

April 1, 1969

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3,436,609

ELECTRONIC ALTERNATING CURRENT SWITCH

Filed Dec. 16, 1966

Sheet 1 of 3

Fig. 1

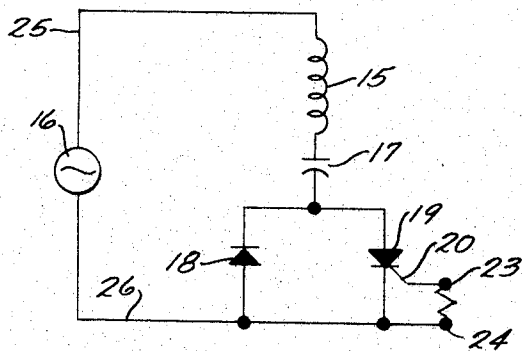


Fig. 2

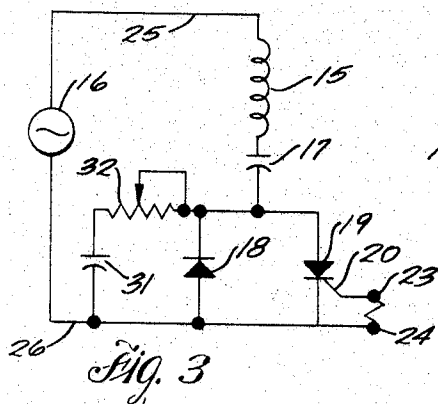
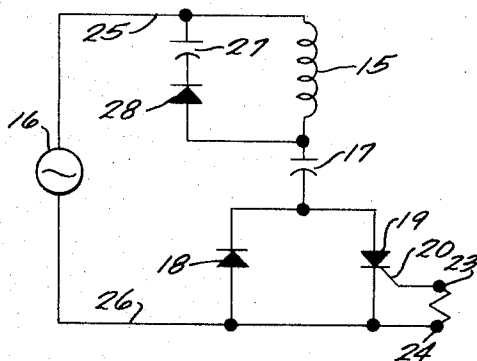


Fig. 3

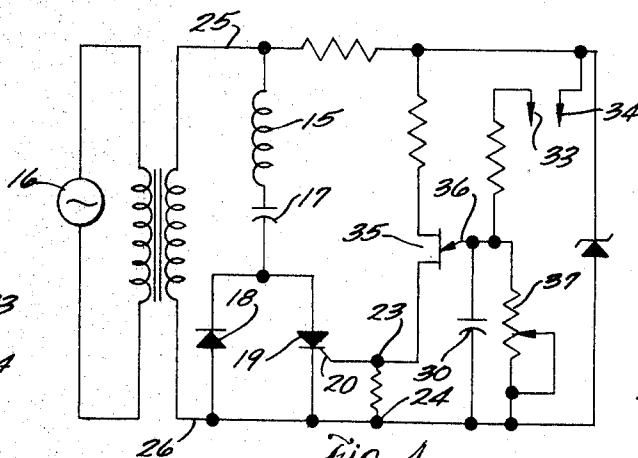


Fig. 4

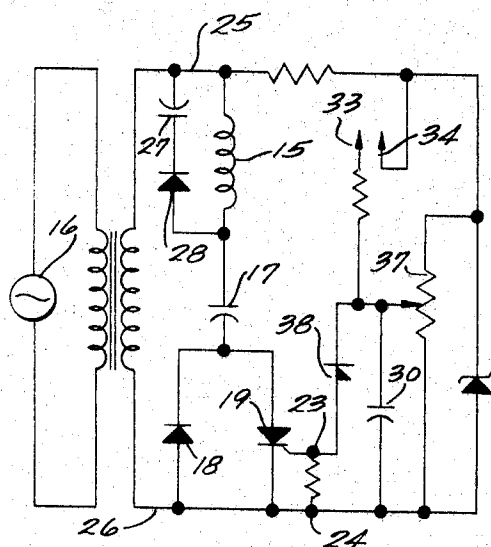


Fig. 5

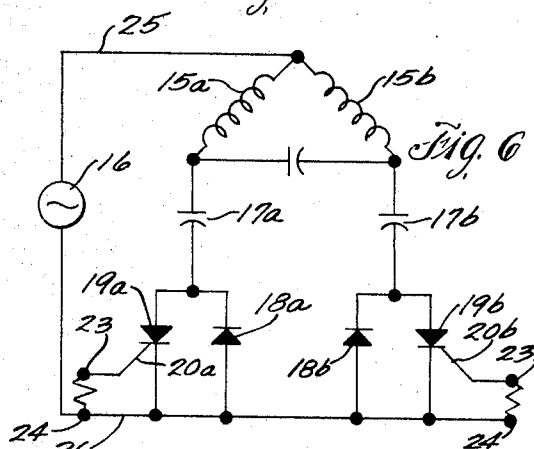


Fig. 6

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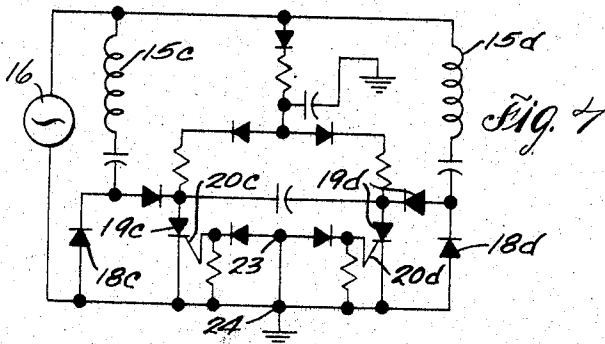


Fig. 7

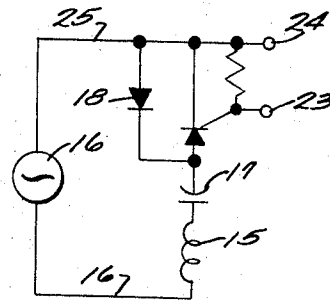


Fig. 8

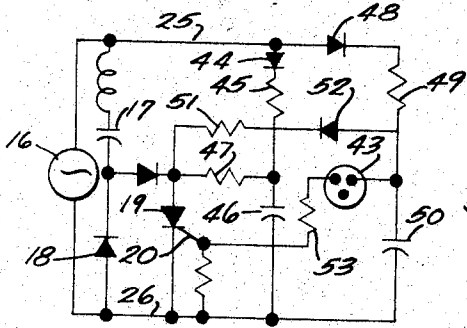


Fig. 9

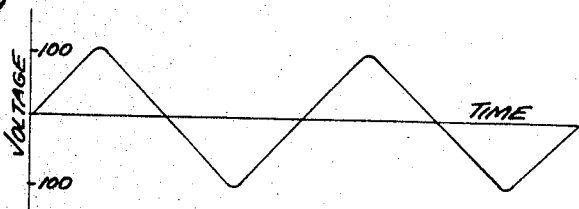


Fig. 10

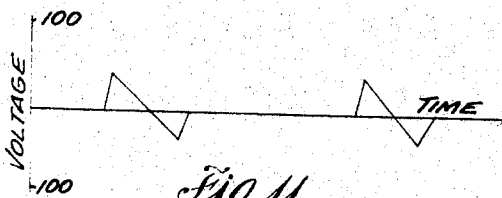


Fig. 11

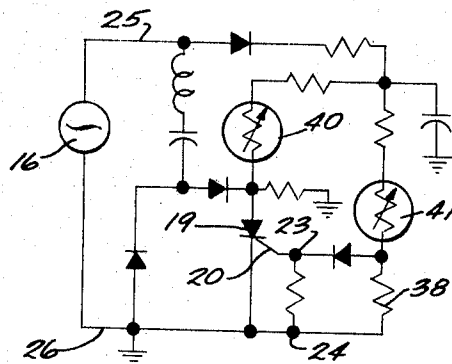


Fig. 12

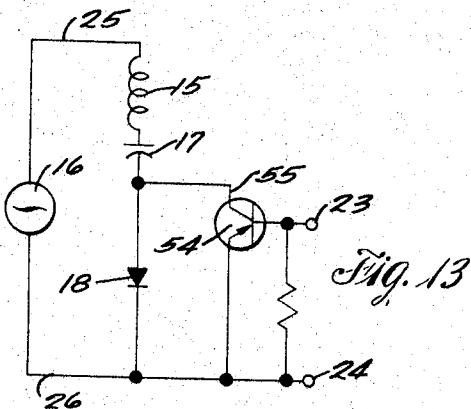


Fig. 13

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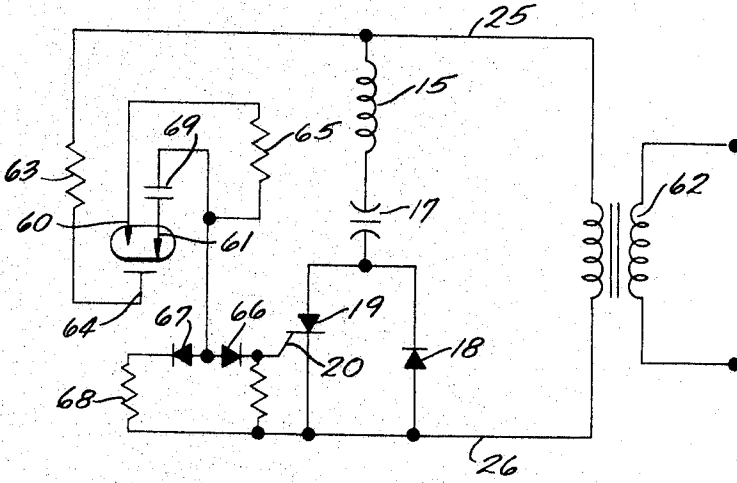


Fig. 14

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ELECTRONIC ALTERNATING CURRENT SWITCH
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U.S. Cl. 317-148.5

16 Claims

ABSTRACT OF THE DISCLOSURE

The electronic A.C. switching circuit disclosed herein controls application of power to an inductive load. The basic circuit has, in series with the load, a capacitor and a network including in parallel connection a diode rectifier and a gate-controlled, semi-conductor switch. Various elaborations of the basic circuit for specific uses are also disclosed.

Background of the invention

An S.C.R. or like gate-controlled, semi-conductor switch has been used in the past to control the flow of alternating current through an inductive load. Prior circuitry of this type typically embodies a bridge rectifier in conjunction with an S.C.R. or two S.C.R.'s connected in parallel inverse. Such circuits are not adapted to control alternating current flow at radio frequencies. Moreover, even in low frequency situations, they involve more costly components than in the circuit of the present invention and are not as versatile.

Summary of the invention

The electronic controller of the present invention features a capacitor in series with the inductive load. The load and capacitor are further in series with a network including in parallel a diode rectifier and a gate-controlled, semi-conductor switch, such as an S.C.R. The rectifier and capacitor filter the A.C. to impose a D.C. charge upon the S.C.R. The capacitor is particularly advantageous at high frequencies, for example, above 20 kcs. Accordingly, an S.C.R. control element can be used in environments in which the time delays inherent in S.C.R. operation would otherwise not permit its use in R.F. control.

While the circuit is particularly advantageous for R.F. applications, it is also useful and finds versatile application in low frequency applications, such as 60 cycle alternating current.

Various embodiments of the invention are disclosed herein. All of the embodiments include the basic circuit aforesaid. Some of these are elaborated for various specific uses as hereinafter indicated.

Drawings

FIG. 1 is an electric circuit diagram of the basic circuit of the invention.

FIG. 2 is an electric circuit diagram similar to that of FIG. 1, but showing a modification in which the initial charging current is bypassed around the inductive load.

FIG. 3 is an electric circuit diagram similar to FIG. 1 showing a latching circuit in parallel with the gate-controlled, semi-conductor switch.

FIG. 4 is an elaboration of the basic circuit of FIG. 1. This circuit shows a signal source for the gate of the semi-conductor switch utilizing a sensitive uni-junction transistor for control of the S.C.R.

FIG. 5 is a circuit diagram similar to FIG. 4, but showing a different form of sensitive control utilizing a Shockley diode in place of the uni-junction transistor.

FIG. 6 is an electric circuit diagram showing an elaboration of the basic circuit for control of a dual field coil motor, such as a servo-motor, for forward and reverse control of motor speed and direction.

FIG. 7 is a further elaboration of the basic circuit of FIG. 1 in which two such circuits form an A.C. flip-flop circuit.

FIG. 8 is a circuit diagram similar to FIG. 1, but showing the polarity of the semi-conductor elements inverted as compared to FIG. 1.

FIG. 9 is a further elaboration of the basic circuit of FIG. 1 in which the control of the gate of the S.C.R. includes time delay components.

FIG. 10 is a time-voltage graph showing one condition of operation of the circuit of FIG. 1.

FIG. 11 is a time-voltage graph showing another condition of operation of the circuit of FIG. 1.

FIG. 12 is a further elaboration of the basic circuit of FIG. 1 adapted for use in liquid level control.

FIG. 13 is an electric circuit diagram similar to FIG. 1, but showing a transistor in place of the S.C.R.

FIG. 14 is a further elaboration of the basic circuit of FIG. 1. This circuit shows an economical liquid level control utilizing only one active device.

Detailed description

Although the disclosure hereof is detailed and exact to enable those skilled in the art to practice the invention, the physical embodiments herein disclosed merely exemplify the invention which may be embodied in other specific structure. The scope of the invention is defined in the claims appended hereto.

The basic circuit of FIG. 1 consists of an inductive load 15 connected by lines 25, 26 to a source 16 of alternating current voltage. Directly in series with load 15 is a capacitor 17 which is desirably variable for tuning purposes.

Also in series with the load 15 and capacitor 17 is a parallel network consisting of a diode rectifier 18 and a gate-controlled, semi-conductor switch, such as the S.C.R. 19. Gate 20 of S.C.R. 19 is adapted to receive a triggering or pulse signal across terminals 23, 24.

A brief description of the typical operation of the basic circuit of FIG. 1 is as follows:

Assume that on the first alternation of the source voltage 16 line 26 is positive with respect to line 25. Diode rectifier 18 will be forward biased permitting it to conduct and charge capacitor 17 through the load 15. S.C.R. 19 is non-conducting since it is reverse biased by the source voltage. Capacitor 17 will now have a negative charge on its upper plate (as viewed in FIG. 1) and a positive charge on its lower plate.

On the next alternation of the source voltage 16, line 25 goes positive with respect to line 26. However, no current flow will occur inasmuch as rectified 18 is now reverse biased, S.C.R. 19 remains non-conducting in the absence of a signal on its gate 20.

On the next positive alternation of line 26, no further conduction will occur through the load 15 or the parallel network 18, 19, inasmuch as capacitor 17 is already fully charged from the first cycle. Accordingly, the circuit is non-conducting and will remain so until a signal is applied to the S.C.R. gate 20.

To turn the circuit on, a signal is applied across terminals 23, 24. Inasmuch as S.C.R. 19 conducts whenever its anode is positive and a signal is imposed on its gate 20, the circuit will now conduct on both alternations of the source voltage and alternating current will flow through the load 15. After the signal is imposed on the gate 20 of S.C.R. 19, it will conduct on the first positive alternation on line 25, thus to discharge capacitor 17

through S.C.R. 19. On the next positive alternation of line 26, capacitor 17 will be recharged through diode 18.

By adjusting the value of capacitor 17, relative to the inductance of the load 15, the magnitude of the current flowing in the load can be adjusted. In this manner the voltage across the load 15 can be varied above and below the source voltage, thus permitting a match to the load voltage rating. With both rectifier 18 and S.C.R. 19 conducting, the circuit becomes a simple L/C series circuit. Accordingly, the required matching value of capacitor 17 can be easily calculated.

As aforesaid, the basic circuit of FIG. 1 can be used in high frequency applications, for example, to control radio frequencies (frequencies in excess of 20,000 cycles per second). In effect, the rectifier and capacitor circuit filters out the radio frequencies and imposes a direct current charge on the S.C.R.

FIG. 8 illustrates the fact that the circuit can be grounded at either line 25, 26. In FIG. 8, the cathode of the S.C.R. 19 is connected to line 25, instead of to line 26, as in the FIG. 1 embodiment. Inasmuch as the rectifier 18 and S.C.R. 19 are in series with the remainder of the circuit, they may be connected into the circuit at any point, thus enabling either side of the line to be made common with the signal ground. This characteristic of the circuit permits use of a single-ended signal source without isolation.

The circuit of FIG. 8 can be used together with the circuit of FIG. 1 in various multiple switching circuits in which it is desired to utilize a single signal source for concurrent control of all circuits.

S.C.R. 19 can be switched on with a D.C. signal which will result in a full sine wave output voltage, if the source voltage is a sine wave and the capacitor 17 does not become fully charged in each one-half of the source sine wave.

The basic circuit can also be controlled by a pulse input to the gate 20 of the S.C.R. 19. This will result in an adjustable output voltage from zero volts to 100 percent voltage. By delaying the gate pulse in time, relative to the source voltage, the average load power can be adjusted. This is illustrated in FIGS. 10 and 11. In FIG. 10 the gate 20 of S.C.R. 19 is triggered for substantially the full 180 degrees on the positive pulse of the source voltage on line 25. In FIG. 11 the phase of the pulse on the gate 20 of S.C.R. 19 is delayed. This reduces the average output voltage. If the trigger pulse is delayed a full 180 degrees, the circuit will be turned off completely.

In the circuit of FIG. 2, the load 15 is bypassed by a series connected capacitor 27 and diode rectifier 28. This bypass circuit short circuits the charging current and precludes energization of the load 15 upon initial application of the alternating current voltage from source 16, in the absence of a control signal on the gate 20 of the S.C.R. 19.

FIG. 3 illustrates the basic circuit of FIG. 1 to which a latching circuit consisting of capacitor 31 and adjustable resistor 32 is connected in parallel with the network 18, 19. In this circuit the load will remain energized after removal of the control signal from the gate 20 of the S.C.R. 19 for a period of time determined by the time constant of the adjustable resistor 32 and capacitor 31.

FIGS. 4 and 5 illustrate elaborations of the basic circuit of FIG. 1 in which the basic circuit is utilized to control the starting and stopping of a mechanism in response to a sensing circuit. For example, the circuits of FIGS. 4 and 5 may be used in a liquid level sensing apparatus in which vertically elongated probes 33, 34 are exposed to the liquid in a tank. Load 15 represents a relay controlling a solenoid actuated valve in the water supply to the tank. Assume the liquid to be of very high electric resistance, such as water. In this circuit, a unijunction transistor 35 furnishes the signal to the gate 20 of S.C.R. 19. Gate 36 of transistor 35 is in circuit with the probes 33, 34. The flow of current through probes 33, 34 provides charging

current for capacitor 30 and is repetitively discharged by transistor 35 into gate 20 of S.C.R. 19. When the current flow drops in response to low water level, capacitor 30 will not receive any charging current, thereby stopping the gate pulses to S.C.R. 19 which will turn off and de-energize relay 15. This turns on the water valve to re-fill the tank. Variable resistor 37 in the gate circuit to transistor 35 adjusts the sensitivity of the circuit.

The circuit of FIG. 5 is substantially for the same purpose, except that a Shockley diode 38 is in the gate circuit of the S.C.R., in place of the uni-junction transistor. In this circuit, sensitivity is varied by the adjustable resistor 37.

FIG. 12 shows another modification of liquid level controller in which gate 20 of S.C.R. 19 responds to a signal from a network including a high probe 40 and a low probe 41. Probes 40, 41 desirably consist of thermistors which are self-heated and are in a low resistance state when not submerged in liquid. When submerged, their resistance will increase.

When the liquid level drops below low probe 41, its resistance will drop, thus increasing the voltage drop across resistor 38 and pulsing the gate 20 of S.C.R. 19. At the same time a holding circuit through high probe 40 is established to keep S.C.R. 19 in a conducting state. The circuit is now turned on and the valve opens in the liquid supply line to fill the tank. As soon as high probe thermistor 40 is submerged, its resistance will increase to lower the charge on the anode of S.C.R. 19, and place it in its non-conducting state, thus turning off the circuit. The circuit will remain off until the liquid level again drops to expose the low probe 41.

In FIG. 6, the load consists of dual forward and reverse field coils 15a and 15b of a reversible motor, such as a servo-motor. Each coil is in series with a basic circuit, such as shown in FIG. 1, respectively including capacitors 17a and 17b, the respective networks 18a, 19a and 18b and 19b. The circuit of FIG. 6 is utilized to control both direction and speed of the motor. Control signal connections are made to the gates 20a, 20b of the S.C.R.'s 19a, 19b. Accordingly, control of the circuit can be accomplished very simply without resort to complex isolation schemes and buffer amplifiers. For example, logic level signals from computer flip-flop circuits can be connected to the two S.C.R. gates, to greatly reduce the logic level to power interface complexity.

An alternating current flip-flop circuit is shown in FIG. 7, in which a common triggering signal is imposed upon dual S.C.R.'s 19c and 19d, each controlling its own load 15c and 15d. The flip-flop will change state each time a pulse is received at the gate of the non-conducting S.C.R.

FIG. 9 shows an elaboration of the basic circuit of FIG. 1 in which the gate 20 of S.C.R. 19 is triggered by a time delay circuit including a neon lamp 43. Diode rectifier 44, resistor 45 and capacitor 46 provide a fixed D.C. voltage coupled to the anode of S.C.R. 19 through resistor 47. The time that the circuit will remain turned on after being triggered by a single gate pulse is determined by the discharge time constant of capacitor 46 and resistor 47. Resistor 45 has an ohmic value too high to maintain the required holding current of S.C.R. 19. Thus S.C.R. 19 remains on only as long as capacitor 46 is able to discharge the minimum required holding current through resistor 47.

Diode 48, resistor 49 and capacitor 50 form a time delay circuit that supplies trigger pulses at relatively long intervals (for example five minutes) to the gate 20 of S.C.R. 19. Capacitor 50 is slowly charged through resistor 49 and diode 48. As the voltage on capacitor 50 reaches the ionizing potential of the neon lamp 43, the lamp will break down and conduct a pulse through resistor 53 into the gate 20 of the S.C.R. 19, thus turning it on. With the S.C.R. turned on, its anode voltage will drop to the point where it will discharge capacitor 50

through the limiting resistor 51, thus resetting timing capacitor 50 to near zero. As capacitor 46 slowly discharges to below the holding current of S.C.R. 19, S.C.R. 19 will recover its forward voltage blocking capability and reverse bias diode 52. Capacitor 50 can now resume charging and the cycle will repeat. By adjusting the time constants of the circuit, short on periods (for example, four seconds on) can be obtained with long off periods in excess of five minutes.

Accordingly, FIG. 9 is a self-cycling time delay circuit which will produce short discharge impulses through the load at relatively long-spaced intervals of time.

FIG. 13 is similar to FIG. 1, except that the gate-controlled semi-conductor is a PNP transistor 54. This circuit operates in a very similar manner to that shown in FIG. 1. A brief description of the typical operation of the circuit is as follows:

Assume that on the first alternation of the source voltage 16 line 25 is positive with respect to line 26, capacitor 17 will charge through the load 15 and through the diode rectifier 18. The upper plate of capacitor 17 will be charged positively and the lower plate, negatively. On the negative half-cycle, line 25 is negative with respect to line 26, reverse-biasing rectifier 18 so that no current will flow if transistor 54 remains at cutoff. On the next positive half-cycle line 25 will again be positive with respect to line 26. However, inasmuch as capacitor 17 is already charged to the peak positive source voltage, no additional charge current will flow through the load 15 and the rectifier 18. The circuit will remain in this non-conducting state until transistor 54 is turned on.

The circuit is turned on through the following action. On the positive alternation of the line voltage, capacitor 17 is charged through the load device 15 and rectifier 18. With a negative control voltage applied between the base terminal 23 and emitter terminal 24 of transistor 54, the transistor will conduct when its collector terminal 55 is negative with respect to its emitter terminal 24. The transistor will then provide a discharge path for capacitor 17, through the load 15. On the negative alternation, the line 25 is negative with respect to line 26, and transistor 54 will conduct, charging the lower plate of capacitor 17 positively and the upper plate negatively. Accordingly, with transistor 54 turned on, the circuit will conduct on both alternations of the line. Diode rectifier 18 and transistor 54 will function as a virtual short circuit in series with capacitor 17 and load 15.

The foregoing description is for full on operation, with the transistor driven to saturation. Proportional control for the load current can be accomplished by adjusting the base drive current of transistor 54. If the transistor is not turned completely on, capacitor 17 will not be completely discharged on the negative alternation, and hence will take a smaller charge on the positive alternation, when rectifier 18 is conducting. Accordingly, the amount of load current that flows on both alternations of the line is controllable by varying the signal on the base of the transistor.

An NPN transistor can be used instead of the PNP transistor 54. In such a case, the polarity of the rectifier 18 is reversed and rectifier 18 will conduct when line 25 is negative with respect to line 26, and the transistor will conduct on a positive control signal to its base terminal 23 when line 25 is positive with respect to line 26.

As with the S.C.R. circuits previously described, rectifier 18 and transistor 54 can be common to either side of the line, thus permitting control signal connections of plus or minus polarity and common to either line.

In the foregoing circuits, the value of the capacitor 17 will decrease as the frequency is increased. This is because the circuit is tantamount to connecting the load through a series capacitor across the line. Accordingly, operation of the circuit at frequencies of 60 cycles per

second can be accomplished with practical values of capacitance. At radio frequencies, very small capacitance values may be used, in conjunction with resistive or inductive loads.

FIG. 14 shows a liquid level control which is economical inasmuch as it uses only one active device, namely, the S.C.R. 19. This particular S.C.R. is type C6A which is a very sensitive device requiring only 200 microamperes of gate current to fire. The circuit of FIG. 14 affords an inexpensive control capable of sensing resistances in excess of 50,000 ohms.

The circuit of FIG. 14 is shown wired in a pump-down arrangement to illustrate one mode of operation. A typical application would be in a storage vat that is being filled with liquid from an external source. As the vat fills to some predetermined maximum level set by the high probe 60, a pump controlled by the relay 15 is started, and the vat is pumped down to a level set by the probe 61. As soon as the liquid breaks contact with probe 61, the pump will stop and remain off until the liquid rises to probe 60. The cycle then repeats.

In this circuit, the source of voltage for lines 25, 26 is provided by a step-down transformer (24 volt output) 62. The same basic circuit as shown in FIG. 1 is incorporated herein. This includes the capacitor 17 in series with the inductive load 15, and parallel network of S.C.R. 19 and diode 18. Assuming that the polarity of the control transformer 62 is such as to make line 25 positive with respect to line 26, signal current will flow from line 25 through resistor 63, to terminal 64 which is connected to the vat (or to a third probe if the vat is not made of a conductive material). The signal current will then flow from terminal 64 through the conductive liquid to probe 60, and thence through resistor 65 and diode 66 to trigger the gate 20 of S.C.R. 19, thus turning it on for the positive alternation of the line. On the negative alternation of the line, diode 18 will conduct. Accordingly, relay coil 15 will be energized through capacitor 17.

As soon as the relay coil 51 picks up, normally open contacts 69 connected in series with the low probe 61 close. This transfers the path of control current from the high probe 60 to the low probe 61, thus to maintain trigger voltage on S.C.R. 19 after the liquid level drops out of contact with high probe 60. Relay 15 will remain energized until the liquid is pumped below low probe 61.

Resistor 63 limits the maximum probe current to a safe value in the event of a direct short between probe 60 and terminal 64. Resistor 65 increases the total resistance in series with the high probe 60. This will prevent relay chattering inasmuch as the resistor 65 is bypassed by the low probe connection as soon as the relay 15 is energized.

Diode 67 and resistor 68 provide a signal path for the negative alteration of signal voltage. Although the negative alteration is not used to control S.C.R. 19, this bypass circuit is provided by diode 67 and resistor 68, to make use of alternating current in the probe circuit.

Features of the circuit of FIG. 14 include utilization of low voltage alternating current on the probes. This reduces shock hazard and minimizes electrolysis and probe degradation. The circuit has a high sensitivity with a minimum number of parts.

I claim:

1. An electronic controller for a circuit including an inductive load, said controller comprising the series connection to said load of a capacitor and a network including in parallel connection a diode rectifier and a gate-controlled, semi-conductor switch.
2. The device of claim 1 in combination with a charging current bypass circuit in parallel with the inductive load.
3. The device of claim 1 in combination with latching means for said semi-conductor switch.
4. The device of claim 3 in which said latching means comprises a network comprising a capacitor and variable

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resistor connected in series, said network connected in parallel with said diode rectifier.

5. The device of claim 1 in combination with signalling means in the gate circuit of the gate-controlled, semi-conductor for triggering said controller in response to an external electric signal.

6. The device of claim 5 in which said signalling means comprises a resistance change sensing network.

7. The device of claim 5 in which said signalling means comprises two liquid level probes, a holding circuit responsive to one of the probes to energize the gate continuously after said one probe has sensed a liquid level condition and a holding circuit contact responsive to the other probe to de-energize the gate after said other probe senses another liquid level condition.

8. The device of claim 5 in which said signalling means comprises means to control the load power by varying the phase of the gate energization cycle to the impressed voltage cycle.

9. The device of claim 5 in which said signalling means comprises means to control the load power by controlling the degree of discharge of the capacitor in each cycle of the source voltage.

10. The device of claim 5 in which said signalling means comprises a time delay circuit for energizing the gate intermittently.

11. The device of claim 1 in which said inductive load comprises a motor having two field coils in parallel, said controller being in series with one of said field coils, and another like controller in series with the other said field coil.

12. The device of claim 1 in which the capacitor is variable for impedance matching.

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13. The device of claim 1 in which the said gate-controlled, semi-conductor switch is an S.C.R.

14. The device of claim 1 in which the said gate-controlled, semi-conductor switch is a transistor.

15. The device of claim 1 in which said diode rectifier and gate-controlled, semi-conductor switch are oppositely poled.

16. An electronic controller for flip-flop control of two inductive loads connected to a common source of A.C. voltage, said controller comprising for each such load:

(a) a capacitor in series with the load,

(b) a network in series with the load and capacitor and comprising in parallel connection a diode rectifier and a gate-controlled, semi-conductor switch,

and a common signalling means in the gate circuits of both gate-controlled, semi-conductors for alternately energizing the respective loads in response to a triggering pulse on said signalling means.

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U.S. Cl. X.R.

323—24