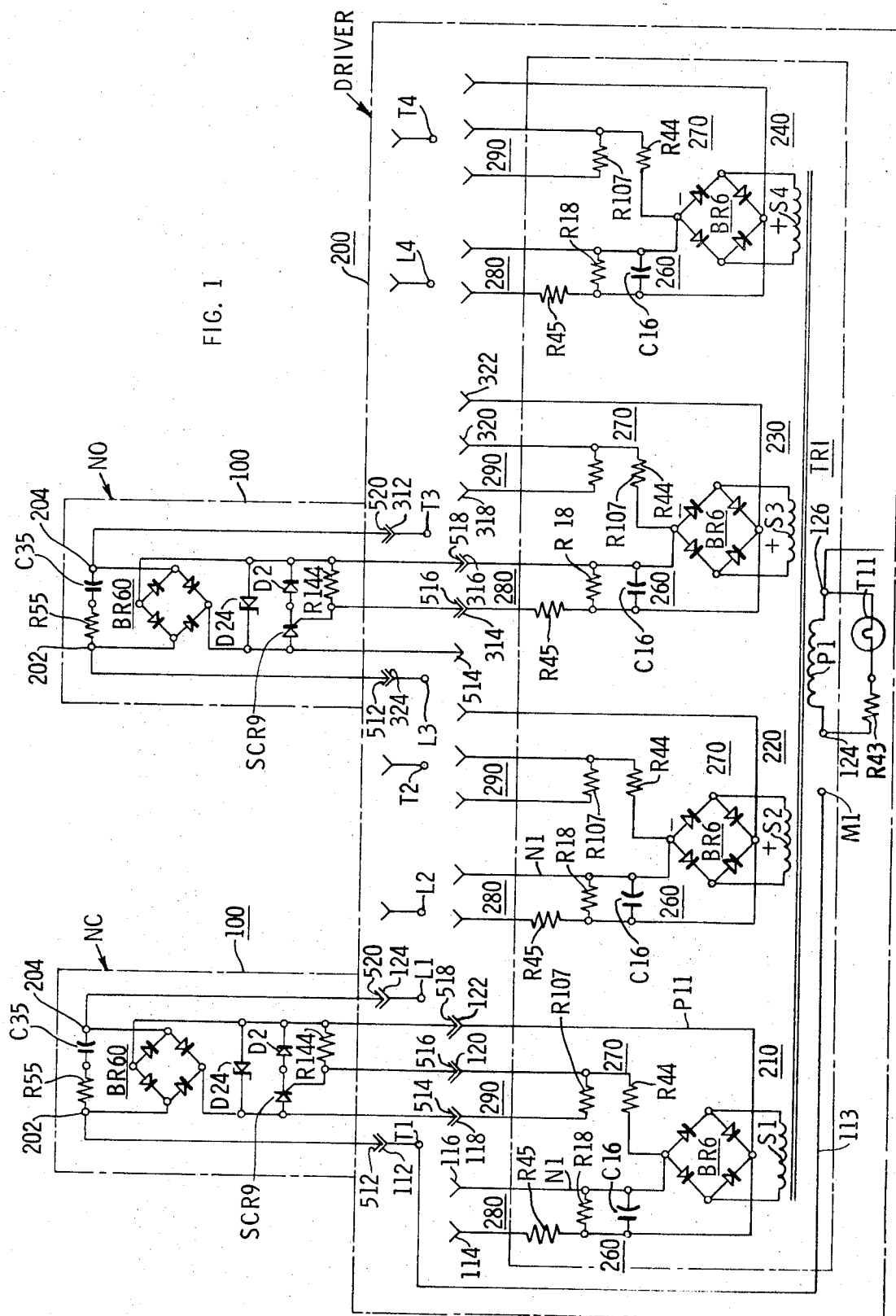
[54] STATIC CONTROL RELAY
12 Claims, 7 Drawing Figs.

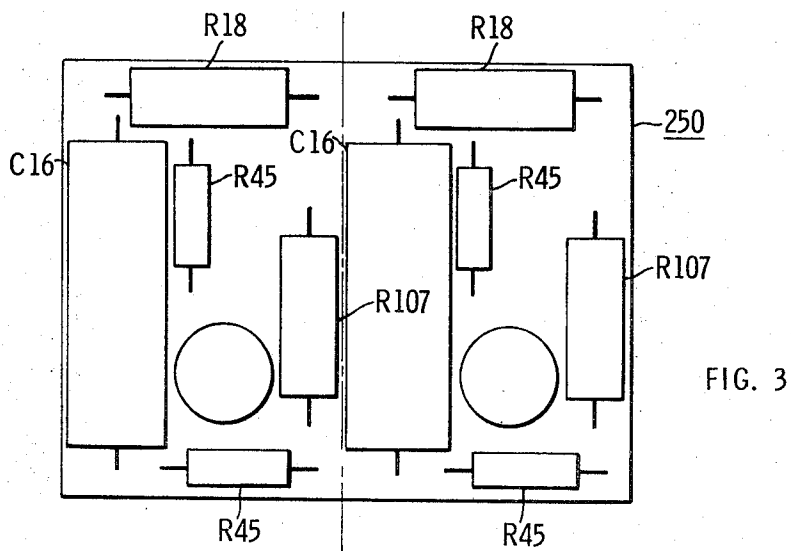
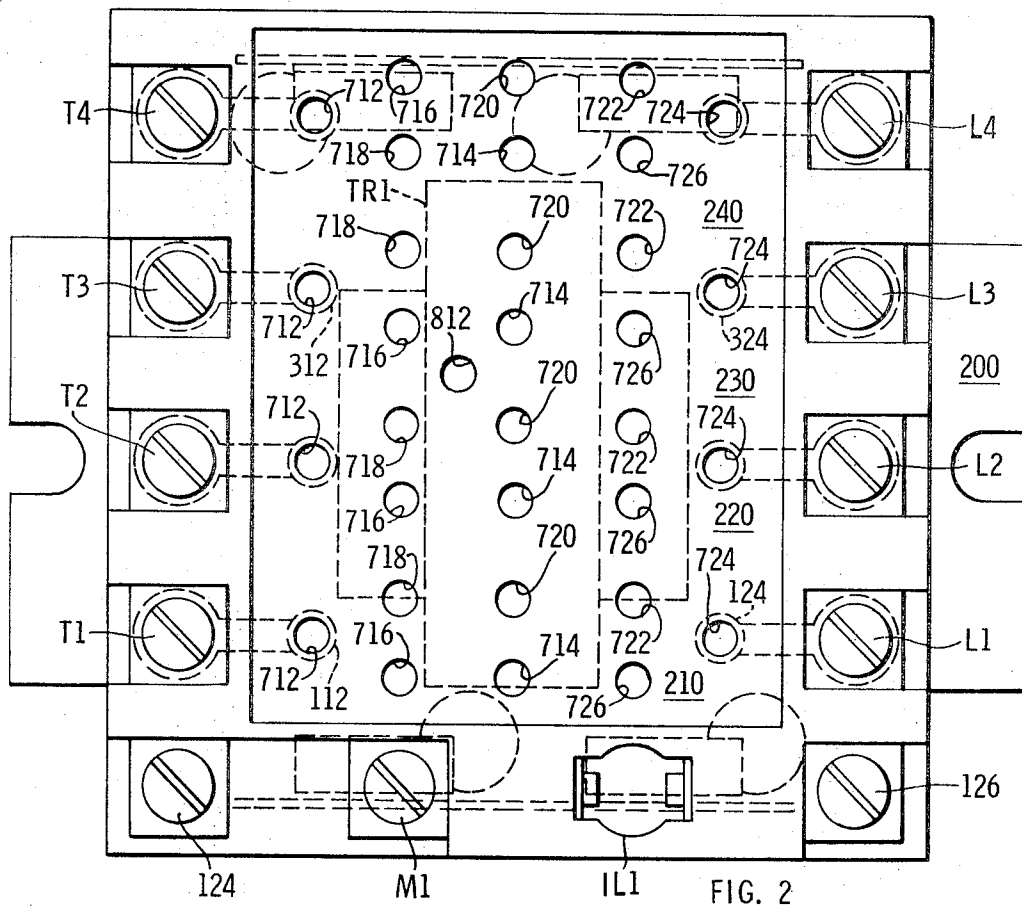
[52]	U.S. Cl.....	307/29, 317/148.5
[51]	Int. Cl.....	H02j 3/00
[50]	Field of Search.....	317/137, 99 (Inquired); 307/18, 29

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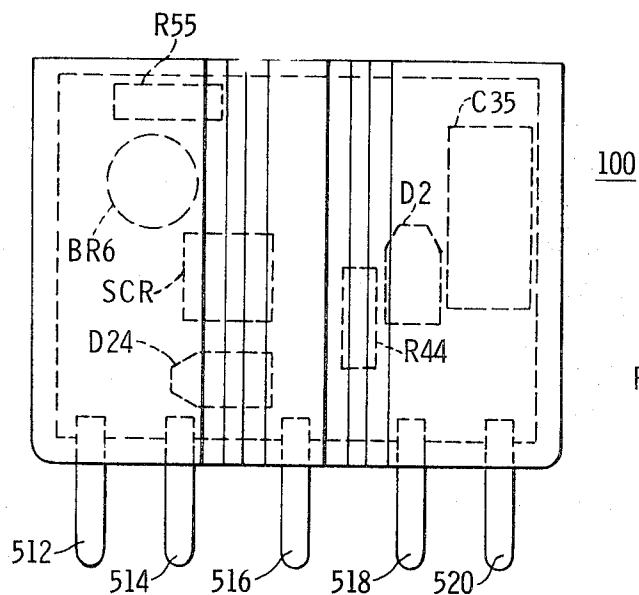


FIG. 4

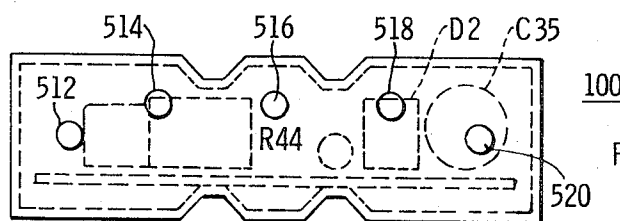


FIG. 5

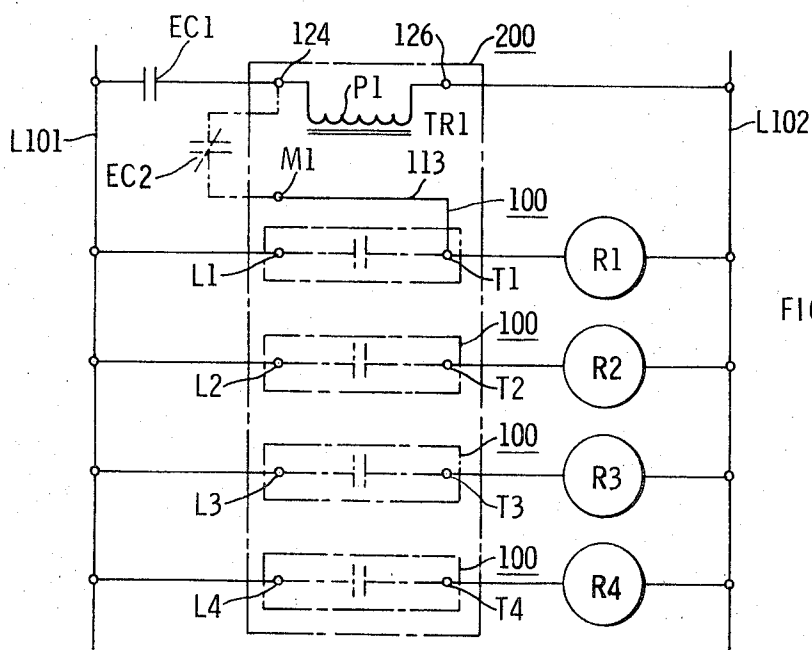


FIG. 7

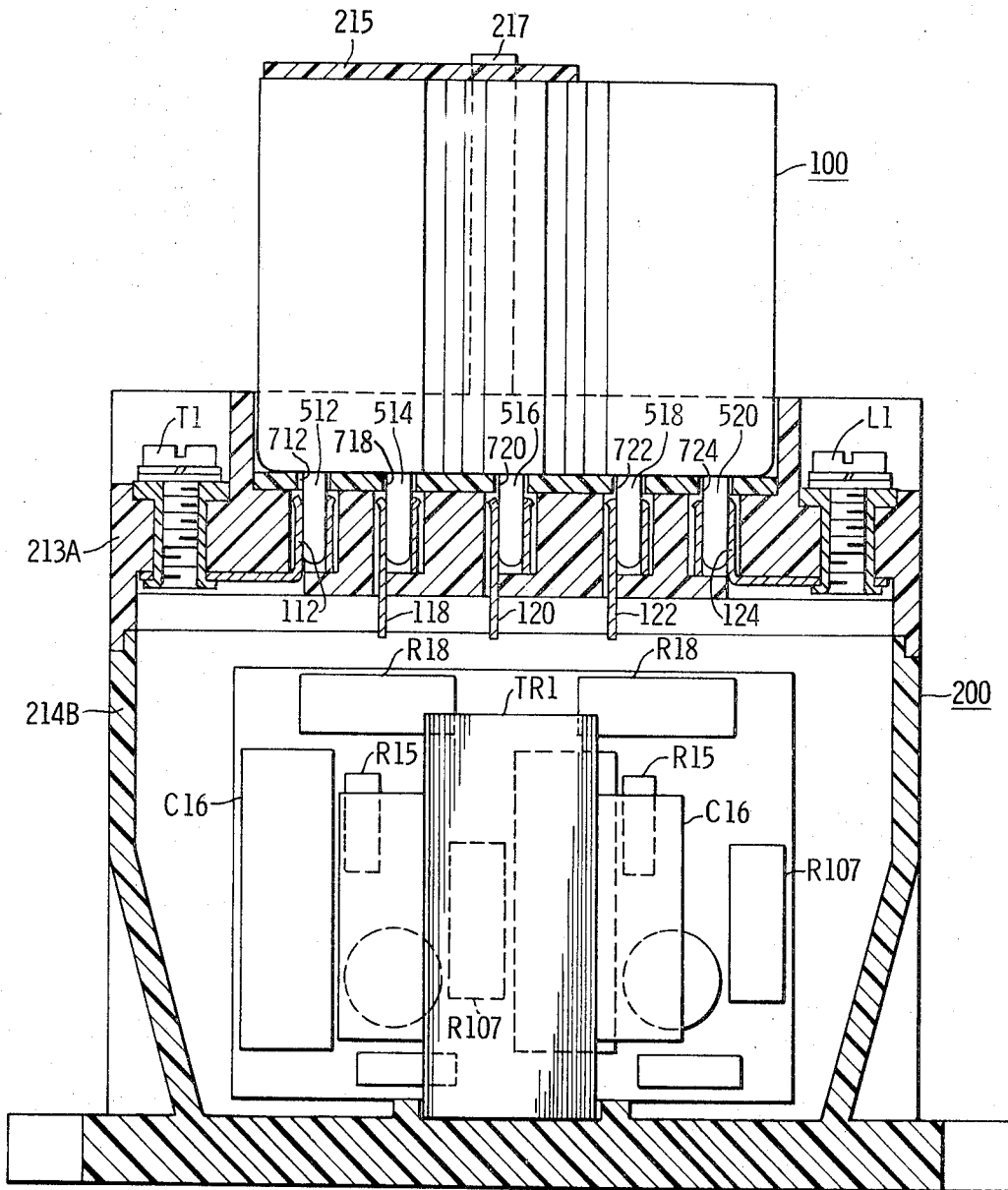


FIG. 6

STATIC CONTROL RELAY

BACKGROUND OF THE INVENTION

This invention relates to control relays or devices and more particularly to static control relays or devices.

In industrial control applications, electromechanical relays have been employed extensively in various types of control arrangements for machine tools and other type of industrial equipment. Such electromechanical relays normally include an operating coil which is energizable to actuate the contacts of a plurality of pole units between normal operating positions which may be either normally open or normally closed, and second operating positions which are of the opposite conducting state, such as disclosed in copending application Ser. No. 686,917 which was filed Nov. 30, 1967 by John H. Mullen and Z. John Kruzic and which is assigned to the same assignee as the present application. It is to be noted that the source of electric power or circuit which energizes the operating coils of such electromechanical relays is electrically isolated from the circuits in which the contacts of the associated pole units are connected where desired and that at least in certain known electromechanical relay structures, the contacts of each pole units may be conveniently changed or converted to be either normally closed or normally open as desired.

Relays of the above type however have certain important disadvantages in that such relays are subject to both contact wear and contact bounce and have limited cycling rates which may be less than 200 cycles a minute. In addition, such electromechanical relays are relatively noisy during operation and may not be safely applied in certain environmental conditions, such as in corrosive or explosive atmospheres.

It is therefore desirable to provide an improved control relay which is of the static type to eliminate the problems of contact wear and contact bounce which are associated with electromechanical relays and to eliminate the relatively noisy operation of such relays.

SUMMARY OF THE INVENTION

In accordance with the invention, a static control relay or device comprises a base unit or operating module which is adapted to removably receive a plurality of plug-in type pole units or switching units, each of which includes a semiconductor switching means, such as a silicon controlled rectifier. The base unit includes an input transformer having a primary winding and a plurality of secondary windings. Separate rectifier means or circuits are connected to the respective secondary windings to provide a plurality of unidirectional or direct current output currents when the primary winding is energized from an external source of alternating current power. First and second pole unit or gate control circuits are connected to each rectifier means of the base unit to be responsive to the energization of the primary winding and are connected, in turn, to first and second sets of recessed terminals, respectively, which are adapted to selectively receive in one of said sets of terminals one of the associated pole units. Each pole unit includes output terminals which are adapted to be connected to an external source of electric power and a load. The semiconductor switching means of each pole unit is connected in circuit relation with the associated output terminals of the pole unit and is actuable between substantially nonconducting and conducting conditions to control the energization of the load connected to the output terminals from the associated external source. Each pole unit also includes a plurality of plug-in type input contacts or prongs which are connected in circuit relation with the associated semiconductor switching means and adapted to selectively engage either the first or second sets of terminals on the associated base unit to thereby operatively connect said switching means to either the first or the second pole unit control circuit, respectively. The switching means of each pole unit is normally substantially nonconducting when the plurality of contacts on the pole unit engage the first set of

terminals on the base unit and the switching means is operatively connected to the first pole unit control circuit and normally conducting when the plurality of contacts on the pole unit engage the second set of terminals on the associated base unit to operatively connect said switching means to the second pole unit control circuit. The normally conducting condition of the semiconductor switching means of each pole unit described above requires that the output terminals of the pole unit are connected to an external source and an associated load. When the primary winding of the base unit is energized, the switching means of each associated pole unit is individually actuated through one of the first and second pole unit control circuits from a normal operating state to the opposite operating state.

In a preferred embodiment of the invention, the semiconductor switching means of each pole unit includes a bridge circuit having a plurality of diodes connected to the output terminals to provide a pair of unidirectional current terminals and a silicon controlled rectifier connected between said unidirectional current terminals. In the latter embodiment, the controlled rectifier of each pole unit includes an anode, a cathode and a gate electrode. Each pole unit also includes a first resistor connected between the gate electrode of the controlled rectifier and one of the unidirectional current terminals of the associated bridge circuit of said pole unit. The first pole unit control circuit of the base unit associated with each pole unit includes a second resistor connected in series circuit relation with the gate-cathode circuit of the controlled rectifier of the associated pole unit when the plurality of contacts on the associated pole unit engage the first set of terminals on the base unit, said series circuit being connected to the associated rectifier means of the base unit. The second pole unit control circuit of the preferred embodiment includes a third resistor connected between the other of said unidirectional current terminals of the bridge circuit of the associated pole unit and the gate electrode of the controlled rectifier of the associated pole unit and means for connecting the first resistor of the pole unit to the rectifier means associated with the pole unit when the plurality of contacts of the latter pole unit engage the second set of terminals of the base unit.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the invention, reference may be had to the exemplary embodiment shown in the accompanying drawings in which:

FIG. 1 is a schematic diagram of a static control relay embodying the invention and including a base unit or module and a plurality of pole units;

FIG. 2 is a top plan view of the base unit which forms part of the static control relay shown in FIG. 1;

FIG. 3 is an elevational view illustrating the structural arrangement of certain components on a printed circuit board which may form part of the base unit shown in FIG. 2;

FIG. 4 is a side elevational view of one of the pole units which forms part of the static control relay shown in FIG. 1;

FIG. 5 is a bottom view of the pole unit shown in FIG. 4;

FIG. 6 is a view, partly in side elevation and partly in section, of the static control relay shown in FIG. 1 illustrating the assembly of one of the pole units of the control relay with the associated base unit and the structural arrangement of certain components which may form part of the base unit of said control relay;

FIG. 7 is a schematic diagram illustrating a typical application of the static control relay shown in FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawings and FIG. 1 in particular, there is shown a static control relay or static control device which in general comprises a base unit or operating module 200 which is adapted to removably receive a plurality of pole units or switching modules 100. Each of the pole units 100 is

of the plug-in type and depending upon which of two orientations or positions in which the pole units 100 are plugged into or assembled with respect to the associated base unit 200, the pole units 100, considered as switching means, are operatively connected as desired to be either normally substantially nonconducting or normally conducting, as will be described in detail hereinafter.

More specifically as shown in FIG. 1, the base unit 200 comprises a plurality of base unit sections or circuits 210, 220, 230 and 240 which are each adapted to receive one of the pole units 100. The base unit 200 includes an input transformer TR1 in order to electrically isolate the external circuit or source of electric power which supplies the necessary electric power to energize the base unit 200 from the associated pole units 100 and to electrically isolate the respective pole units 100 from one another where desired. The transformer TR1 includes a primary winding P1 which is electrically connected between a pair of input terminals 124 and 126 which, in turn, are adapted to be connected to an external source of alternating current power or voltage which serves to energize the primary winding P1 in response to the operation of an external initiating or control means, such as the normally open contact of an associated control relay (not shown). In order to indicate the energization of the primary winding P1, a suitable indicating means may be provided, such as the indicating lamp IL1 which, as illustrated, is connected in series with a voltage dropping resistor R43 across the input terminals 124 and 126. The input transformer TR1 also includes a plurality of separate secondary windings S1, S2, S3 and S4 which form part of the base unit sections 210, 220, 230 and 240, respectively.

In order to provide a plurality of separate unidirectional output currents to the respective base unit sections 210, 220, 230 and 240 whenever the primary winding P1 is energized, each of said base unit sections includes a rectifier means which is connected in circuit relation with the associated secondary winding of the transformer TR1. For example, the rectifier means of the first base unit section 210 comprises a full wave, rectifier bridge circuit BR6 which includes a plurality of diodes connected to form said bridge circuit and whose input terminals are connected to the associated secondary winding S1. The rectifier bridge circuits BR6 of the other base unit sections 220, 230 and 240 are connected in the same manner to the associated secondary windings S2, S3 and S4, respectively.

In order to actuate the operation of each of the pole units 100 between first and second operating conditions or states in response to the energization of the primary winding P1 of the transformer TR1, each of the base unit sections 210, 220, 230 and 240 includes a first pole unit control circuit or gate control circuit 260 and a second pole unit control circuit or gate control circuit 270 which are both connected in circuit relation with the output terminals of the associated bridge circuit BR6. Since the corresponding first pole unit control circuit 260 and the second pole unit control circuit 270 of each of the base unit sections 210, 220, 230 and 240 are identical, only the first and second pole unit control circuits 260 and 270, respectively of the base unit section 210 will be described in detail. In order to filter the unidirectional output current of each of the bridge circuits BR6, a filter capacitor C16 is connected across the output terminals of each of said bridge circuits. In order to permit a relatively fast discharge or reset of each filter capacitor C16 whenever the primary winding P1 of the transformer TR1 is deenergized after being previously energized, a resistor R18 may be connected in parallel circuit relation with each filter capacitor C16. The first pole unit control circuit 260 of the base unit section 210 includes the resistor R45 which is connected between the positive output terminal of the associated bridge circuit BR6 and an externally accessible recessed terminal 114. The first pole unit control circuit 260 also includes an electrical conductor N1 which is connected between the negative output terminal of the associated bridge circuit BR6 and an

external recessed terminal 116. The external terminals 114 and 116 taken together comprise a first set of terminals 280 which are adapted to be engaged by certain contacts on one of the pole units 100 where desired, as will be described hereinafter. The second pole unit control circuit 270 of the base unit section 210 includes a current limiting resistor R44 which is connected between the negative output terminal of the associated bridge circuit BR6 and an external recessed terminal 120. In addition, the second pole unit control circuit 270 includes a resistor R107 which is connected between the upper end of the resistor R44 at the terminal 120 and an external recessed terminal 118 for a purpose which will be described hereinafter. Finally, the second pole unit control circuit 270 includes an electrical conductor P11 which is connected between the positive output terminal of the associated bridge circuit BR6 and an external recessed terminal 122, as shown in FIG. 1. The terminals 118, 120 and 122 taken together comprise a second set of terminals 290 which is adapted to be engaged by certain contacts on one of the pole units 100, where desired, as will be described hereinafter.

Each of the base unit sections 210, 220, 230 and 240 includes an additional pair of external recessed terminals, as indicated at T1 and L1 for the base unit section 210 in FIG. 1, and which are adapted to be engaged by a corresponding pair of contacts on one of the pole units 100 whenever an associated pole unit 100 is plugged into or assembled with one of the base unit sections 210, 220, 230 or 240.

Referring again to FIG. 1, each of the pole units 100 shown in FIG. 1 in general comprises a semiconductor switching means which is actuatable between substantially nonconducting and fully conducting conditions in response to the energization of the input transformer TR1 of the associated base unit 200 into which the pole units 100 are plugged or assembled. The normal operating state of the semiconductor switching means which forms part of each of the pole units 100 is determined by whether a particular pole unit 100 is plugged into and operatively connected to either the first set of terminals 280 or the second set of terminals 290 of the associated base unit section into which the pole unit 100 is plugged or assembled. When a particular pole unit 100 is plugged into the first set of terminals 280 as is the pole unit 100 which is plugged into the base unit section 230 shown in FIG. 1, the semiconductor switching means which forms part of the pole unit 100 will be normally open or substantially nonconducting. When a particular pole unit 100 is plugged into and operatively connected to the second set of terminals 290 of the associated base unit section as is the pole unit 100 which is plugged into the base unit section 210, the semiconductor switching means which forms part of the pole unit 100 will be normally conducting assuming that the output terminals of the pole unit 100 as will be described hereinafter are connected in circuit relation with an associated external source of alternating current power and a load.

More specifically as shown in FIG. 1, each of the pole units 100 includes a pair of output terminals 202 and 204 which are electrically connected to the associated plug-in contacts or stabs 512 and 520, respectively, which, in turn, are adapted to frictionally engage a pair of spring-type recessed terminals on the associated base unit 200. For example, the contacts or prongs 512 and 520 of the pole unit 100 which is plugged into the base unit section 210 engage the recessed terminals 112 and 124, respectively, which, in turn, are electrically connected to the external terminals T1 and L1, respectively, which may be of the screw type. As illustrated, each of the pole units 100 comprises a semiconductor switching means which includes a bridge circuit BR60 and an associated silicon controlled rectifier SCR9 which is connected in circuit relation with said bridge circuit. The bridge circuit BR60 includes a plurality of diodes and the input alternating current terminals of the bridge circuit BR60 are connected to the output terminals 202 and 204 of each pole unit 100 to provide a pair of unidirectional current output terminals to which the

associated controlled rectifier SCR9 is connected. More specifically the controlled rectifier SCR9 includes an anode, a cathode and a gate electrode with the anode of said controlled rectifier being connected to the positive output terminal of the bridge circuit BR60 and with the cathode of said controlled rectifier being connected to the negative output terminal of said bridge circuit through the forward poled diode D2. The anode of the controlled rectifier SCR9, as well as the positive terminal of the bridge circuit BR60, are connected to the plug-in type contact 514 of each pole unit 100, while the gate electrode of said controlled rectifier is electrically connected to the plug-in type contact 516 of each pole unit 100. In order to provide a shunt current path in parallel with the gate-cathode circuit of the controlled rectifier SCR9 when the pole unit 100 is assembled with the associated base unit 200 as a normally open switching means, and for another purpose which will be explained hereinafter, the resistor R144 is connected between the gate electrode of said controlled rectifier and the cathode side of the diode D2 which is also connected to the negative terminal of the bridge circuit BR60.

In order to limit the rate of rise of the forward voltage applied to the controlled rectifier SCR9 of each pole unit 100 when an external source of voltage is connected at the output terminals 202 and 204 of said pole unit to thereby prevent an undesired actuation of said controlled rectifier from a substantially nonconducting condition to a conducting condition, each pole unit 100 includes a resistor R55 and a capacitor C35 which are connected in series with one another between the output terminals 202 and 204. In addition, a reversely poled Zener diode DZ4 is electrically connected in parallel with the series circuit which includes the anode-cathode circuit of the controlled rectifier SCR9 and the diode D2 to limit the noise voltage spikes which might otherwise be applied to said controlled rectifier and cause an undesired actuation of said controlled rectifier from a substantially nonconducting or open condition to a fully conducting or closed condition.

When one of the pole units 100 is plugged into and operatively connected to the base unit 200 as a normally conducting or closed switching means, as is the pole unit 100 which is plugged into or assembled with the base unit section 210 in FIG. 1, the output terminals 202 and 204 of the pole unit 100 are connected through a pair of plug-in contacts on the pole unit 100 as indicated at 512 and 520, respectively, for the latter pole unit to a pair of external energizing terminals located on the base unit 200 as indicated at T1 and L1, respectively, for the above pole unit. In addition, the other plug-in contacts of the normally conducting pole unit 100 are connected to the second pole unit control circuit 270 of the associated base unit section 210 through the second set of recessed terminals 290 on the base unit 200. More specifically, the positive terminal of the bridge circuit BR60 is connected to the gate electrode of the associated controlled rectifier SCR9 through a series circuit which includes the plug-in contact 514, the recessed terminal 118, the voltage dividing resistor R107, the recessed terminal 120, and the plug-in contact 516 of the normally conducting pole unit 100. The resistor R107 forms part of a series circuit which includes the resistors R107 and R144 and which is connected between the positive and negative terminals of the bridge circuit BR60 as a voltage-dividing network to apply the proper gating current to the controlled rectifier SCR9. In addition, the bridge rectifier circuit BR6 of the base unit section 210 is connected in circuit relation with the pole unit 100 through the recessed terminals 120 and 122 and the plug-in contacts 516 and 518, respectively, of said pole unit which engage said recessed terminals. In particular, the positive terminal of the bridge circuit BR6 is connected one end of the resistor R144 through the electrical conductor P11, the recessed terminal 122, and the plug-in contact 518, of the pole unit 100. The negative terminal of the bridge circuit BR6 is connected through a current-limiting resistor R44, the recessed terminal 120, the plug-in contact 516 to the other end of the resistor

R144 and also to the gate electrode of the controlled rectifier SCR9.

On the other hand, when one of the pole units 100 is plugged into and operatively connected to the associated base unit 200 as a normally open or normally substantially nonconducting switching means as is the pole unit 100 which is plugged into the base unit section 230, the output terminals 202 and 204 of said pole unit are connected to the pair of external energizing terminals L3 and T3, respectively, located on said base unit through the plug-in contacts 512 and 520, respectively, on said pole unit which engage the recessed terminals 324 and 312, respectively, of the base unit section 230. In addition, the pole unit 100 is connected to the first pole unit control circuit 260 of the base unit section 230 through the first set of recessed terminals 280 through the plug-in contacts 516 and 518 of said pole unit which engage the recessed terminals 314 and 316, respectively, of the base unit section 230. More specifically, the positive terminal of the bridge circuit BR6 of the base unit section 230 is electrically connected to the gate electrode of the associated controlled rectifier SCR9 through the current-limiting resistor R45, the recessed terminal 314 and the plug-in contact 516 on the pole unit 100. The negative terminal of the bridge circuit BR6 of the base unit section 230 is connected to the cathode side of the diode D2 and also to the right end of the resistor R144 as viewed in FIG. 1. It is to be noted that the operating connections between the normally open pole unit 100 which is plugged into the base unit section 230 do not include any gating circuit between the positive terminal of the bridge circuit BR60 and the gate electrode of the associated controlled rectifier SCR9 since the plug-in contact 514 of then normally open pole unit 100 is not operatively connected to the gate electrode of the associated controlled rectifier SCR9 through the first pole unit control circuit 260 of the base unit section 230 as in the operative connections of the normally conducting or normally closed pole unit 100 as previously described.

In the operation of the normally conducting or normally closed pole unit 100 which is plugged into and operatively connected to the base unit section 210, it will be assumed initially that the primary winding P1 of the input transformer TR1 of the base unit 200 is not energized but that an external source of alternating current voltage is applied to the output terminals 202 and 204 of the pole unit 100 through the external energizing terminals T1 and L1 of the base unit section 210 and that a load is also connected in circuit relation with said external source of alternating current voltage. When an alternating current voltage is applied at the output terminals 202 and 204 of the normally closed pole unit 100, a unidirectional voltage will be present at the unidirectional terminals of the bridge circuit BR60. During each half cycle of the alternating current voltage applied at the terminals 202 and 204, a gating current will flow from the positive terminal of the bridge circuit BR60 through the plug-in contact 514 of said pole unit, the recessed terminal 118, the current-limiting resistor R107, the recessed terminal 120, the plug-in contact 516 of said pole unit, the gate-cathode circuit of the controlled rectifier SCR9, the diode D2 and back to the negative terminal of the bridge circuit BR60. During each half cycle, therefore, the controlled rectifier SCR9 will be actuated from a substantially nonconducting condition by the gating current just described to a fully conducting or "closed" condition. Whatever external load is connected in circuit relation with the external source of voltage applied at the terminals T1 and L1 will be energized through the pole unit 100 by a circuit which extends from one of the terminals T1 or L1 depending on the instantaneous polarity of the voltage through one of the associated output terminals 202 or 204, respectively, of said pole unit through one of the diodes in the bridge circuit BR60, through the anode-cathode circuit of the controlled rectifier SCR9, the diode D2 and back through a second diode of the bridge circuit BR60 to the other of the energizing terminals 202 or 204. Since during the assumed

operating condition the primary winding P1 of the input transformer TR1 is not energized, no unidirectional output voltage will be present at the output terminals of the bridge circuit BR6 of the base unit section 210. At the end of each half cycle of the alternating current voltage applied at the terminals T1 and L1, the instantaneous alternating current will decrease to zero and the controlled rectifier of the pole unit 100 which is operatively connected to the base unit section 210 will be actuated to a substantially nonconducting condition until the gating current flows in the following half cycle of the alternating current voltage.

In the operation of the normally closed or conducting pole unit 100 when the primary winding P1 of the input transformer TR1 of the base unit 200 is energized, a unidirectional, filtered output voltage will appear at the output terminals of the bridge circuit BR6 of the base unit section 210. As previously mentioned, the primary winding P1 is normally energized by an external initiating means, such as a normally open contact of an associated relay (not shown) which closes to connect the primary winding P1 to an external source of alternating current voltage or power. When a unidirectional output voltage is present at the output terminals of the bridge circuit BR6, a neutralizing or blocking current will flow which prevents the gating current previously described from flowing into the gate electrode of the controlled rectifier SCR9 of the pole unit 100 which is plugged into the base unit section 210. In particular, the neutralizing or blocking current will flow from the positive terminal of the bridge circuit BR6 upwardly, as viewed in FIG. 1, through the electrical conductor P11, the recessed terminal 122, the plug-in contact 518 of the pole unit 100, the resistor R144, the plug-in contact 516, the recessed terminal 120 and the current-limiting resistor R44 to the negative terminal of the bridge circuit BR6. It is important to note that the neutralizing current just described flows in a direction which is away from the gate electrode of the controlled rectifier SCR9 and in a direction which is opposite to the gating current which flows from the positive terminal of the bridge circuit BR60 during each half cycle of the alternating current voltage applied at the external terminals T1 and L1 to thereby prevent the actuation of the controlled rectifier SCR9 from a substantially nonconducting condition to a conducting condition during each half cycle of said alternating current voltage. The neutralizing current from the bridge circuit BR6 is preferably arranged to be greater than the gating current which tends to flow from the positive terminal of the bridge circuit BR60 to insure that the controlled rectifier SCR9 is maintained in a substantially nonconducting or open-operating condition whenever the transformer TR1 is energized. It is to be noted that when a forward voltage is applied to the controlled rectifier SCR9 from the external source connected at the terminals T1 and L1, whatever leakage current which is permitted to flow from the anode to the cathode of said controlled rectifier might accidentally or inadvertently actuate said controlled rectifier from a substantially nonconducting or open condition to a conducting condition. The resistor R144 assists in preventing such an undesired actuation of said controlled rectifier due to a forward applied voltage by providing a shunt current path which diverts the leakage current from the anode through the gate electrode of said controlled rectifier and back to the negative terminal of the bridge circuit BR60. In addition, the presence of the diode D2 also assists in preventing such an undesired actuation of the controlled rectifier due to the forward applied voltage by introducing an additional impedance in the anode-cathode circuit of said controlled rectifier which reduces the leakage current which might otherwise cause such an undesired actuation of said controlled rectifier from a substantially nonconducting or open condition to a conducting or closed condition.

In the operation of the normally open or normally substantially nonconducting pole unit 100 which is plugged into and operatively connected to the base unit section 230 as

shown in FIG. 1, it will be assumed initially that the primary winding P1 of the input transformer TR1 is not energized but that an external source of alternating current voltage is applied at the output terminals 202 and 204 of the pole unit 100 through the external terminals L3 and T3 of the base unit section 230 and that a load is connected in circuit relation with said external source of alternating current voltage. It is to be noted that during the assumed operating condition, that a unidirectional output voltage will not be present at the unidirectional output terminals of the bridge circuit BR6 of the base unit section 230 since the primary winding P1 is not energized. During the assumed operating condition, the controlled rectifier SCR9 of the normally open pole unit 100 which is plugged into or assembled with the base unit section 230 will remain in a substantially nonconducting or open condition since no gating circuit is provided to the gate electrode of said controlled rectifier from the positive terminal of the bridge circuit BR60 as in the normally closed pole unit 100 previously described. As previously mentioned, during the assumed operating condition the resistor R144 assists in preventing the turning on or the actuation of the controlled rectifier SCR9 from a substantially nonconducting state to a conducting state due to the leakage current which flows in said controlled rectifier because of the forward applied voltage from the external source connected to the terminals L3 and T3 by diverting the leakage current from the anode of said controlled rectifier away from the cathode and into the gate electrode in a direction which is opposite to that required for the gating of said controlled rectifier. In addition, the diode D2 assists in preventing such an undesired turning "on" or actuation of said controlled rectifier due to the forward applied voltage by introducing additional impedance in the anode-cathode circuit of said controlled rectifier and additionally reducing the leakage current which might otherwise flow to the cathode by causing a greater portion of said leakage current to flow to the gate electrode in a direction which is opposite that required for the gating or turning "on" of said controlled rectifier. In addition, as previously mentioned the Zener diode DZ4 assists in preventing accidental turning on or actuation of the controlled rectifier from a substantially nonconducting to a conducting condition by limiting the noise voltages which may be applied to said controlled rectifier from the external source of voltage connected to the terminals L3 and T3. In addition, the resistor R55 and the capacitor C35 limit the rate of rise of the voltage applied to the controlled rectifier SCR9 from the external source of voltage connected to the terminals L3 and T3 to prevent an undesired actuation of said controlled rectifier to thereby improve the reliability of operation of the normally open pole unit 100.

In the operation of the normally open pole unit 100 which is plugged into and operatively connected to the base unit section 230 and more specifically to the first pole unit control circuit 260 of said base unit section, when the primary winding P1 is energized from an external source of alternating current voltage by an external initiating means as previously mentioned, a unidirectional output voltage appears at the unidirectional output terminals of the bridge circuit BR6 of the base unit section 230. The unidirectional output voltage at the unidirectional output terminals of the bridge circuit BR6 is filtered by the capacitor C16 and causes a gating current to flow to the gate electrode of controlled rectifier SCR9 from the positive terminal of the bridge circuit BR6 through the current limiting resistor R45, the recessed terminal 314, the plug-in contact 516, the gate electrode of said controlled rectifier, the cathode of said controlled rectifier, the diode D2, the plug-in contact 518 of the pole unit 100, the recessed terminal 316 of the base unit section 230 and back to the negative terminal of the bridge circuit BR6. When the gating current flows through the path just described, the anode-cathode circuit of the controlled rectifier SCR9 is actuated from a substantially nonconducting or open condition to a

conducting or closed condition to thereby permit whatever load is connected to the external source of voltage at the terminals L3 and T3 to be energized through a current carrying or conducting path which extends from one of terminals L3 or T3 depending upon the instantaneous polarity of the external voltage source through one of the associated output terminals 202 and 204 of the pole unit 100, one of the diodes of the bridge circuit 60, to the positive output terminal of said bridge circuit, through the anode-cathode circuit of the controlled rectifier SCR9, the diode D2, through a second of the diodes of the bridge circuit BR60 to the other output terminal of said pole unit. In summary, when the primary winding P1 is energized, the pole unit 100 which is connected to the base unit section 230 will be actuated from a substantially nonconducting or open condition, considered as a switching means, to a conducting or closed operating condition so long as the primary winding P1 remains energized. When the primary winding P1 is deenergized after being energized, the unidirectional output voltage will no longer be present at the output terminals of the bridge circuit BR6 and the filter capacitor C16 will be discharged relatively fast or reset by the resistor R18 to thereby remove the gating current from the gate electrode of the associated controlled rectifier SCR9. When the gating current is removed from the controlled rectifier SCR9 of the normally open pole unit 100, said controlled rectifier will continue to conduct in the anode-cathode path until the end of the particular half cycle of alternating current voltage applied at the terminals L3 and T3 and said controlled rectifier will then be actuated or returned to a substantially nonconducting or open operating condition when the instantaneous alternating current passes through current zero.

Referring now to FIGS. 2, 3 and 6, a suitable construction of the base unit 200 is illustrated. Referring to FIG. 2, the pairs of corresponding external terminals T1 and L1, T2 and L2, T3 and L3 and T4 and L4 of the respective base unit sections 210, 220 230 and 240 may be of the screw type and disposed at the opposite sides of the base unit 200. The external terminals 124 and 126 associated with the primary winding P1 of the input transformer TR1 may be disposed at opposite sides of the base unit 200 at one end of said base unit. An additional external terminal M1 and the indicating lamp IL1 may also be disposed at the same end of the base unit 200 as are the terminals 124 and 126. Each of the base unit sections 210, 220, 230 and 240 includes a plurality of openings in the base unit 200 as indicated at 712, 714, 716, 718, 720, 722, 724 and 726 through which the plug-in contacts of the associated pole units 100 pass to frictionally engage the spring-type recessed terminals of each of said base unit sections. For example, the plurality of openings associated with the base unit section 210 include a pair of openings 712 and 724 in which the recessed terminals 112 and 124, respectively, are disposed. The terminals 112 and 124 are electrically connected to the external terminals T1 and L1, respectively, as shown structurally in FIG. 6. The pair of openings 712 and 724 are disposed along a centerline of the base unit section 210 with two sets of openings being disposed on opposite sides of said centerline. For example, the openings 718, 720, and 722 on one side of a line extending between the openings 712 and 724 provide access to the recessed terminals 118, 120 and 122, respectively, which form the second set of terminals 290 of the base unit section 210 and which are connected to the second pole unit control circuit 270 of said base unit section. The openings 716 and 714 on the other side of a centerline extending between the openings 712 and 724 of the base unit section 210 provide access to the recessed terminals 116 and 114, respectively, of the base unit section 210 which are disposed in said openings and which comprise the first set of openings 280. The opening 726 of the base unit section 210 is merely a dummy opening to accommodate one of the plug-in contacts of one of the pole units 100 when said pole unit is plugged into the first set of terminals 280 which includes the recessed terminals 114 and 116 which, in turn, are electrically

connected to the first pole unit control circuit 260 as previously described.

Referring to FIG. 3 the circuit components which form the base unit sections 210, 220, 230 and 240 may be conveniently mounted on first and second printed circuit boards 250 of each of which accommodates the circuit components of two of said base unit sections. The components on the printed circuit boards 250 may then be electrically connected by suitable electrical conductors to the associated input transformer TR1 and to the recessed terminals associated with the respective base unit sections. An electrically insulating casing may be then formed around the circuit components of the base unit 200 by potting, molding, casting or other known types of encapsulation in an electrically insulating medium such as a thermosetting resin of the epoxy type or the casing may be formed separately and the circuit components of the base unit 200 assembled and mounted inside the casing.

Referring to FIGS. 4, 5, and 6, a suitable construction of each pole unit 100 is illustrated. More specifically the circuit components of each pole unit 100 may be assembled and electrically connected together as indicated diagrammatically in FIG. 1 with one another and to the plug-in contacts or electrically conducting prongs 512, 514, 516, 518, and 520 indicated in FIGS. 4, 5 and 6. The circuit components of each pole unit 100 may be then enclosed in an electrically housing which may be formed in the same manner as just mentioned in connection with the base unit 200 by potting, molding or casting to thereby encapsulate said circuit components in a suitable electrically insulating medium such as a thermosetting resin of the epoxy type or the housing may be formed separately. As best shown in FIG. 5 the plug-in contacts at the ends of each pole unit 100 are disposed along a common centerline of said pole unit and the balance of the intermediate plug-in contacts 514, 516 and 518 are disposed along a second line which is generally parallel to the line extending between the plug-in contacts 512 and 520 but spaced from or offset from the centerline of the pole unit extending between the plug-in contacts 512 and 520. When one the pole units 100 is inserted into the openings of one of the associated base unit sections of the base unit 200 with the intermediate plug-in contacts 514, 516 and 518 disposed on one side of a line extending between the end openings 712 and 724, the pole unit 100 will be normally closed or conducting as previously described. For example, if the pole unit 100 as shown in FIG. 5 is plugged into the base unit section 210 with the intermediate plug-in contacts 514, 516 and 518 passing through the openings 718, 720 and 722, respectively, to engage the recessed terminals 118, 120 and 122, respectively, the pole unit 100 will be connected to the second pole unit control circuit 270 and will be normally conducting or closed as indicated diagrammatically in FIG. 1 and as shown structurally in FIG. 6. On the other hand, if the pole unit 100 is plugged into the base unit section 230 with the intermediate plug-in contacts 514, 516 and 518 passing through the openings 726, 714 and 716, respectively, to engage the recessed terminals 316 and 314 which form part of the first set of terminals 280 of the base unit section 230, the pole unit 100 will be normally open or substantially nonconducting. It is to be noted that the plug-in contact 514 in the latter operating condition is disposed in a dummy opening 726 and does not engage a corresponding recessed terminal as shown diagrammatically in FIG. 1. In other words, if a particular pole unit 100 is oriented to engage the first set of terminals 280 corresponding to the openings on one side of the centerline of each base unit section, the pole unit will be normally open or substantially nonconducting as previously described. If the orientation of the pole unit 100 is reversed and the plug-in contacts engage the second set of terminals 290 in the openings on the other side of the centerline of a particular base unit section, the pole unit 100 will be normally conducting or closed as previously described.

It is to be noted that in the construction of the base unit 200, as shown in FIG. 6, the insulating housing of the base unit 200 may be formed as a cover portion 213B which supports the various recess terminals of each of the base unit sections 210, 220, 230 and 240 and a bottom cup-shaped portion 213B which is bonded or secured to the cover portion by suitable means, such as a thermosetting resin. In addition, a generally L-shaped pole unit retaining member 215 may be provided to retain the pole units 100 in their assembled positions on the base unit 200 as shown in FIG. 6. The retaining member 215 may be removably secured to the base unit 200 by suitable means, such as the bolt 217 which passes between the pole units 100 to engage a threaded opening 812 provided in said base unit as shown in FIG. 2. To indicate the normal operating condition of each pole unit 100, diagrammatic symbols may be provided at each end of each pole unit with the appropriate symbol being exposed by the retaining member 215.

Referring now to FIG. 7, there is illustrated a typical application of the disclosed static control relay which includes the base unit 200 and a plurality of pole units 100, each of which is diagrammatically represented as being of the normally open type. In this particular application, the primary winding P1 of the transformer TR1 is illustrated as being connected electrically in series with a normally open energizing contact EC1, said series circuit being connected between the conductors L101 and L102 of an external source of alternating current voltage or power. In this case, the pole units 100 are electrically connected operatively in series with a plurality of associated control relays R1, R2, R3 and R4 between the conductors L101 and L102. The relays R1 through R4 are therefore normally deenergized as long as the primary winding P1 is deenergized due to the normally open energizing contact EC1. When the contact EC1 closes to thereby energize the primary winding P1 from the conductors L101 and L102, each of the normally open pole units 100 is actuated to a conducting or closed condition to thereby energize the control relays R1 through R4. It is to be noted that in this application, the same external source of alternating current power is employed to energize the primary winding P1 and is employed to energize the control relays R1 through R4 which correspond to the individual loads connected to the respective pole units 100.

Where desired, the disclosed static control relay lends itself to providing a convenient memory or holding circuit by internal connections which may be made between the external terminals on the base unit 200. For example, if the energizing contact EC1 represents a start pushbutton contact which may be momentarily closed or depressed, the normally closed contact EC2 which may correspond to a stop pushbutton may be connected between the input terminal 124 and the memory terminal M1 provided on the base unit 200 as shown in FIG. 7. The terminal M1 on the base unit, in turn, is electrically connected internally by the electrical conductor 113 shown in FIGS. 1 and 7 to the external terminal T1 at one side of the load or control relay R1. In the operation of this arrangement, when the energizing contact EC1 is momentarily closed to thereby energize the primary winding P1, the normally open pole unit 100 which is connected between the terminals L1 and T1 is actuated to a conducting condition to thereby form a memory or holding circuit which extends from the conductor L101, through the pole unit 100 between the terminals L1 and T1, the internal conductor 113, the memory terminal M1, the normally closed contact EC2, the terminal 124, the primary winding P1, the terminal 126 and to the other line conductor L102 to thereby maintain the primary winding P1 in an energized condition. If, however, the voltage between the conductors L101 and L102 decreases below a value necessary to maintain the pole unit 100 connected to the relay R1 in a conducting or closed condition, the primary winding P1 will be deenergized to thereby return the pole units 100 associated with the base unit 200 to their normal operating conditions in an arrangement which is functionally equivalent to a low voltage protection arrangement which is well known in the electromechanical control relay art.

It is to be understood that a static control relay as disclosed may include whatever number of pole units is desired to cooperate with a common base unit which is adapted to receive the associated pole units and that the plurality of pole units associated with a particular base unit or with several base units may be electrically connected in parallel to increase the current carrying capacity required in a particular application. In addition, it is to be understood the external energizing terminals of each pole 100 may be structurally located on said pole unit rather than being provided on the associated base and connected through a pair of plug-in contacts on said pole unit. In other words, the plug-in contacts 512 and 520 could be eliminated and the output terminals 202 and 204 made externally accessible. Finally, it is to be understood that certain types of static timing circuits may also be plugged into the base unit 200, such as disclosed in U.S. Pat. No. 3,457,433 which issued July 22, 1969 and which is assigned to the same assignee as the present application. In such a combination the output voltage of one of the bridge circuits BR6 would serve as the DC source 24 shown in FIG. 1 of the above patent.

The static control relay or device embodying the teachings of this invention has several important advantages. For example, the source of electric power or voltage which energizes the input transformer TR1 of the base unit 200 is electrically isolated from the semiconductor switching means which form part of the respective pole units associated with the base unit and the pole units are also electrically isolated from one another where desired. A second important advantage of the disclosed static control relay is that the individual pole units may be plugged in as either normally closed or normally open units or may be changed whenever desired by reversing the orientation of the pole unit as it is plugged into the associated base unit. A third important advantage of the disclosed static control relay is that the noise associated with the operation of conventional electromechanical relays is eliminated. A fourth advantage of the disclosed static control relay is that it readily lends itself to application in environmental conditions such as corrosive or explosive atmospheres which would not safely permit the use of conventional electromechanical relays. A fifth advantage of the disclosed static control relay is that it lends itself to application in exactly the same manner as electromechanical relays are applied without requiring special connections or complicated arrangements and while also permitting application in hybrid systems which include both static control relays of the type disclosed and also electromechanical control relays where desired. A sixth advantage of the disclosed static control relay is that reliable operation is insured despite the presence of noise or interfering voltages due to the disclosed circuit arrangements which prevent the undesired actuation of the semiconductor switching means which form part of each of the pole units 100.

I claim:

1. A static control device comprising a base unit and one or more removable pole units, said base unit including a transformer, first and second pole unit control circuits for each pole unit connected to said transformer, first and second sets of terminals connected to said first and second pole unit control circuits, respectively, one of said sets of terminals being adapted to selectively receive one of said pole units at a time, each of said pole units comprising a semiconductor switching means actuable between substantially nonconducting and conducting conditions, output terminals connected to said switching means and adapted to be connected to an external source and a load, and a plurality of contacts connected in circuit relation with said switching means and adapted to selectively engage either said first set or said second set of terminals, said switching means of each pole unit being normally nonconducting when said plurality of contacts engages said first set of terminals and normally conducting when said plurality of contacts engages said second set of terminals, said switching means being actuated from the normal operating condition corresponding to the set of terminals engaged by said plurality of contacts to the opposite operating condition by said pole unit control circuits when said transformer is energized from said source.

2. The combination as claimed in claim 1 wherein said semiconductor switching means includes at least one silicon controlled rectifier.

3. The combination as claimed in claim 1 wherein said semiconductor switching means comprises a bridge circuit including a plurality of diodes connected to provide a pair of unidirectional current terminals and a silicon controlled rectifier connected between said pair of unidirectional current terminals.

4. The combination as claimed in claim 2 wherein means is connected in circuit relation with the output terminals of each pole unit for limiting the rate of rise of the voltage applied to said controlled rectifier from the external source connected to the associated output terminals.

5. The combination as claimed in claim 3 wherein means is connected in circuit relation with the output terminals of each pole unit for limiting the rate of rise of the voltage applied to said controlled rectifier from the external source connected to the associated output terminals.

6. A static control relay comprising a base unit and one or more removable pole units, said base unit comprising a transformer having a primary winding and a plurality of secondary windings, rectifier means connected to the respective secondary windings for providing a plurality of separate corresponding unidirectional output currents when said primary winding is energized from an external source of alternating current power, first and second pole unit control circuits connected to each of said rectifier means, first and second sets of terminals connected to said first and second control circuits, respectively, and adapted to selectively receive in only one of said sets of terminals one of said pole units, each of said pole units comprising output terminals adapted to be connected to an external source of electric power and a load, semiconductor switching means actuatable between substantially nonconducting and conducting conditions connected in circuit relation with said output terminals to control the energization of said load from the last-mentioned source, and a plurality of plug-in type input contacts connected in circuit relation with said switching means and adapted to selectively engage either said first or second sets of terminals on said base unit, said switching means of each pole unit being normally nonconducting when the contacts of said pole unit engage said first set of terminals on said base unit and being normally conducting when the contacts of said pole unit engage said second set of terminals on said base unit and the output terminals of said pole unit and the output terminals of said pole unit are connected to said external source and a load, said switching means of each pole unit being actuated from the normally operating condition to the opposite operating condition when said primary winding is energized from the first-mentioned source.

7. The combination as claimed in claim 6 wherein said

semiconductor switching means includes at least one silicon controlled rectifier.

8. The combination as claimed in claim 6 wherein said semiconductor switching means of each pole unit comprises a bridge circuit including a plurality of diodes connected to provide a pair of unidirectional current terminals and a silicon controlled rectifier connected between said pair of unidirectional current terminals.

9. The combination as claimed in claim 8 wherein said controlled rectifier of each pole unit includes an anode, a cathode and a gate electrode, each of said pole units includes a first resistor connected between said gate electrode and one of said unidirectional terminals of said bridge circuit, said first pole unit control circuit includes a second resistor connected in series circuit relation with the gate-cathode circuit of said controlled rectifier of the associated pole unit when said plurality of contacts of the latter pole unit engage said first set of terminals, said series circuit being connected to the associated rectifier means, and said second pole unit control circuit includes a third resistor connected between the other of said unidirectional terminals of said bridge circuit and said gate electrode of said controlled rectifier of the associated pole unit and means for connecting said first resistor to the rectifier means associated with the pole unit when said plurality of contacts of the latter pole unit engage said second set of terminals.

10. The combination as claimed in claim 7 wherein said controlled rectifier of each pole unit includes an anode, a cathode and a gate electrode, each of said pole units includes a first resistor connected between said gate electrode and the cathode of said controlled rectifier, said first pole unit control circuit includes a second resistor connected in series circuit relation with the gate-cathode circuit of said controlled rectifier of the associated pole unit when said plurality of contacts of the latter pole unit engage said first set of terminals, said series circuit being connected to the associated rectifier means, and said second pole unit control circuit includes a third resistor connected between the anode and the gate electrode of said controlled rectifier of the associated pole unit and means for connecting said first resistor to the rectifier means of the associated pole unit when said plurality of contacts of the latter pole unit engage said second set of terminals.

11. The combination as claimed in claim 7 wherein each pole unit includes means connected in circuit relation with the output terminals of said pole unit for limiting the rate of rise of the voltage applied to said controlled rectifier from the external source connected to the associated output terminals.

12. The combination as claimed in claim 8 wherein each pole unit includes means connected in circuit relation with the output terminals of said pole unit for limiting the rate of rise of the voltage applied to said controlled rectifier from the external source connected to the associated output terminals.

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