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[54] **DUAL-MODE SOLID STATE RELAY**

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[51] **Int. Cl.** **H03k 17/72**
[58] **Field of Search** ..... 307/252 N, 252 T, 307/269

[56] **References Cited**

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[57] **ABSTRACT**

A solid state power relay which may optionally provide either a fast turn-on, as is preferred for luminous gas discharge lamps, or a gradual turn-on, as is preferred for incandescent lamps to prolong filament life. Interchanging from one mode to the other is readily accomplished to provide interchangeability in standard traffic signal controllers or like applications.

8 Claims, 2 Drawing Figures

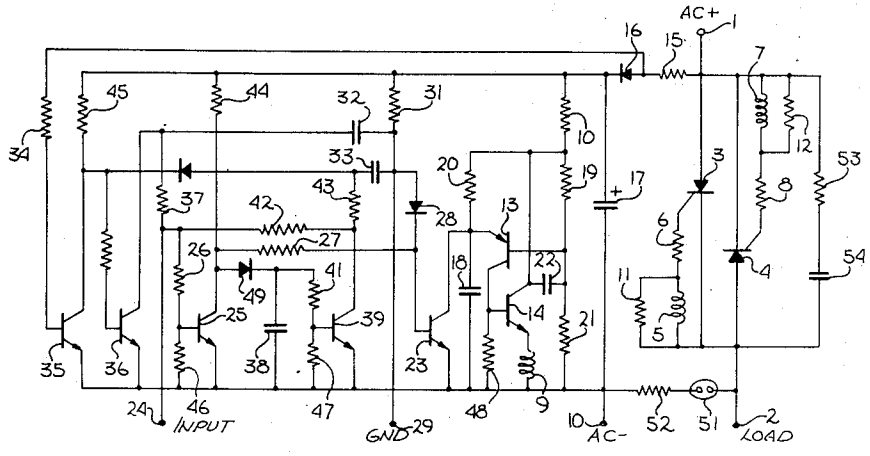


Fig. 1

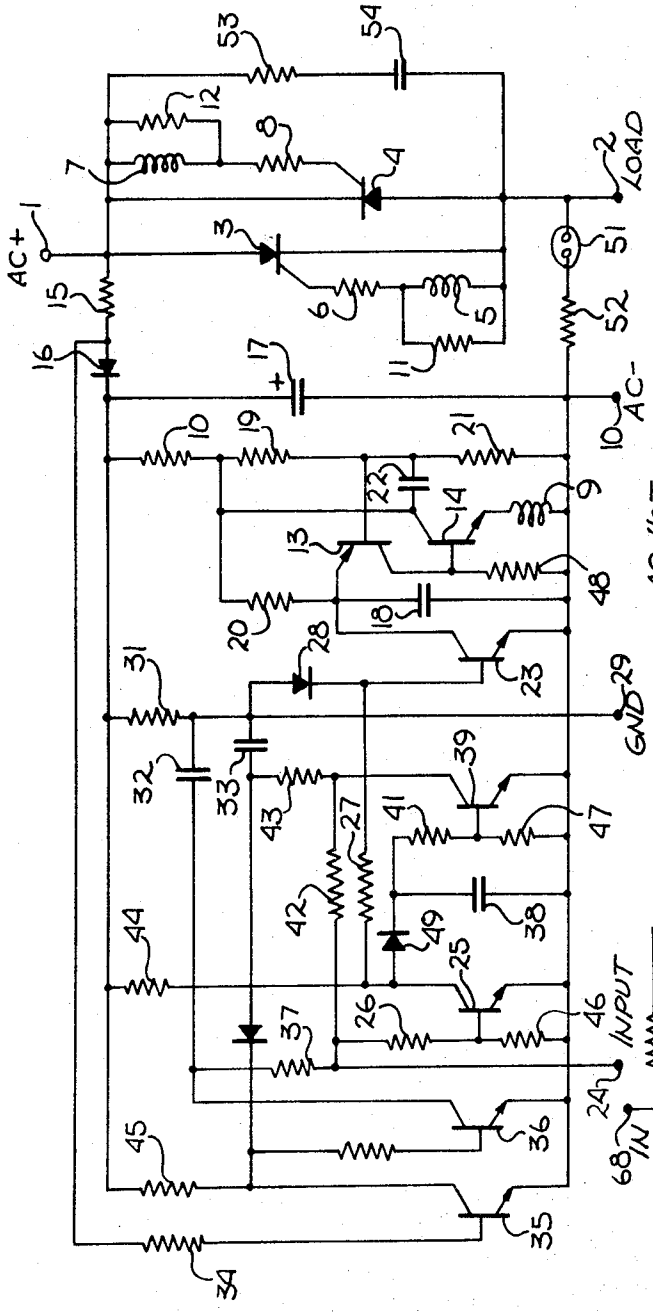
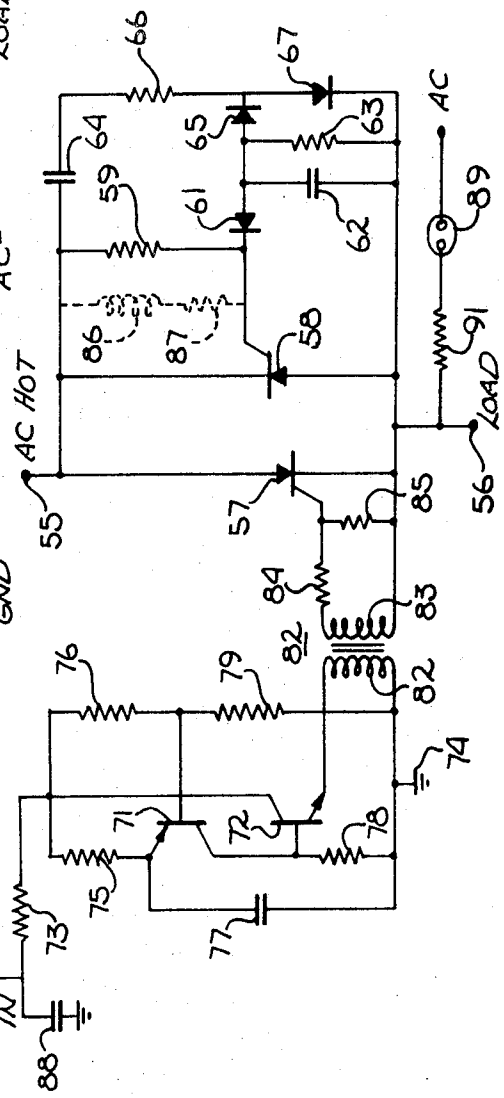


Fig. 2



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DUAL-MODE SOLID STATE RELAY

BACKGROUND OF THE INVENTION

This invention relates to solid state power relays of the general type described in my co-pending patent application, Ser. No. 680,176, filed Nov. 2, 1967, now U.S. Pat. No. 3,612,945, and which employ a pair of back-to-back silicon controlled rectifiers (or their equivalent). The rate of current conduction through the relay may be selectively controlled to provide one of two operating modes. During the gradual turn-on mode, the alternating current is gradually applied to the load through an interval of several cycles of the AC supply. This function is similar to that provided by the device described in my aforementioned patent application (which description is to be incorporated herein by reference) as applied to incandescent lamp loads. Upon affecting a simple adjustment, the device may be made to yield rapid, high-current, turn-on characteristics as is desirable in certain related applications of the invention, such as in traffic signals utilizing neon lamps or the like.

DESCRIPTION OF THE PRIOR ART

The use of solid state switching devices, in lieu of electromechanical relays, have found wide acceptance in many applications. Among the many advantages of so-called "solid-state relays" is their absence of mechanical wear and their high reliability. One application of solid state relays, for which the aforementioned advantages are particularly important, is for use in traffic-light controllers.

Conventional traffic-light controllers usually comprise banks of switching relays, a flasher, and a timing or sequencing device. These controllers may include many options and there exists many variations in the basic device. For example, some are traffic activated by switches which respond to moving vehicles, others employ fixed timing controlled by an internal clock. However, in all cases, the desired end result of the operation of the controller is to turn the traffic lights (semaphore) off and on at the proper time.

There is described in my co-pending patent application Ser. No. 680,176, filed Nov. 2, 1967, entitled "Delayed Turn-on Solid State Relay," a device which includes, in addition to the aforementioned advantages of solid state relays, an improvement whereby the current surge normally associated with the turn-on of incandescent lamps is prevented.

The conventional incandescent lamp, as used in a traffic semaphore, draws more than thirteen times its normal operating current when it is first turned on. This sudden in-rush of current causes a thermal shock which stresses the lamp's filament, and is the major cause of lamp failure. The lamps customarily used in traffic signals are of a special type designed for heavy duty use, and are significantly more expensive than standard-quality incandescent lamps. Notwithstanding this, these heavy-duty lamps are rated by the manufacturers as being suitable for only 8 to 9 months under the severe type of duty encountered in traffic signal use. It is, therefore, common practice to replace all of the lamps in a given semaphore at specified intervals, yet there is still a requirement for replacement of random burn outs.

The delayed turn-on relay of my aforementioned co-pending patent application has been found to extend the expected life of incandescent lamps used in traffic signal service by a factor of three. This substantial improvement accrues to the fact that said device slowly applies the operating current to the lamp at an optimal rate so as to minimize the undesirable thermal shock. While such delay is effective for the intended result, it is still so rapid that it goes unnoticed to the human observer, and has met with favorable commercial acceptance.

Certain traffic signal systems, in addition to the familiar red, amber, and green lamps found in the overhead semaphore, also include auxiliary signals in the form of lighted signs. One such auxiliary signal comprises a "walk" and "dont't walk" sign wherein the words are in the form of green and red luminous gas discharge tubes, commonly called "neon" signs. As is well known to those versed in the art, neon lamps do not exhibit the same starting impedances as do incandescent lamps, nor do they have filaments which are subject to the previously mentioned thermal shocks. Thus, the slow turn-on feature of the aforementioned improvement invention, is not applicable to neon lamps. Furthermore, it has been found that the slow turn-on feature of the "soft-start" relay is undesirable as the direct-current (DC) component caused by only one silicon controlled rectifier (SCR) conducting for several cycles of the applied alternating-current (AC) tends to damage the neon lamp's power transformer. Also, the slow turn-on feature causes a starting flicker of the lamp's output which is undesirable. Thus, it is desired to have a solid state relay which will provide the advantages of slow starting for incandescent lamps, and provide the advantages of high-reliability, contact-less, hard-start switching for neon lamps.

As mentioned previously, traffic controllers comprise systems incorporating a plurality of relays to control the signal lamps. These relays are made to respond to low level control signals derived from timers, traffic-actuated switches and the like. In the interest of economy and to facilitate maintenance, it is desirable to employ interchangeable relays of uniform characteristics, and preferably such relays should be of "plug-in" variety. The conflicting characteristics of soft starting for incandescent lamps, and hard (fast)-starting for neon lamps has, heretofore, precluded the desired interchangeability of plug-in solid state relays.

There is provided by the present invention, a novel and improved solid state relay device which will optionally provide a soft-start mode, or a hard-start mode as required by the circuit into which it is placed.

SUMMARY OF THE INVENTION

There is provided by the present invention a novel and improved solid state relay which utilizes a pair of SCRs parallel-connected in oppositely poled relationship in series with one side of the AC power line to be switched. When it is desired to operate the relay in a slow, or soft, start mode, the first SCR is activated by the application of an input signal, the second SCR being caused to operate at a delayed time. Following a preset interval, equivalent to several cycles of the AC line voltage, the second SCR will be fully turned on.

When it is desired to operate the relay in a fast, or hard, start mode, it is merely necessary to ground one terminal of the device and both SCRs will be fully turned on at the same time. In both instances (hard start and soft start) the control signals are derived from

a free-running oscillator the output of which is in turn controlled by an input control signal applied to the device from the external related equipment.

In those applications in which incandescent lamps are to be turned on and off, the mode-selection terminal is left ungrounded. If luminous gas discharge lamps are to be turned on and off, the mode-selection terminal is permanently grounded; in all other respects the devices are interchangeable with respect to their external circuit connections, thus facilitating their use in standard traffic signal controllers.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic circuit diagram of a first embodiment of a dual-mode solid state relay constructed in accordance with the invention;

FIG. 2 is a schematic circuit diagram of an alternate embodiment of a relay according to the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, there is shown a schematic circuit of a first embodiment of the invention. The relay is intended to be placed in series with one side of the AC line to be controlled; relay terminals 1 and 2 serve as the equivalent of the SPST terminals of an electromechnical relay. Terminal 1 is connected to the AC line with the remaining terminal being connected to the load (which generally will comprise a signal lamp which is to be turned ON or OFF). Two SCRs, 3 and 4 are connected back-to-back in parallel between terminals 1 and 2 to permit the AC power to pass therethrough when they are turned on by the appropriate control signals applied to their gate electrodes, thereby applying power to the series-connected load.

The gate electrode of SCR 3 obtains its control signal from transformer winding 5 via resistor 6. Similarly, SCR 4 obtains its gate control signal from transformer winding 7, via series resistor 8. Windings 5 and 7 comprise secondary windings of the transformer having primary winding 9. Resistors 11 and 12 are connected across windings 5 and 7, respectively, for the purpose of preventing noise spikes from causing unwanted conduction of the SCRs (3 and 4), since the transformer winding itself would otherwise appear as a high impedance to noise.

Gate control signals are derived from an oscillator comprising transistors 13 and 14. The primary winding 9 is connected in series with the emitter of transistor 13. The oscillator and its control circuits derive their operating voltage from a half-wave rectifier comprising dropping resistor 15, rectifier diode 16, and filter capacitor 17. The source of power is the line voltage derived between pin 1 and pin 10 where pin 10 is connected to the other end of the line from pin 1.

The oscillator functions as follows: Normally transistors 13 and 14 are in their non-conducting (off) condition, and the collector of transistor 14 is high. This allows a charging current to flow via the collector load resistor 10, and charging resistor 20, to capacitor 18. Also, the base of transistor 13 is biased to a preset voltage determined by the voltage divider comprising resistors 19 and 21.

The common terminal of the DC power supply (ground) coincides with terminal 2.

Capacitor 18 continues to charge until it reaches a voltage level, at the base of transistor 13, which is sufficient to cause the transistor 13 to turn on (conduct). When transistor 13 conducts, its collector current flows through the base of the transistor 14, causing it to conduct. When transistor 14 turns on, the collector load resistor 10 is pulled towards ground, thereby pulling the bias voltage at the base of transistor 13 down. This action is regenerative since it tends to cause transistor 13 to conduct harder. Capacitor 18 is totally discharged through both transistors 13 and 14. The peak discharge current flows, via the emitter of transistor 14, through the transformer primary winding 9, which in turn will generate a pulse in the secondary windings 5 and 7 causing the two SCRs (3 and 4) to conduct.

Resistor 6, which is in series with gate of SCR 3, as well as resistor 8, which is in series with the gate of SCR 4, provide for equal distribution of the pulse signal between the two SCRs (3 and 4). As is well known, SCRs do not necessarily have uniform characteristics, and without resistors 6 and 7 one SCR could possibly load its associated transformer winding so that there would be insufficient drive signal for the remaining SCR of the pair.

After capacitor 18 is discharged there will be no longer any drive current to keep transistors 13 and 14 turned on; thus, transistor 14 will cease conducting. This raises the base voltage at transistor 13 causing it to be back biased and turned off hard. As can be seen, this portion of the operating cycle, like the first-described turn-on cycle, is regenerative.

Capacitor 22 is included in the circuit to speed up the regnerative action.

The frequency of the oscillator, in a typical construction, is adjusted to be at least 10 KHz. This will provide a continuous train of pulses at a rate sufficient to maintain the SCRs 3 and 4 in conduction when it is required that they be on. The oscillator is controlled by transistor 23 which has its collector connected to the emitter circuit of oscillator transistor 13. When transistor 23 is conducting, the oscillator will be inhibited from operating since the charging current for capacitor 18 will be shunted to ground. When transistor 23 is held in a non-conducting state, the oscillator will operate normally.

To facilitate describing the balance of the circuit, it will be convenient to consider the hard-start mode of operation. When an input voltage is applied to the oscillator in this mode of operation, the oscillator will generate a train of pulses until the input voltage is removed. This is accomplished as follows: The input voltage is applied to input terminal 24. This input voltage is applied to the base of transistor 25, via resistor 26, thereby turning it on. Once transistor 25 is turned on, transistor 23 will be turned off and thereby permit the oscillator to run. As can be seen, the collector of transistor 25 is connected to the base of transistor 23 via resistor 27. The other input to the base of transistor 23 is via diode 28 which is clamped to ground (2) via terminal 29, since this external connection is a prerequisite to the hard-start mode of operation.

If it is desired to operate the relay in the soft-start mode of operation, then the connection to the terminal 29 is lifted from ground. This will allow transistor 23 to remain conducting at all times by reason of the current flowing through resistor 31 and series diode 28, except when a negative pulse is applied through either capacitor 32 or capacitor 33.

As was stated earlier, in the soft-start mode it is necessary to turn on one SCR of the pair as soon as the

input control voltage is applied to terminal **24**, while at the same time delay fully turning on the other SCR of the pair for a predetermined interval. To accomplish this, the **10** KHz oxillator must run only for a short period during a single full cycle of the AC line voltage. This will permit only one of the SCRs to conduct. After a given period of time has elapsed, the oscillator will be allowed to run for two periods during each full cycle of the AC line voltage, namely at the beginning of each half-cycle of the line voltage. This action will permit both of the SCRs of the pair to conduct. As will be obvious, this requires that the oscillator be synchronized to a multiple of the AC line frequency.

Synchronization with the line frequency is provided by taking the **60** Hz line voltage at the anode of rectifier **16** and supplying it via resistor **34** to the base of transistor **35**. This will cause a **60** Hz squarewave to be produced at the collector of transistor **35**. This squarewave is inverted by transistor **36** and appears at the collector of transistor **36** whenever an input is applied to terminal **24**. When the input control voltage is applied (via terminal **24**), capacitor **32** will be charged through resistor **37** during the period that transistor **36** is off. When transistor **36** again conducts, which can be seen to occur at the beginning of the negative half of the AC line voltage cycle, the sudden turn-on causes the current flowing through resistor **31** (which is maintaining transistor **23** in the on condition) to momentarily flow into capacitor **32**. This action will allow transistor **23** to turn off, and the oscillator will run for a few cycles of operation (at 10 KHz), which is adequate to turn on (in this instance) SCR **4**. Also, when the input control voltage is applied, transistor **25** is turned on and thereby removes the charging current for capacitor **38**. The current from capacitor **38** has been maintaining transistor **39** in the on condition via resistor **41**. After an interval determined by the values of capacitor **38** and resistor **41**, transistor **39** is allowed to turn off. When transistor **39** is off, current can flow through resistors **42** and **43** to charge capacitor **33**. In this manner, when the collector of transistor **35** goes negative at the beginning of the positive half cycle of the AC line voltage, transistor **23** is held in an off condition momentarily by the diversion of the current into capacitor **33**. Thus, when the input control signal is first applied, the oscillator runs only at the beginning of the negative half cycle of the line voltage.

After the predetermined time constant period has elapsed, transistor **39** will turn off and the oscillator will then run at the beginning of both half cycles of the line voltage. This action will result in both SCRs being fully turned on.

Operating potentials are supplied to transistors **25** and **35** through resistors **44** and **45**, respectively. Also, resistors **46–48** provide bias for transistors **25**, **39** and **14**, respectively. The charging voltage for capacitor **38** is obtained via diode **49**.

If desired, a neon indicator lamp **51** may be connected, via series dropping resistor **52** between the AC neutral (ground) terminal **10** and the load to visibly indicate when the relay is conducting (turned on). Also, an optional noise suppression network, comprising series resistor **53** and capacitor **54**, may be shunt-connected across the SCRs **3** and **4**.

Referring to FIG. **2**, there is shown a schematic circuit diagram of an alternate embodiment of the invention in which the soft-start portion of the device more closely resembles the circuit of my aforementioned Delayed Turn-on Solid State Relay, than does the first-mentioned embodiment. However, as in the embodiment of FIG. **1**, the apparatus of FIG. **2** likewise employs an oscillator to provide the SCR gating signals. This circuit comprises terminals **55** and **56** which are connected in series with the AC power line and the load device (which in the usual case comprises a traffic signal lamp). Silicon controlled rectifiers **57** and **58** are connected in parallel so that their cathode/anode circuits are oppositely polarized. The first SCR (**57**) is directly controlled by the oscillator (to be described later), and the second SCR (**58**) receives its gate control signal from an associated slave circuit which accomplishes the gradual (soft-start) turn-on of the relay. This slave circuit comprises resistors **59**, **63** and **66**, capacitors **62** and **64**, and diodes **61**, **65** and **67**.

The control oscillator comprises transistors **71** and **72**. When the input control voltage (from an external circuit not shown) at terminal **68** is supplied the collector of transistor **72** via resistor **73**, the oscillator will immediately begin operating. The input control voltage supplies the operating potential for the oscillator, and is returned to terminal **74**. Reference is made to circuit descriptions on page **8**, paragraph **3**, through page **9**. The oscillator output control pulses are in the form of a square-wave pulse train supplied to the primary winding **81** of transformer **82**. These pulses, appearing at the secondary winding **83**, are supplied to the gate electrode of SCR **57** via the input network comprising resistors **84** and **85**

With terminal **55** connected to the AC line and terminal **56** connected to the external load, and with no input control signal applied to terminal **68**, on alternate half cycles of the AC line voltage, terminal **56** will be positive and negative with respect to terminal **55**. (Unless otherwise noted, the polarity of all voltages will be given with respect to terminal **55** in the discussion which follows).

When terminal **56** is negative, SCR **58** will not conduct since it is reverse-biased, and SCR **57** will not conduct since no control pulses are being received from the oscillator. Under these conditions, the AC line voltage appears across the anode-cathode of SCR **58**. Current then flows through diode **67** and resistor **66**, charging capacitor **64**. When capacitor **64** is charged, the voltage at the junction between capacitor **64** and resistor **66** will be negative.

As the voltage at terminal **56** decreases from its initial negative value, current will begin to flow through capacitor **64**, diode **65**, and capacitor **62**. Thus, in effect, part of the voltage stored by capacitor **64** is used to charge capacitor **62** to a voltage level which, at the junction of diode **61** and capacitor **62**, is negative with respect to terminal **56**. It is preferred that the value of capacitor **64** be much larger than that of capacitor **62** (e.g., 2.2. uf as compared to 0.22 uf), so that capacitor **64** does not completely discharge during this action.

When terminal **56** begins to go positive (during the alternate half of the AC line cycle), current does not flow in the path comprising resistor **59**, diode **61**, and capacitor **62**, until a voltage more positive than that with which the capacitor **62** is charged, is reached at terminal **56**. If there were no charge on capacitor **62**, the voltage at the gate of SCR **58** soon would be sufficiently positive to turn SCR **58** on. However, since there is a charge on capacitor **62**, the anode of diode

61 never reaches a sufficiently positive voltage to initiate forward conduction of diode 61, and hence SCR 58. That is, the voltage at terminal 56 never gets sufficiently positive to overcome the negative voltage to which capacitor 62 has been charged. Thus, in the absence of an input signal, the relay remains off.

When the oscillator is supplied with a control voltage (at terminal 68), the output squarewave pulse train will be supplied, via transformer 82, through resistor 84 to SCR 57. After the appropriate time delay, as determined by the above-described slave circuit, SCR 58 commences conduction, and the ensuing functioning is as previously described.

In the event that a hard-start mode of operation is desired, a second winding 86, and series resistor 87, is connected between terminal 55 and the gate electrode of SCR 58. Resistors 63 and 66, capacitors 62 and 64, and diodes 61, 65, and 67 are omitted from the circuit for hard-start operation. Thus, the application of gate control pulses, via secondary winding 86, will simultaneously turn on SCR 58 with SCR 57.

Noise suppression is obtained by shunting input terminal 68 to ground via capacitor 88. Also, as an option, neon indicator lamp 89 and current-limiting resistor 91 may be connected between the AC neutral terminal 56 and the high-side of the external load to visibly display the operation of the relay.

While the relays have been described as they may be applied to traffic signal controller systems, it should be understood that the novel and improved relay of the present invention may be used for many other and diverse applications, as will be readily appreciated by those versed in the art.

While particular embodiments of the invention have been shown and described, it will be obvious that those skilled in the art may readily make changes and modifications therein without the exercise of invention, and, therefore, the intent of the appended claims is to cover all such changes and modifications as may properly fall within the true spirit and scope of the invention.

What is claimed is:

1. A dual-mode solid state relay comprising:
first and second silicon controlled rectifiers connected in parallel with their respective cathode/anode electrodes oppositely polarized;
oscillator means for generating a train of control pulses at a pulse repetition rate exceeding the turn-off time of said silicon controlled rectifiers;
first means for selectively applying said control pulses to the gate electrode of said first silicon controlled rectifier in response to an external control signal;
delay means for applying said control pulses to the gate electrode of said second silicon controlled rectifier at a given time following the application of said external control pulse, in a first, soft-start, mode of operating said relay;
second means for selectively applying said control pulses to the gate electrode of said second silicon controlled rectifier, simultaneously with the activation of said first control pulse applying means, in response to said external control signal in a second, hard-start, mode of operating said relay; and
means for connecting said first and second silicon controlled rectifiers in series with an external load and an alternating-current power source.

2. A dual-mode solid state relay as defined in claim 1 including:
pulse transformer means having a primary winding connected to the output of said oscillator means, a first secondary winding comprising said first control pulse applying means, and a second secondary winding comprising said second control pulse applying means.

3. A dual-mode solid state relay as defined in claim 1 wherein said delay means comprises:
a transistor switch synchronized to the frequency of said alternating-current power source for inhibiting operation of said oscillator means during a portion of each full cycle of said power source.

4. A dual-mode solid state relay as defined in claim 1 including:
indicator means shunted connected across said first and second silicon controlled rectifiers to visibly display the operating state of said relay.

5. A dual-mode solid state relay as defined in claim 1 including:
first and second equalizing resistors, of substantially equal value, connected in series between each of said control pulse applying means and its corresponding gate electrode to provide equal distribution of the control pulses applied thereto.

6. A dual-mode solid state relay as defined in claim 3 including:
means for inhibiting the operation of said transistor switch during the second, hard-start, mode of operating said relay.

7. A dual-mode solid state relay as defined in claim 1 including:
pulse transformer means having a primary winding connected to the output of said oscillator means, a first secondary winding connected to the gate and cathode electrodes of said first silicon controlled rectifier, and a second secondary winding connected to the gate and cathode electrodes of said second silicon controlled rectifier.

8. A solid state relay comprising:
first and second silicon controlled rectifiers connected in parallel with their respective cathode/anode electrodes oppositely polarized;
oscillator means for generating a train of control pulses at a pulse repetition rate exceeding the turn-off time of said silicon controlled rectifiers;
pulse transformer means having a primary winding connected to the output of said oscillator means, a first secondary winding connected to the gate and cathode electrodes of said first silicon controlled rectifier, and a second secondary winding connected to the gate and cathode electrodes of said second silicon controlled rectifier;
delay means for selectively turning said oscillator means on and off in response to an externally applied control signal including a transistor switch synchronized to the frequency of an alternating current power source; and
means for connecting said first and second silicon controlled recitifiers in series with an external load and an alternating-current power source.

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