

[54] **THYRISTOR CIRCUITS FOR APPLYING A VOLTAGE TO A LOAD**

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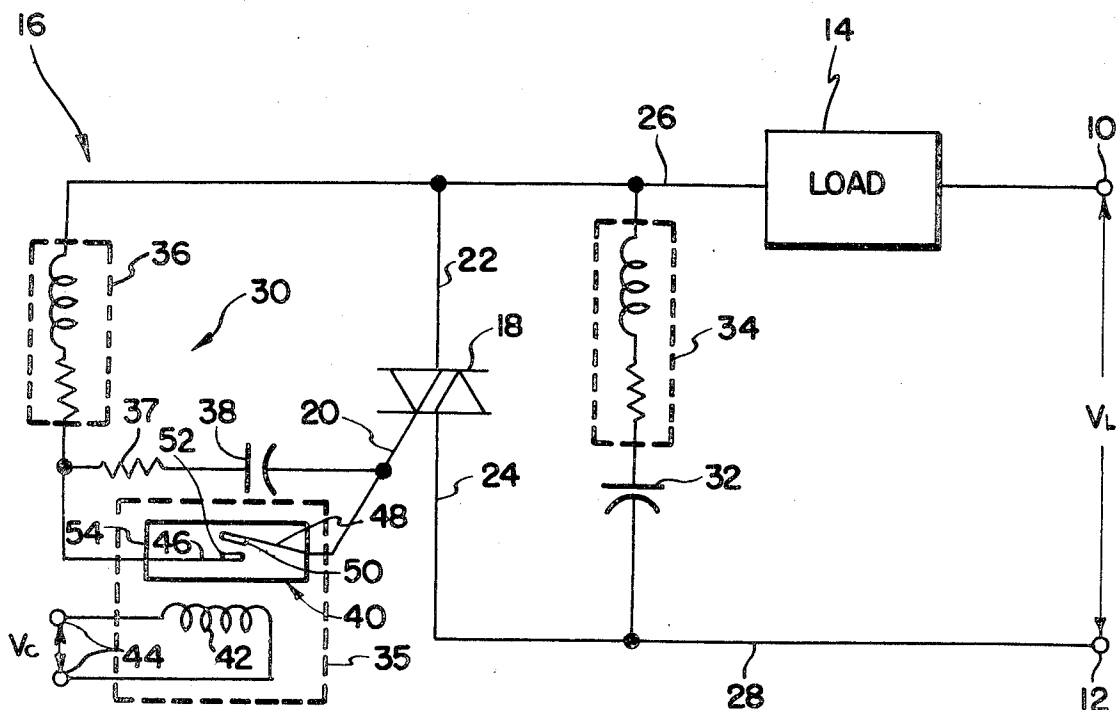
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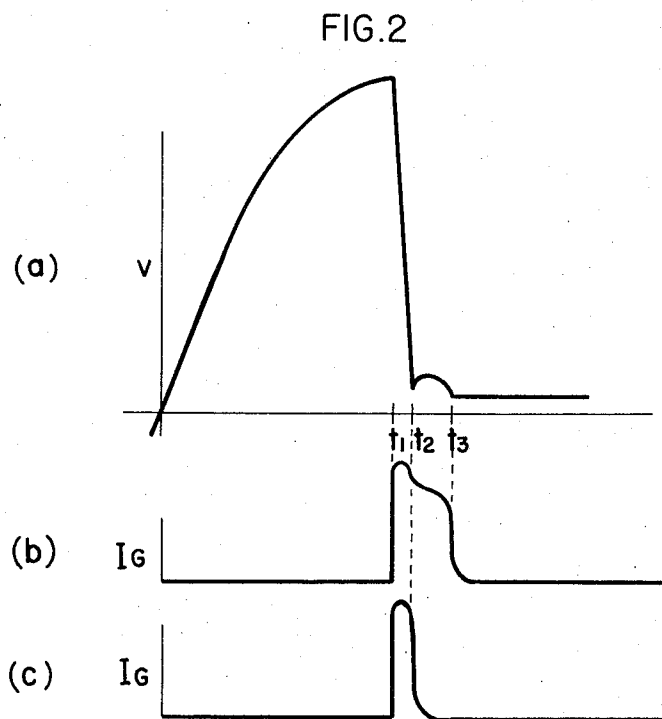
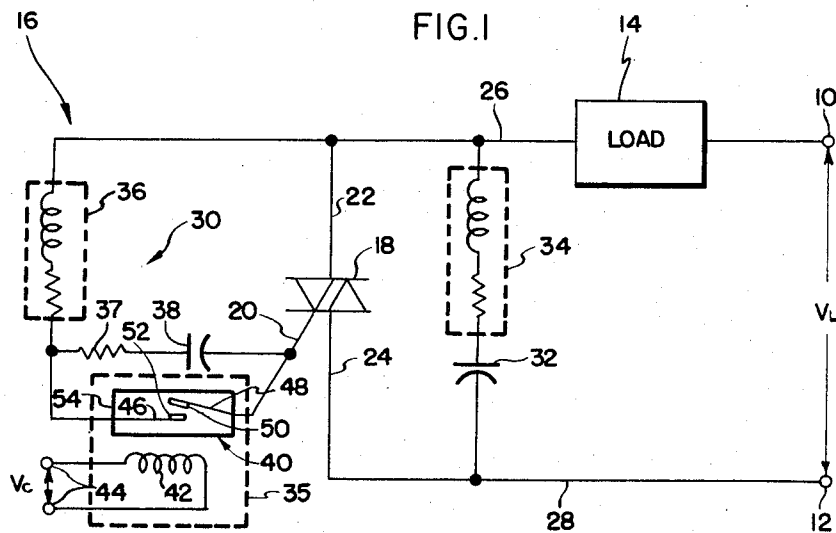
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[57] **ABSTRACT**

Thyristor circuits are disclosed for applying a voltage to a load wherein substantial improvements are provided with respect to increasing the operating life of switch contacts employed therein. A reduction in the amount of radio frequency interference generated in such circuits upon circuit switching may also be obtained. Such improvements are provided by the appropriate use of one or more inductors in the circuits, which may be employed together with certain other circuit components.

21 Claims, 2 Drawing Figures





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THYRISTOR CIRCUITS FOR APPLYING A VOLTAGE TO A LOAD

The present invention relates generally to improved circuits for applying an electrical voltage to a load, and more particularly to such circuits employing a thyristor for performing switching or phase control functions. This application is a division of Ser. No. 108,269, filed Jan. 21, 1971, assigned to the assignee hereof, and now abandoned.

The present embodiment of the invention relates to such circuits utilizing a switch having mechanical contacts, such as a hermetically sealed reed switch, as a control element for selectively switching or applying a switching or triggering signal to the control or gate terminal of a thyristor.

The use of hermetically sealed reed switches as control elements for thyristors, such as silicon controlled rectifiers (SCR's) and triacs, has become conventional in many types of circuits. Such reed switches have generally been considered as offering many advantages over other forms of control devices, and indeed they do, since, in addition to their small size, they can typically be actuated by passing A.C. or D.C. through a small winding thereabout, or by the placement of a small magnet in proximity thereto. While, at the same time, they can maintain complete electrical isolation between the control signal input and the switched power output of the circuit. Moreover, it has also been generally considered that a long operating life was assured the thyristor-reed switch combination by the minimal volt-ampere switching load placed on the reed switch by the SCR or triac triggering requirements, which are well within the normal ratings of conventional reed switch designs. This is discussed, for example, in the *General Electric SCR Manual*, 4th Edition, 1967, pp. 143-144, published by the Semiconductor Products Department of General Electric Company, Syracuse, New York.

However, it has been found that although the rate or percentage of failures of such reed switch circuits is generally low, it is still high enough to be significant in many situations. Also, the operating life of reed switches in such circuits appears to be substantially less than would normally be expected from a consideration of the circuit parameters. This is especially a problem where a large number of such circuits are employed in a single, complex apparatus, thus tending to reduce significantly its overall reliability.

Such switch failures have heretofore been generally attributed to merely defective reed switch constructions, since the applied voltages and loads normally employed with such thyristor-reed switch circuits would not be expected to cause gate currents which could exceed the switch contact ratings. However, the measurement of the thyristor gate current in such circuits and the observation of the reed switch upon switch closure has lead to my recognition and belief that the switch failures have not generally been due to latent switch defects, but to contact destruction from burning, pitting, sputtering or other forms of contact degradation. Furthermore, I believe that such contact degradation is due to arcing within the reed switch prior to complete switch closure caused by extremely high frequency gate currents (i.e., in the gigahertz range) which may be generated in the thyristor gate circuit. Such high

frequency currents as I have detected may be generated by the negative resistance effects produced by the electrical discharge through the gas within the hermetically sealed reed switch, and the initial high current surge for the discharge appears to be produced in the gate circuit upon or during switch closure by the abrupt discharging of the capacitor circuit typically connected across the thyristor load terminals for commutation purposes, as well as of the inherent junction capacitance of the thyristor. In A.C. circuits I believe this action occurs to the greatest extent when by chance the reed switch is actuated for closure at a moment in time when the line voltage to the thyristor circuit is at or near its peak, so that the commutation capacitor for reducing the dv/dt across the thyristor, and the thyristor itself, have a relatively large charge. However, it also occurs during the other portions of the line voltage cycle, and the degree of arcing appears to be proportional to the instantaneous amplitude of the line voltage at the moment of switching.

More particularly, the damaging and sputtering of the reed switch contacts caused by this arcing phenomenon results in substantially decreasing the useful operating life of the reed switch, and consequently of the circuitry of the device or apparatus with which it might be employed. Also, where the switch contacts are perhaps close to their extremes in operating tolerances, or where their operation may be otherwise marginal, this phenomenon may cause the switch to fail in a relatively short operating time after its initial operation. For A.C. operation, the shortening of the useful contact life may be related to the probability of switch closure during portions of the voltage cycle when its magnitude is sufficiently high to cause the greatest discharge and arcing intensity.

Additionally, from my observation of the high frequency components of current which appear to be present in the thyristor gate circuit upon switching, I believe that the gate circuit of thyristor switching and phase control circuits, generally provide a substantial contribution to the total radio frequency interference (RFI) that such circuits typically produce. This contribution to RFI would then be present in conventional thyristor switching and phase control circuits employing, for example, a triac having a switch connected in its gate circuit for triggering the triac in response to a given signal.

Accordingly, it is one object of the present invention to improve the operating life of a mechanical switch, such as a conventional hermetically sealed reed switch, in thyristor circuits used for applying a voltage to a load.

It is another object of the invention to provide improved thyristor circuits producing a minimum of radio frequency interference.

It is a further object of the invention to provide an improved circuit for applying a voltage to a load impedance, which circuit employs a thyristor-reed switch combination wherein the reed switch has a substantially greater operating life than has heretofore been the case, thus significantly increasing the reliability of the circuit.

These and other objects of the invention are more particularly set forth in the following detailed description and the accompanying drawings of which:

FIG. 1 is a schematic diagram showing a thyristor switching circuit in accordance with one embodiment of the present invention including certain optional components; and

FIG. 2 is a graphical representation showing voltage and current as a function of time at certain points in the circuit of FIG. 1.

In general, referring to FIG. 1, there is shown a circuit for applying an A.C. voltage V_L across terminals 10 and 12 to a load impedance 14 through a thyristor circuit 16. The thyristor circuit 16 is a selectively controlled switching circuit and comprises a thyristor, illustrated as triac 18, having a control or gate terminal 20 and a pair of load terminals 22 and 24, which may be referred to hereinafter as the anode and cathode, respectively. First or load circuit means, illustrated as conductive connections 26 and 28, couples the voltage source V_L to the load 14 through the pair of triac load terminals 22 and 24. Second or gate circuit means, designated generally as 30, couples the triac gate terminal 20 to one of the triac load terminals, such as anode 22 as shown, to provide triggering signals for the triac which render the same conductive in a manner well known to the art, applying the voltage V_L to the load 14. To limit the dv/dt for commutation purposes, and to enable the circuit to operate with inductive loads, a shunt capacitor 32 is connected across the triac 18 as is also known; but in the present circuit, for reasons to be hereinafter explained, the capacitor is connected in series with an inductor 34 rather than a resistor as is conventional in such circuits.

The second or gate circuit means 30 includes switching means, illustrated as a reed relay 35, connected in series circuit relation to the triac gate terminal 20 and the triac anode 22, and an inductor 36 is also connected in series circuit relation to the switching means 35 in the gate circuit. The gate circuit 30 further comprises a series connected combination of a resistor 37 and a capacitor 38 in parallel circuit relation to the reed relay 35. The action of the series inductor and the shunt RC network substantially increases the life of the reed switch by eliminating the chance of contact sputtering or degradation by high frequency current components in the initial discharge of capacitor 32 and the junction capacitance of triac 18. Further, this same increase in switch life may alternatively be achieved without the use of the shunt RC network 37, 38 by employing an inductor 36 with a sufficiently high Q, as will be discussed in greater detail hereinafter.

More particularly, the reed relay 35 is of a conventional type comprising a hermetically sealed reed switch 40 and a coil 42 which is normally wound about the reed switch 40 and terminates in terminal pair 44 to which a suitably switched energizing control voltage V_C is applied. Application of the appropriate voltage V_C to relay terminals 44 energizes the coil 42 which generates a magnetic field which, in turn, causes the contacts of the reed switch 40 to close. The reed switch 40 conventionally comprises two conductive reeds 46 and 48 of magnetic material having respective electrical contacts 50 and 52 disposed in mutually facing relation at the overlapping adjacent ends thereof. The contacts 50 and 52 are typically composed of gold with rhodium, silver or tungsten cladding or plating, or of gold on some other base metal. The opposite ends of

the respective reeds 46 and 48 are supported in and extend through the opposing ends of an elongated glass housing 54 which hermetically seals the reed switch and maintains a predetermined environment therewithin. Such conventional reed switches typically contain a gaseous environment consisting essentially of nitrogen at pressures ranging from 1 to 6 atmospheres. Also, such switches may sometimes have an evacuated environment so that the space within the glass housing is at a substantially reduced or very low pressure relative to one atmosphere.

In conventional thyristor switching circuits of the general type on which the circuit of FIG. 1 is an improvement, the elements 34 and 36 would typically be resistors rather than inductors and the RC circuit 37, 38 would be omitted. When such conventional thyristor circuits are triggered by closure of the reed switch, especially at or near the peak or maximum line voltage, I have observed white arcing or lightning-like flashes, containing possibly a trace of red, within the glass reed switch enclosure 54. This arcing or flashing appears to occur after the reed relay is energized, but before the contacts 50 and 52 of the reed switch are completely closed. Such arcing results in substantial degradation or deterioration of the reed switch contacts, such as from burning and pitting, and accounts for otherwise unexpected failures of such circuits in view of the generally random relation between the energization of the reed relay and the instantaneous value of the line voltage.

With the addition of the inductance provided by the inductor 36 to the conventional aforementioned thyristor circuit, the arcing or flashing previously observed in the reed switch is eliminated, but is replaced by a blue glow discharge. While it is believed that the contact degradation from the glow discharge will be less than that caused by the arcing, still the sputtering off of the plating or cladding of the switch contacts may well occur to some extent within such an ionic glow discharge. Thus, the presence of the inductor 36 in the gate circuit of the triac 18 will increase the useful operating life of the reed switch 35, and consequently of the thyristor circuit, since it causes the highly damaging arcing phenomenon to be replaced by a less damaging glow discharge phenomenon upon energization of the reed relay.

Now, with the further addition of the series resistance-capacitance circuit 37, 38 in shunt with the reed switch 40, the glow discharge is eliminated, even upon reed switch actuation at the peak line voltage. Consequently, no sputtering or contact degradation is believed to take place with these additional components, and the useful operating life of the reed switch is now merely a function of its mechanical construction.

As a further improvement, I have also found that the resistor 37 and capacitor 38 can be eliminated, while still preventing the glow discharge in the reed switch 40, by selecting a coil for inductor 36 with appropriate frequency and Q characteristics. For example, a 10 mh coil (70F 102Al of J.W. Miller Company, Compton, California) having a minimum Q of 41 at 250 kHz., a resonant frequency not less than 0.52 MHz., and a D.C. resistance of about 101 ohms, performed satisfactory in the gate circuit of a triac switching circuit controlled by

a conventional reed switch operating at the peaks of 100 volts r.m.s. line voltage. No arcing or glow discharge was observed, even without any RC circuit across the switch. For relatively low Q coils, however, the RC circuit as illustrated will generally be required. Thus, if desired, the Q and frequency characteristics of the coil to eliminate the RC network across the switch may be empirically determined for any specific circuit construction by trying coils of increasing Q until a sufficiently high Q is obtained, when the glow discharge within the reed switch upon closure is eliminated. The coil may thus function to choke or damp the high frequency current components which appear to be produced in the gate circuit, and to eliminate the cause of the ionic glow discharge between the reed switch contacts during closure.

I have further found that the presence of the inductor 36 in the thyristor gate circuit substantially reduces or eliminates the radio frequency interference (RFI) which appears to be typically produced in the gate circuit of the triac. While the generation of RFI in such circuits has been commonly attributed to the voltage and current switching of the load (i.e., to the triac load circuit), it has been my observation that a significant, if not principal, contribution to the total RFI of the circuit is caused by the gate circuit of the triac. And it is this component or contribution which is now eliminated by the inductor 36 serially connected with the reed switch 40 between the triac anode 22 and the gate 20.

More specifically, without the inductor 36 or the RC circuit 37, 38 in the thyristor switching circuit of FIG. 1, and with a 100 ohm current limiting resistor substituted for the inductor 36, a triac gate current pulse at 20 is produced on reed switch closure at peak line voltage (110 v.r.m.s.) which has a magnitude of approximately 1.0 ampere and a duration of 1.5 microseconds. And this occurs regardless of the particular load 14, i.e., whether the load is of relatively low resistance, such as is provided by a 15 amp. lamp, or a high resistance, such as a 10 K ohm resistor. I noted that when the reed switch 40 was pressurized, such as to 6 atmospheres, the gate current in-rush was somewhat higher than when the reed switch was of the so-called back-filled type having one atmosphere pressure. However, in either case the addition of inductor 36 having a resistance equal to 100 ohms and an inductance of 10 mh in series with the reed switch 40 reduces the initial peak current surge to approximately 50 percent of that occurring without the inductor and, further, reduces the duration of the pulse to approximately 0.1 microsecond.

Referring, more particularly, to FIG. 2, there is graphically shown in FIG. 2(a) a portion of the voltage V appearing across the triac 18 in the circuit of FIG. 1, but with resistors for the inductors 36 and 34 and without the RC circuit 37, 38. The load 14 is assumed to be resistive. Also, it is assumed that the reed relay 35 is energized by voltage V_c so that the reed switch 40 closes when the voltage V is at or near its maximum at the time t_1 . At the same time, the gate current to the triac 18 is shown in FIG. 2(b) where the gate current is shown to rise steeply at time t_1 . The voltage V across the triac 18 falls off rather sharply to a minimum at time t_2 which occurs approximately 0.1 microseconds

from t_1 . During this 0.1 microsecond interval the gate current rises to a peak of about 0.9 amperes. The gate current then decreases gradually until time t_3 approximately 1.5 microseconds after t_1 , at which time the gate current drops off rapidly to approximately zero. During the time interval between t_2 and t_3 the voltage V across the triac 18 increases gradually to about 2 volts and then decreases again to the normal 1 volt drop across the triac when it is in its conductive state.

FIG. 2(c) illustrates the gate current at the triac gate 20 when the reed relay 35 is replaced by a semiconductor switch, such as silicon controlled rectifier in a full-wave bridge circuit. As can be seen, for turn-on at time t_1 the gate current again rises sharply to a value of 0.9 amperes and then decreases rapidly after a duration of 0.1 microseconds. However, during the period $t_3 - t_2$ the gate current goes to approximately zero. Thus, it can be seen that the switching of the triac 18 by means of the reed switch 35 causes a different circuit operation than if the triac were switched by some other means. The switching of the reed switch, with its mechanical contacts, and the arcing phenomenon occurring during the switch closure appears to be the cause of the extended current pulse and its particular shape as shown in FIG. 2(b), which may be the result of the gas discharge characteristic of the reed switch.

The graphs of FIGS. 2(a) and 2(b) correspond to circuits having reed switches as described with environmental pressures of 6 atmospheres. For switches of the one atmosphere type, the wave forms are similar, but the gate current pulses appear to diminish in amplitude with the operating life of the switch. The wave forms resulting from the so-called evacuated or "vacuum" reed switches are essentially the same as those for the one atmosphere switches, since they are probably not completely evacuated.

The addition to the circuit of the series resistance and capacitor combination 37, 38 in shunt with the reed switch 40 appears to act together with the inductor 36 to further prevent an initial high current surge on closure of the reed switch contacts 50 and 52 and may act as a by-pass filter for the high frequency current components which I believe are generated in the gate circuit during switch closure. It may be noted that although RC networks are conventionally employed in some circuits across switch contacts to prevent arcing on opening of the contacts (especially where power is being removed from an inductive load), in the present circuit the RC network is provided for the prevention of current surges on closure of the contacts.

Although the inductor 36 may be employed in the triac gate circuit without the optional RC circuit 37, 38 to obtain partial or full advantages as hereinbefore discussed, the provision of the RC circuit 37, 38 without the inductor 36 appears to have no effect or improvement on the conventional circuit operation. Also, I have noted that a 0.2 ampere high frequency noise or "hash" may still appear in some cases on the leading and trailing edges of the gate current pulses. However, most of this hash can be eliminated by connecting a resistor in parallel with the inductor. In the illustrated circuit, a 3,300 ohm resistor worked satisfactorily.

The inductor 34 in the commutation circuit optionally replaces the 100 ohm resistor typically used in

series with a 0.1 mfd. capacitor, such as 32, in such circuits to further damp and impede the high frequency components of the initial current discharged from the capacitor 32 upon closure of the reed switch contacts 50, 52. Since the charge which is stored in the commutation capacitor 32 may significantly contribute to the initial current in-rush when the reed switch is closed, the delaying action of the inductor 34 aids the action of the inductor 36, as a secondary measure, assuring that no arcing will take place within the reed switch. The use, if desired, of inductor 34, which may be of the same value as the gate circuit inductor 36, in an RLC commutation circuit as shown, also provides an additional advantage of improved commutation or shut-off as compared with the typical RC commutation circuit conventionally employed.

With respect to component values for the circuit of FIG. 1, the inductor 36 preferably has an inductance of from 1 to 100 mh and a resistance of approximately 100 ohms. The resistance of the inductor 36 may be selected as in conventional designs to be just greater than the peak supply voltage divided by the peak gate current rating of the thyristor device, being typically 100 ohms. The values of the resistor and capacitor in the RC circuit 37, 38 are preferably determined by selecting the value of resistor 37 to minimize the fuse function i^2t to provide, for example, a 50 milliamp gate current for one microsecond. Thus, the capacitor 38 may preferably have a value of 0.001 mfd. and the resistor 37 a resistance value of 100 ohms or 10 K ohms. I have found that excellent results are obtained with either of the two alternate values of resistance. However, in any particular circuit design, the optimum component values may be determined empirically by observing the gate current on an oscilloscope while switching the gate current circuit on line voltage peaks.

Although the principles of the present invention were tried and found to be applicable to the following reed switches employed for testing, they are believed to be generally applicable to all reed switches and their associated thyristor circuitry for applying a voltage to a load impedance:

Hamlin, Inc., Lake Mills, Wis.

Gordos Corp., Bloomfield, N.J.

C.P. Clare, Chicago, Ill.

General Electric, Owensboro, Ky.

MRR-5	6 atmos.
MRO-2	evacuated
MRR-2	1 atmos.
MR 138	6 atmos.
MRO 88	1 atmos.
pico reed	1 atmos.
DR 123	1 atmos.

The principles of the present invention relative to improving the operating life of reed switches are also believed to be applicable to mechanical contact switches generally, such as, for example, conventional relay or switch contacts disposed in the ambient air environment.

Although several specific embodiments of the present invention have been illustrated and described, various modifications and applications thereof will be apparent to those skilled in the art; accordingly, the present invention should be defined only by the appended claims and equivalents thereof.

Various features of the invention are set forth in the following claims.

What is claimed is:

1. A circuit for applying a voltage to a load, comprising a thyristor having a control terminal and a pair of load terminals, first circuit means for coupling a voltage source to a load through said pair of thyristor load terminals, and second circuit means for coupling said thyristor control terminal to one of said thyristor load terminals to provide a triggering signal for said thyristor derived from said voltage source, said second circuit means including contact switching means and an inductor connected in conductive series circuit relation between said control terminal and said one thyristor load terminal for preventing arc discharge in said contact switching means upon contact closure.

2. The circuit of claim 1 wherein said contact switching means comprises a pair of mechanical contacts normally having an arc or glow discharge occurrence therebetween upon closure, and said inductor being of sufficiently high Q to prevent the occurrence of said discharge.

3. The circuit of claim 2 wherein said contact switching means comprises a reed switch having said pair of mechanical contacts.

4. The circuit of claim 1 wherein said contact switching means comprises a pair of mechanical contacts and said second circuit means further comprises a series connected resistor and capacitor in parallel circuit relation to said contacts.

5. The circuit of claim 1 wherein a series connected capacitor and inductor combination is connected in parallel circuit relation to said thyristor load terminals.

6. The circuit of claim 4 wherein said contact switching means comprises a reed switch having said pair of mechanical contacts.

7. A circuit for applying a voltage to a load, comprising a thyristor having a control terminal and a pair of load terminals, means for applying the voltage source to the load through said pair of thyristor load terminals, a capacitor circuit coupled across said pair of thyristor load terminals, and means for coupling said thyristor control terminal to one of said thyristor load terminals through mechanical contact switching means conductively series connected to an inductor to provide a triggering signal for said thyristor derived from said voltage source, said inductor preventing high frequency arc discharge in said contact switching means upon contact closure.

8. The circuit of claim 7 wherein said switching means comprises a hermetically sealed reed switch normally producing a glow discharge therein due to high frequency current components flowing therethrough, and said inductor being such as to inhibit said current components to prevent the occurrence of said glow discharge in said switch.

9. The circuit of claim 7 wherein said switching means comprises a hermetically sealed reed switch normally producing a glow discharge therein due to high frequency current components flowing therethrough, and a further capacitor circuit coupled across said reed switch for causing said current components to by-pass said switch to prevent the occurrence of said glow discharge therein.

10. The circuit of claim 7 further comprising an additional inductor connected in series with a capacitor in said capacitor circuit, and the series combination being coupled across said pair of thyristor load terminals.

11. In a thyristor circuit for applying a voltage to a load, comprising a thyristor having a control terminal and a pair of load terminals, commutation circuit means including a capacitor connected across said thyristor load terminals, load circuit means coupled to said thyristor load terminals for responsively switching a voltage source to the load in accordance with the state of said thyristor, gate circuit means for selectively coupling said thyristor control terminal to one of said thyristor load terminals through switch contacts to provide a triggering signal derived from said voltage source to effect the state of said thyristor, the improvement wherein said gate circuit means comprises an inductor conductively connected in series circuit relation to said switch contacts between said control terminal and said one thyristor load terminal so that the signal derived from said voltage source is conducted to said control terminal through said inductor upon closure of said switch contacts, and said inductor prevents high frequency arc discharge between said contacts upon closure.

12. In the thyristor circuit of claim 11, said inductor having a sufficiently high Q to prevent glow discharge between said switch contacts upon closure.

13. In the thyristor circuit of claim 11, said gate circuit means further comprising a series connected resistor and capacitor combination connected in parallel circuit relation to said switch contacts to prevent glow discharge between said contacts upon closure.

14. In the thyristor circuit of claim 11, said commutation circuit means including an inductor connected in series with said capacitor.

15. A circuit for applying a voltage to a load, comprising a triac having a gate, an anode and a cathode, a commutation circuit including a capacitor connected across the anode and cathode of said triac, means for coupling the anode and cathode in circuit relation to the load to apply a voltage source thereto in accordance with the state of said triac, and a series circuit combination of an inductor and a reed switch conductively connected between the anode and the gate of said triac to provide a triggering signal thereto.

16. The circuit of claim 15 wherein said inductor has a sufficiently high Q to prevent glow discharge between the switch contacts of said reed switch upon closure.

17. The circuit of claim 15 further comprising a series connected resistor and capacitor combination connected in parallel circuit relation to said reed switch to prevent glow discharge between the contacts thereof upon closure.

18. The circuit of claim 15 wherein said commutation circuit includes an inductor connected in series with said capacitor.

19. A circuit for applying line voltage to a load, comprising a thyristor having a pair of load circuit terminals and a gate terminal; a load circuit coupled to said load circuit terminals for applying the line voltage to the load in response to the thyristor being in a conductive state; and a gate circuit including switch contacts and an inductor connected in conductive series circuit relation between said gate and the line voltage for supplying, from the line, a gate driving current through said inductor to effect said conductive state of the thyristor, said inductor preventing high frequency arc discharge between said contacts upon closure.

20. A circuit for applying a voltage source to a load, comprising a thyristor having an anode, a cathode, and gate terminal; first circuit means coupled to said anode and cathode for applying said source to the load in response to the thyristor being in a conductive state; and second circuit means including switch contacts and an inductor for selectively applying a gate drive signal derived from said source to said gate terminal through said inductor to effect said conductive state of the thyristor, said inductor having a sufficiently high Q to prevent glow discharge between said contacts upon actuation.

21. A circuit for applying a voltage to a load, comprising a thyristor having a control terminal and a pair of load terminals, first circuit means coupled to said load terminals for applying a voltage source to the load in response to the thyristor being in a conductive state; second circuit means including switch contacts and an inductor connected in conductive series circuit relation between said control terminal and one of said load terminals; and means storing a charge in response to said voltage source and discharging through said second circuit means upon closure of said switch contacts, said inductor preventing high frequency arc discharge between said contacts upon closure.

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