

March 8, 1966

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3,238,992

SOLID-STATE CONTROL SYSTEM

Filed Jan. 24, 1964

4 Sheets-Sheet 1

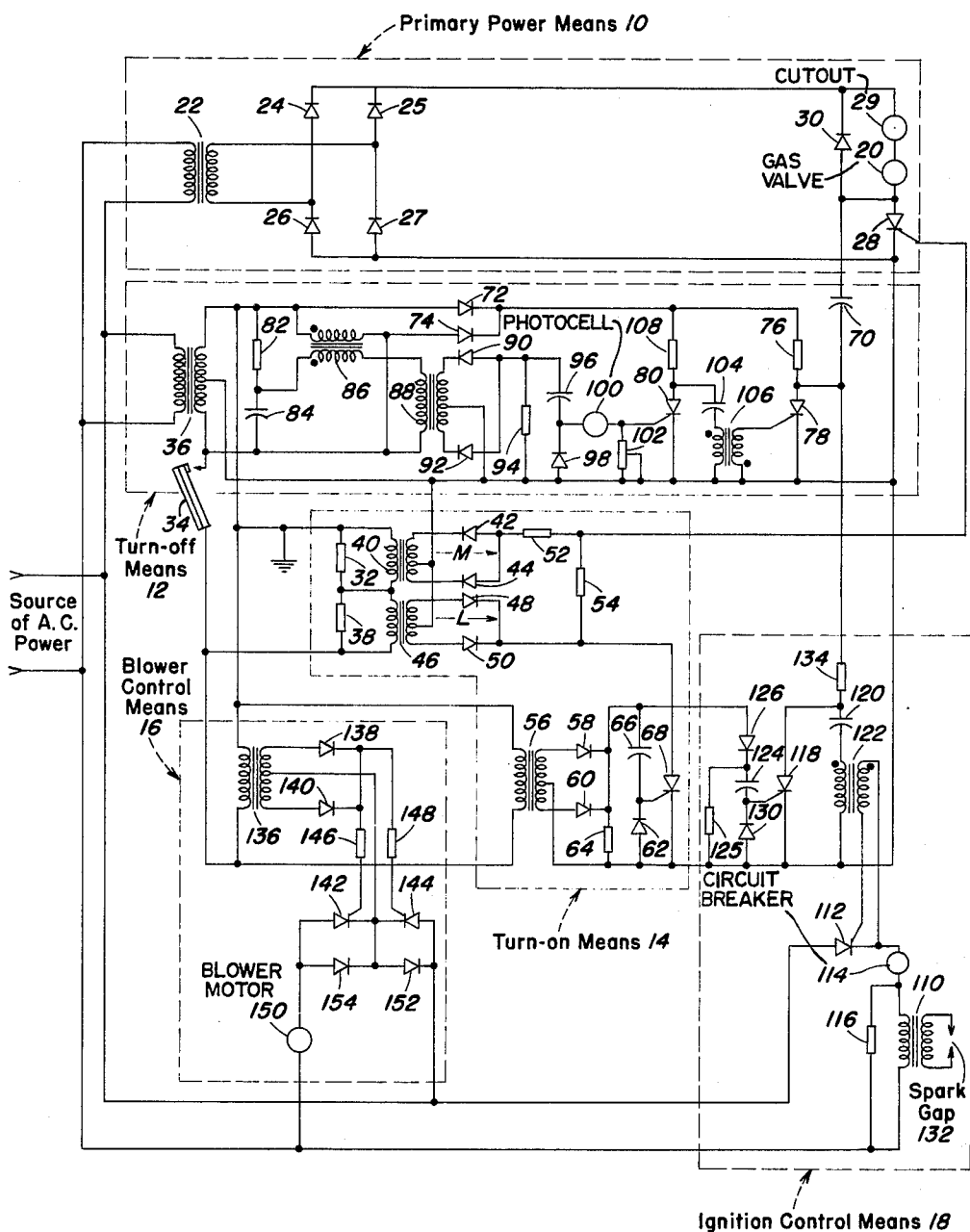


Fig. 1.

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4 Sheets-Sheet 2

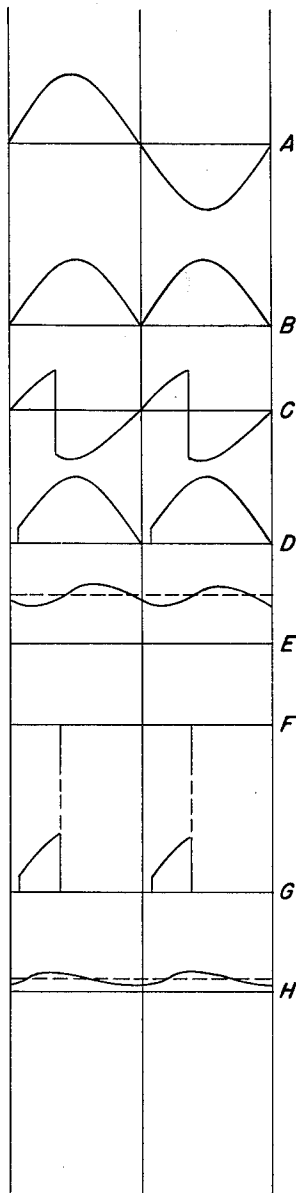


Fig. 2.

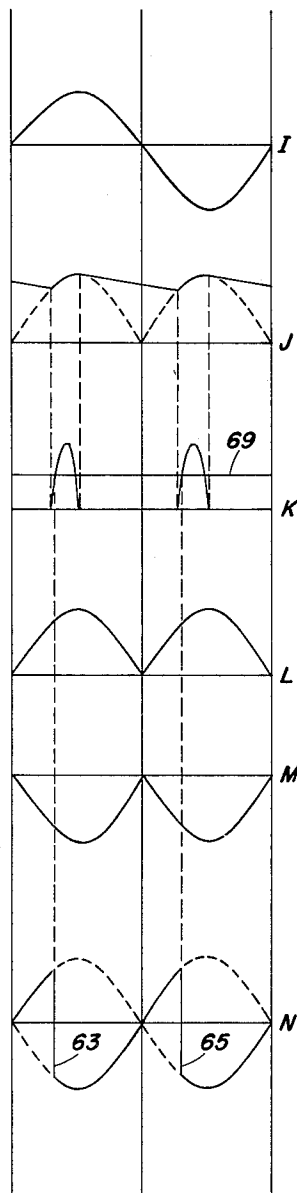


Fig. 3.

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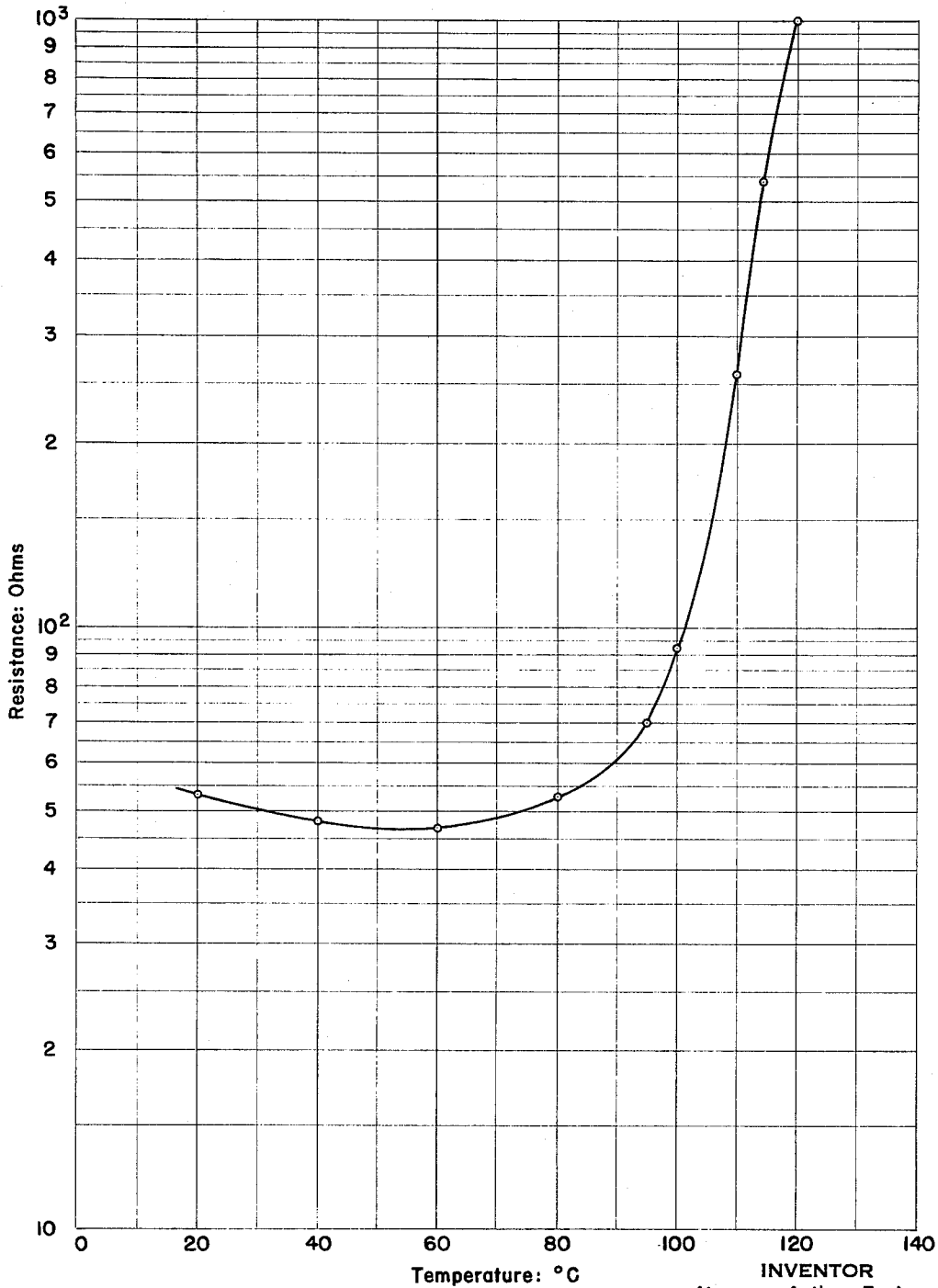


Fig. 4.

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4 Sheets-Sheet 4

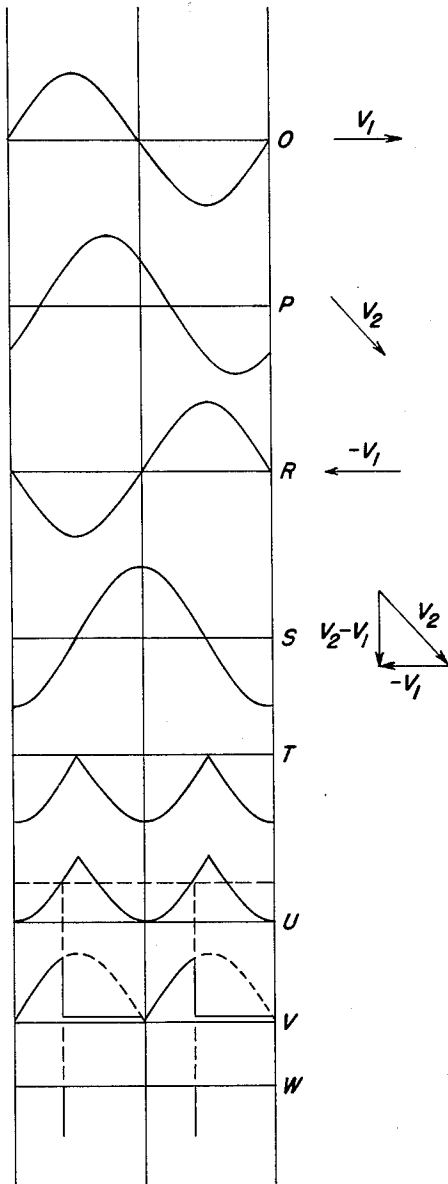


Fig. 5.

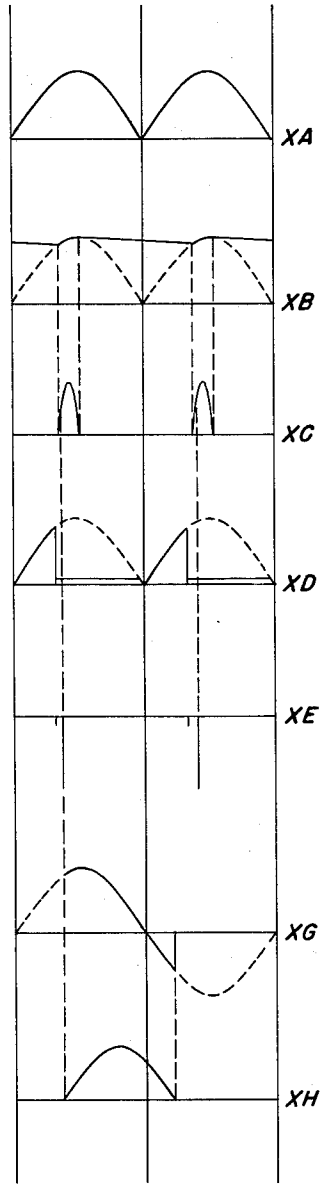


Fig. 6.

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3,238,992

SOLID-STATE CONTROL SYSTEM

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Filed Jan. 24, 1964, Ser. No. 339,976
13 Claims. (Cl. 158-28)

This invention relates generally to a control circuit and more particularly to a fail-safe complete combustion safety control circuit.

Briefly, in a boiler control system, whenever the thermostat calls for heat, the system must release fuel to the combustion chamber for a short interval of time, here referred to as the trial-for-ignition time.

If ignition is by a standing pilot, the pilot flame must be monitored. Additionally, care must be exercised to prevent the release of fuel during trial-for-ignition time if the pilot goes out. If ignition is by spark, the spark must be maintained throughout the entire trial-for-ignition time interval.

If ignition is not accomplished, or if the flame goes out some time after it has been established, the circuit must turn off the supply of fuel in a manner which requires manual resetting.

Boiler water temperature must be controlled by a temperature-limit circuit which turns off the flow of fuel whenever the water temperature rises to an unsafe level.

Additionally, all control functions must be achieved in a fail-safe manner such that the opening or shorting of an electrical component will cause the fuel to be turned off at once, or alternatively shall prevent the fuel from being turned on at the beginning of the next combustion cycle.

It is an object of this invention to provide a control circuit which is fast acting.

It is another object of this invention to provide a control circuit which can distinguish between two flame conditions to prevent the occurrence of an incomplete combustion condition.

It is also an object of this invention to provide a control circuit which eliminates the pilot burner in gas applications.

It is an additional object of this invention to provide a control circuit which reduces the erosion of the spark electrodes during ignition by reducing the fuel released during the trial-for-ignition period.

It is also an object of this invention to provide a control device which is fail-safe.

It is also another object of this invention to provide a control device which is economical to produce and reliable in operation.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the apparatus becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawing wherein;

FIG. 1 is a schematic of structure in accordance with the principles of the invention;

FIG. 2 illustrates the voltage and current waveforms present in the primary power means of the structure of the invention;

FIG. 3 illustrates the voltage and current waveforms present in the turn-on means of the structure of the invention;

FIG. 4 illustrates the resistance-temperature characteristic of a typical P.T.C. (positive temperature coefficient) thermistor used within the structure of the invention;

FIG. 5 illustrates the voltage and current waveforms present in the turn-off means of the structure of the invention; and

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FIG. 6 illustrates the voltage and current waveforms present in the ignition-control means of the structure of the invention.

With reference to FIG. 1, therein is illustrated a schematic diagram in accordance with the principles of the invention comprising a primary power means 10, a turn-off means 12, a turn-on means 14, a blower control means 16, and an ignition control means 18.

The primary power means 10, supports a solenoid operated gas valve 20 coupled to control the flow of fuel gas to a boiler; source of electrical energy or power supply comprising a transformer 22 coupled to feed diodes 24, 25, 26, and 27 which generates a rectified voltage suitable for energizing the gas valve 20, a control means such as a silicon controlled rectifier 28 to switch electric power to the gas valve 20 at the commands of the turn-on means 14 and turn-off means 12, and a thermal circuit breaker 29 to disconnect the electric power from the gas valve 20 if there is sustained excessive current through the gas valve. The operation of the control system is such that excessive gas valve current occurs whenever there is either a flame failure, or the occurrence of a yellow flame which results from incomplete combustion. Whenever the circuit breaker 29 operates, the gas valve 20 is de-energized, and remains so until the circuit breaker 29 is manually reset. The operating principles of the main power circuit are as follows: the gas valve 20, being solenoid operated, requires a much larger current to assume its open valve condition than to hold it in its open valve condition. In a representative example, the pull-in current was found to be approximately 0.8 ampere, and the holding current was approximately 0.18 ampere. This invention takes advantage of the large current differential by urging the gas valve to its open valve condition with an "operate" current that is well over 0.8 ampere, even during low line voltage conditions, and reducing this current to a "hold" level well under 0.8 ampere after a flame has been established. The large differential between "operate" and "hold" currents permits the circuit breaker 29 to be designed to trip or open quickly if the "operate" current is maintained for too long a time, yet to permit "hold" current to flow indefinitely without being tripped. In a representative control system, the "operate" current is normally between 1.0 and 1.2 ampere, the "hold" current is normally between 0.3 and 0.4 ampere, and the circuit breaker rating is 0.5 ampere.

Control of the magnitude of gas valve current is achieved by turning the silicon controlled rectifier 28 on and off cyclically; representative current and voltage waveforms present in the primary power means 10 are illustrated in FIGURE 2. It should be noted that a transient current is able to flow through the gas valve 20 even when the silicon controlled rectifier 28 is turned off, and that this current flows through diode 30. The effects of this current transient are threefold:

First, the silicon controlled rectifier 28 turns off without causing a large voltage transient. Attempts to turn off the silicon controlled rectifier 28 without the presence of diode 30 in the circuit would cause the gas valve 20 to generate a 200 volt transient. This transient potential would urge the silicon controlled rectifier to its on state and nullify the turn-off;

Second, the gas valve current is smoothed, to permit the gas valve to operate in a chatter-free manner at low current levels; and

Third, the current through the silicon controlled rectifier 28 is permitted to fall to a very low level during the voltage minima that occur twice per cycle (without diode 30 the gas valve inductance would maintain much more than the silicon controlled rectifier's holding current

throughout the cycle) so that the silicon controlled rectifier is extinguished twice per cycle and must be fired twice per cycle. In effect, this feature protects the circuit against random firing pulses as from lightning, since a random pulse can cause only a single half-cycle pulse of gas valve current.

With reference to FIG. 2, there are illustrated voltage and current waveforms which occur in the primary power means 10 wherein:

"A" is a waveform of the A.-C. input to the rectifier network composed of the diodes 24, 25, 26, and 27;

"B" is a waveform of the signal at the output of the rectifier network;

"C" is a waveform of the "on" pulse signals fed to the plate terminal of the silicon controlled rectifier 28;

"D" is a waveform of the gas valve voltage with "on" pulses only;

"E" is a waveform of the gas valve current with "on" pulses only, wherein the average "operate" current is shown by the dotted line to be 1.2 amperes (typically);

"F" is a waveform of the "off" pulse signals at the anode terminal of the silicon controlled rectifier 28;

"G" is a waveform of the gas valve voltage with "on" and "off" pulse signals; and

"H" is a waveform of gas valve current with "on" and "off" pulses wherein the typically average "hold" current of 0.3 ampere is indicated by means of the dotted line.

The fail-safe features of the primary power means 10 are as follows:

(a) Any failure in any of the diodes 24, 25, 26, or 27 cause "operate" current to vanish for alternate half cycles. Thus, "operate" current falls approximately to half its normal value, and the gas valve cannot pull in.

(b) A shorted silicon controlled rectifier 28 will cause full "operate" current to flow continuously to trip the circuit breaker.

(c) Failure of the turn-on signal to appear will cause the gas valve current to remain essentially at zero.

(d) The turn-on signal must vanish when the thermostat is satisfied, as the turn-on circuit obtains its electrical energy from the thermostat circuit.

(e) Failure of the turn-off signal to appear will cause the gas valve current at the full "operate" level to flow continuously whenever the thermostat calls for heat, and the circuit breaker will be tripped.

(f) Failure of the turn-off signal to vanish, or its appearance due to some malfunction between heating cycles, will prevent the full "operate" current from being established, and the gas valve will not pull in.

Turn-on means 14

The turn-on means 14 performs the following functions:

(a) Generates turn-on pulse signals for the gate terminal of the silicon controlled rectifier 28 whenever the thermostat is closed (that is, calls for heat).

(b) Stops the generation of turn-on pulse signals whenever thermistor 32 signals that the water temperature in a hot water system has risen to a dangerous level.

(c) Generates a turn-on pulse signal that extends well into the conduction period and then terminates abruptly. The purpose of such a turn-on pulse waveform is to prevent extremely early turn-off, such as can be produced by a number of malfunctions, as will be described presently. Any tendency to turn-off early will result, eventually, in the turn-off pulse signals coinciding in time with the turn-on pulse signals and the silicon controlled rectifier 28 will not turn off (actually, the silicon controlled rectifier first turns off and then immediately turns on again, because the turn-on pulse is still present).

The operation of the turn-on circuit is as follows: When thermostat 34 calls for heat by closing, the 24-volt (nominal) output of transformer 36 is applied to a voltage divider made up of a temperature sensitive means such as a thermistor 32 and resistor 38. The voltage across thermistor 32 appears across the primary winding of

transformer 40, and the secondary voltage of transformer 40 is rectified by diodes 42 and 44 to produce a pulsating negative-going voltage M (illustrated in FIG. 3). In a similar manner, the voltage across resistor 38 and transformer 46 is rectified by diodes 48 and 50 to produce a pulsating positive-going voltage L (illustrated in FIG. 3). The algebraic sum of these two voltages appears across the voltage divider made up of resistors 52 and 54, and the gate terminal of the silicon controlled rectifier 28 which is connected to the junction of the resistors 52 and 54. Under normal conditions, the thermistor 32 is relatively low in resistance, therefore the signal L is relatively large and the signal M is relatively small. The gate terminal of the silicon controlled rectifier 28 is driven positive enough to fire the silicon controlled rectifier 28 early in the cycle.

The turn-on pulse is terminated by the action of that portion of the turn-on circuit made up of transformer 56, diodes 58, 60 and 62, resistor 64, capacitor 66 and silicon controlled rectifier 68.

Representative waveforms of the turn-on means 14 are illustrated in FIG. 3 and are as follows:

"I" is a waveform of the A.-C. input to the rectifier;

"J" is a waveform of the rectified voltage across the resistor 64;

"K" is a waveform of the charging current through the capacitor 66 wherein the line 69 indicates the current value at which the silicon controlled rectifier 68 fires;

"L" is a waveform of the voltage at the cathode terminals of the diodes 48, 50;

"M" is a waveform of the voltage at the anode terminals of the diodes 42, 44; and

"N" is a waveform of the turn-on pulse signal.

The vertical lines 63 and 65 indicate the times at which the silicon controlled rectifier 68 will fire.

The operation of the turn-on means 14 of this invention is as follows:

When thermostat 34 closes, 24 volts A.C. are applied to the primary of transformer 56. The voltage at the terminal of the secondary winding of transformer 56 is rectified by diodes 58 and 60 to form a positive-going voltage signal which charges capacitor 66 rapidly immediately prior to the peak of the applied voltage. Charging current through capacitor 66 flows through the gate terminal of silicon controlled rectifier 68 and urges it to fire. For the remainder of the half cycle, the voltage L is reduced to the "on" voltage of silicon controlled rectifier 68, about one volt. The effect on the bridge circuit formed by the diodes 42, 44, 48 and 50 and the resistors 52 and 54 is to unbalance the bridge so that the output is negative. The gate terminal of the silicon controlled rectifier 28 is also driven negative when the silicon controlled rectifier 68 fires. From this moment on, silicon controlled rectifier 28 can be turned off successfully by a turn-off pulse signal; before then, it could not. This feature provides a protection against malfunctions in the turn-off means 12 and against the occurrence of a yellow-flame condition as will be described later.

The thermistor 32 also alters the bridge unbalance. As the boiler water temperature rises, thermistor 32 which is positioned to indicate the temperature of the boiler water, eventually enters the range of temperatures in which its resistance increases abruptly (see the thermistor characteristic curve, FIG. 4). An increase in the resistance of the thermistor 32 results in an increase in the signal "M" and a decrease in the signal "L" until the output signal of the bridge is not positive enough to turn silicon controlled rectifier 28 to its "on" state. At this instant, the gas valve current falls essentially to zero, and the gas valve closes.

In this invention the turn-on means 14 has been designed to be fail-safe in the presence of either an open or a shorted thermistor. This is achieved in the turn-on means 14 by making the turn-on pulse out of portions of M and L signals, and arranging the circuit so that both components of the turn-on pulse signal are necessary for

normal ignition control. That is, if signal L is greatly reduced the silicon controlled rectifier 28 will not fire, and the gas valve 20 will not be turned on. On the other hand, if signal M is greatly reduced, the silicon controlled rectifier 28 will receive a gate drive signal throughout the entire cycle and will not be turned off by the turn-off pulse. Thus, the gas valve current will be kept at its full "operate" level, the circuit breaker will be tripped and the gas valve will be disconnected.

The foregoing analysis holds true in modified form even if a component failure affects only every other half-cycle. If every other L signal pulse is missing, the silicon controlled rectifier 28 will be turned on every other half-cycle, and the resulting gas valve current will not be sufficient to pull it in. On the other hand, if every other M signal pulse is missing, the silicon controlled rectifier 28 will fail to turn off every other half-cycle, and the resulting gas valve current will be high enough to trip the circuit breaker. The fail-safe characteristics of the turn-on means 14 are as follows.

CONDITION:

RESULT

Thermistor 32 open -----	Signal L is reduced.
Thermistor 32 is shorted ----	Signal M is reduced.
Resistor 38 open -----	Signal M is reduced.
Resistor 38 shorted -----	Signal L is reduced.
Transformer 40 is open or shorted -----	Signal M is reduced.
Transformer 46 is open or shorted -----	Signal L is reduced.
Diode 42 or 44 is open or shorted -----	Signal M is reduced.
Diode 48 or 50 is open or shorted -----	Signal L is reduced.
Resistor 52 is open -----	Same effect as signal M disappearing.
Resistor 52 is shorted -----	Same effect as signal L disappearing.
Resistor 54 is open -----	Same effect as signal L disappearing.
Resistor 54 is shorted -----	Same effect as signal M disappearing.
Transformer 56 is open or shorted -----	Silicon controlled rectifier 68 never fires.
Diodes 58 or 60 are open or shorted -----	Silicon controlled rectifier 68 fires every other half cycle.
Resistor 64 is open -----	Capacitor 66 cannot discharge and, therefore, silicon controlled rectifier 68 will fire only once.
Resistor 64 is shorted -----	The silicon controlled rectifier 68 will not fire.
Capacitor 66 is open -----	The silicon controlled rectifier 68 will not fire.
Capacitor 66 is shorted -----	The silicon controlled rectifier 68 will fire early; same effect as signal L disappearing.
Diode 62 is open -----	Capacitor 66 cannot discharge; silicon controlled rectifier 68 will fire only once.
Silicon controlled rectifier 68 is open -----	Same effect as silicon controlled rectifier not firing.
Silicon controlled rectifier 68 is shorted -----	Same effect as silicon controlled rectifier firing too early.

The effect of the silicon controlled rectifier 68 not firing is the same as having the signal M disappear. The silicon controlled rectifier 68 obtains its gate drive

throughout the cycle, thus defeating the turn-off pulses, increasing the gas valve current, and tripping the circuit breaker.

Turn-off means 12

One of the characteristics of controlled rectifiers such as are used in this invention is that they can be turned on by a short gate pulse but can be turned off only by momentarily lowering the anode current. In the turn-off means 12, the silicon controlled rectifier 28 is turned off by discharging capacitor 70 through its anode terminal, thus reversing its anode current. Charging of capacitor 70 is accomplished by means of transformer 36, diodes 72 and 74, and resistor 76. The time constant of resistor 76 and capacitor 70 is sufficiently short (200 microseconds, nominally) so that the junction of these two components closely follows the pulsating positive-going voltage signal generated by transformer 36, diode 72 and diode 74. There is, therefore, sufficient charge on capacitor 70 during any of the useful turn off times to insure turn-off of the silicon controlled rectifier 28. (The turn-off time cannot be later than 90 electrical degrees because the turn-off trigger voltage is peaked at about 90°, and the turn-off time cannot be earlier than 50 electrical degrees, because the turn-on pulse does not end until then.) The turn-off pulse signal is generated when the silicon controlled rectifier 78 discharges capacitor 70 and the gate drive for the silicon controlled rectifier 78 is generated by the firing of silicon controlled rectifier 80. A description of the generation of the trigger voltage for the silicon controlled rectifier 78 is presented below. Starting with the 24-volt (nominal) output of transformer 36, a conventional phase shift circuit made up of resistor 82 and capacitor 84 delay the voltage by approximately 45°, and the component of this voltage that is in phase with the output of transformer 36 is essentially cancelled by the output of transformer 86, with the result that transformer 88 receives a voltage that lags behind the voltage at transformer 36 by approximately 90°. After transformation by transformer 88 this voltage is rectified by diodes 90 and 92 so that a pulsating negative-going voltage appears across resistor 94. This rectified voltage which is applied across resistor 94 is also fed to capacitor 96 and diode 98, which forms a conventional clamping circuit, to generate a positive-going voltage across diode 98 with sharp, well-defined peaks at approximately 90°. The positive-going voltage across diode 98 also appears across the series circuit made up of color sensitive means such as photoconductive cell 100 or the like and potentiometer 102. Normally, the resistance of the photoconductive cell 100 is high, several megohms or more, when there is no flame, and under these conditions not enough current will flow through the photoconductive cell 100 and the potentiometer 102 to fire the silicon controlled rectifier 80. Thus, no turn-off pulse signal is generated. Once a flame is established, however, the resistance of the photoconductive cell 100 falls to a relatively low value, and enough current flows through cell 100 and potentiometer 102 to fire the silicon controlled rectifier 80 with the result that silicon controlled rectifier 78 fires.

The following items will be helpful in understanding the turn-off mean 12:

(a) The silicon controlled rectifier 80 generates a gate pulse signal for the silicon controlled rectifier 78 by discharging capacitor 104 through the primary winding of pulse transformer 106.

(b) The time constant of resistor 108, capacitor 104 (nominally one millisecond) is sufficiently short to follow the waveform at the cathode terminal of diodes 72, 74 closely enough to insure that there is always sufficient voltage at the anode terminal of the silicon controlled rectifier 80 to generate a usable pulse. However, the time constant of resistor 108, capacitor 104 is long enough to protect silicon controlled rectifier 80 from high-frequency transients caused by the firing of silicon controlled rectifier 28.

(c) During yellow-flame conditions, the resistance of the photoconductive cell 100 will fall well below the blue-flame resistance (a change from 200,000 ohms to 20,000 ohms is typical) due to an abrupt change in the spectral response of the cell in the blue-yellow region, so that the turn-off pulse will occur so early that turn-off is defeated by the turn-on pulse. Therefore, a yellow flame will cause a large increase in gas valve current and will trip the circuit breaker.

(d) The reason for generating a trigger voltage with well-defined positive peaks at about 90° is to give a well-defined turn-off time for a wide range of photoconductive cell resistances, to make the circuit tolerant of variations in fuel burning rates and cell resistance. A change in the cell resistance from 250,000 ohms to 125,000 ohms, changes the turn-off time from approximately 80° to 70°.

Representative current and voltage waveforms for the turn-off means 12 are illustrated in FIG. 5 and are as follows:

"O" is a waveform of the A.C. input signal to the turn-off means 12;

"P" is a waveform of the delayed voltage across the capacitor 84;

"R" is a waveform of the voltage across transformer 86—used to cancel the in-phase component of signal "P";

"S" is a waveform of the final phase-shifted voltage signal presented to transformer 88;

"T" is a waveform of the rectified output signal of transformer 88 which appears across resistor 94;

"U" is a waveform of the trigger voltage appearing across diode 98, the dotted line indicating the voltage at which silicon controlled rectifier 80 normally fires when a flame is present;

"V" is a waveform of the anode voltage of the silicon controlled rectifier 80 showing normal firing; and

"W" is a waveform of the pulses which appear across the primary winding of transformer 106.

The fail-safe operation of the turn-off means 12 is as follows:

(a) If the resistance of the photoconductive cell 100 falls to a value typical of blue-flame conditions when there is no flame (as could happen with ambient light illuminating the cell), then turn-off pulses will be generated continuously, the gas valve will never receive more than "hold" current, and will never pull in.

(b) If potentiometer 102 is open, or if the photoconductive cell 100 is shorted, or if the resistance of the cell 100 falls to a value typical of yellow-flame conditions, then the turn-off pulse will occur very early, just as under yellow-flame conditions, and the circuit breaker will trip.

(c) If the photoconductive cell 100 opens, then no turn-off pulses will be generated, and the circuit breaker will trip.

(d) If diode 98 shorts, no turn-off pulse will be generated, and the circuit breaker will trip.

(e) If diode 98 opens, the average current through the photoconductive cell 100 will fall from some positive value to zero (because there is a capacitor in series with it), and the peak positive voltage will be greatly reduced (theoretically, by a factor of 3.1416 or pi). However, the circuit can tolerate only a 2:1 change in photoconductive cell current; therefore if potentiometer 102 is adjusted to recognize any blue flame the circuit must fail safe by failing to generate turn-off pulses when diode 98 opens.

(f) If capacitor 96 opens, the turn-off pulses will not be generated, and the circuit breaker will trip.

(g) If capacitor 96 shorts, the gate voltage for silicon controlled rectifier 80 will be entirely negative, no turn-off pulse will be generated, and the circuit breaker will trip.

(h) If resistor 94 opens, capacitor 96 will charge up in one half cycle and remain charged. With no charging current through capacitor 96, there will not be any drive

for silicon controlled rectifier 80, no turn-off pulse will be generated, and the circuit breaker will trip.

(i) If resistor 94 shorts, the turn-off pulses will not be generated, and the circuit breaker will trip.

(j) If any of the diodes 72, 74, 90 or 92 open or short, the turn-off pulse will be generated only once per cycle instead of twice, the gas valve current will rise above the circuit breaker trip point, and eventually the circuit breaker will trip.

(k) If transformer 88 opens or shorts, if the secondary winding of transformer 86 opens, if resistor 82 opens or if capacitor 84 shorts, the secondary voltage of transformer 88 will disappear, no turn-off pulses will be generated, and the circuit breaker will trip.

(l) If the primary of transformer 86 opens, if resistor 82 shorts, or if condenser 84 opens, the phase shift at transformer 84 will change from about 90° to about 45°. The effect of this is that the turn-off pulses will occur 45° earlier than normal, so that the turn-off pulses will be defeated by the turn-on pulses, and the circuit breaker will trip.

Ignition control means 18

The ignition control means 18 has two functions:

(a) To provide a continuous train of sparks throughout the trial-for-ignition period, so that unburned fuel is not normally released; and

(b) To remove energy from the spark gap when a flame has been established, so that spark gap erosion is minimized.

The ignition transformer 110 delivers energy to the spark gap on alternate half cycles whenever the silicon controlled rectifier 112 fires. Should the silicon controlled rectifier 112 fire continuously, or be shorted, circuit breaker 114 will trip and remove the entire circuit from the line. Resistor 116 is necessary to enable the silicon controlled rectifier 112 to turn on, and also serves to reduce voltage transients across transformer 110. Firing pulses for the silicon controlled rectifier 112 are obtained from the firing of silicon controlled rectifier 118, which discharges capacitor 120 through the primary of pulse transformer 122. Gate drive for the silicon controlled rectifier 118 is obtained from the charging current capacitor 124, which is charged via diode 126 from a pulsating voltage obtained from across resistor 64 in the turn-on means 14. Resistor 125 and diode 130 permit capacitor 124 to discharge gradually between charging pulses. The design is such that the charging pulse occurs relatively late in the cycle, so that silicon controlled rectifier 118 receives gate drive at about 75 electrical degrees. This gate drive exists only when the thermostat 34 calls for heat.

Removal of power from the spark gap 132 is accomplished by the choice of the anode voltage for the silicon controlled rectifier 118, this voltage being obtained from across the silicon controlled rectifier 78 which performs the turn-off function in response to the establishment of a flame. When no flame is present, the silicon controlled rectifier 78 is not fired, a high voltage is available for the anode of silicon controlled rectifier 118, and a gate pulse for the silicon controlled rectifier 112 is generated. When a flame is established, the silicon controlled rectifier 78 is fired, and this firing occurs early enough in the cycle so that there is only a low voltage available for the anode of silicon controlled rectifier 118, and a gate pulse for the silicon controlled rectifier 112 is not generated. The charging time constant in the anode circuits of the silicon controlled rectifier 118 (resistor 134, capacitor 120 equals 1 millisecond nominally) is short enough to enable the anode voltage of silicon controlled rectifier 118 to follow the changes in the anode voltage of silicon controlled rectifier 78. In essence, the spark gap 132 is fired whenever the thermostat 34 calls for heat, and continues to fire until a flame is established.

Representative current and voltage waveforms for the ignition control means 18 are illustrated in FIG. 6 and are as follows:

"XA" is a waveform of the gate voltage for the ignition circuit appearing across the resistor 64;

"XB" is a waveform of the modified gate voltage which appears across resistor 128;

"XC" is a waveform of the charging current through the capacitor 124 (hence the gate drive for the silicon controlled rectifier 118);

"XD" is a waveform of the anode voltage for the capacitor 124 showing no flame conditions (dotted line) and flame condition (solid line);

"XE" is a waveform of the pulse signals across the transformer 122, for both "flame" and "no flame" conditions.

"XG" is a waveform of the ignition transformer 110 voltage while energized; and

"XH" is a waveform of the ignition transformer 110 current while energized.

Blower control means 16

The blower control means 16 has only the one function of turning on the blower that supplies combustion air when the thermostat calls for heat. It is, therefore, used only in forced-draft boilers. This circuit, like those described above, is fail-safe.

When the thermostat 34 calls for heat, 24 volts A.C. appears across the primary of transformer 136, and the secondary voltage of transformer 136 is rectified by diodes 138 and 140. This rectified voltage supplies gate current to silicon controlled rectifiers 142 and 144. Resistors 146 and 148 limit the current fed to the gate terminals of the rectifiers 142 and 144 to a safe value. With the gate drive present for silicon controlled rectifiers 142 and 144, the blower motor 150 becomes energized. During one-half cycle, current flows to the motor 150 via silicon controlled rectifier 142 and diode 152, and on the alternate half-cycle current flows to the motor 150 via silicon controlled rectifier 144 and diode 154.

The fail-safe features of the blower control circuit are as follows:

(a) Transformer 136 open—no gate drive to silicon controlled rectifiers 142 and 144. Therefore, there is no voltage on the motor 150 and there is no combustion air. In this instance there is either no flame or else the flame is yellow, each of which will cause the circuit breaker to trip.

(b) Open or shorted diodes 138 or 140, open resistors 146, 148—the gate drive for one of the silicon controlled rectifiers 142 or 144 vanishes, the motor 150 receives only half-wave power and does not start, and the current through the motor 150 rises and blows the line fuse.

(c) Shorted resistors 146 or 148—the gate in series with the shorted resistor receives so much power that it burns open or short. Regardless of whether it develops a cathode-to-gate short or open, the circuit reverts to half-wave operation. In the case of a shorted gate, it does so when the thermostat opens. The result is always that the line fuse blows.

(d) Open diodes 152, and 154, silicon controlled rectifier 142 or silicon controlled rectifier 144—the motor 150 receives only half-wave power, with the same result as when the diodes 138 or 140 are open or shorted as described above.

(e) Shorted diode 152, diode 154, silicon controlled rectifier 142 or silicon controlled rectifier 144—when the thermostat is satisfied and opens, the motor 150 receives half-wave power, with the same result as when the diodes 138 or 140 are open or shorted as described above.

Obviously many modifications and variations of the present invention are possible in light of the above teachings. It is, therefore, to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A control system comprising a solenoid operated valve, a circuit breaker coupled in series with said solenoid operated valve, a diode coupled in shunt with said solenoid operated valve, a source of electrical energy coupled to feed said diode and said solenoid operated valve, a silicon controlled rectifier interposed between said source of electrical energy and said diode and solenoid operated valve, a thermostat turn-on means interposed between said thermostat and said silicon controlled rectifier to initiate activation of said solenoid operated valve when said thermostat calls for heat, temperature sensitive means positioned to detect the temperature of water in a boiler coupled to said turn-on means to inhibit the activation of said solenoid operated valve when said thermostat calls for heat during that period when the temperature of the water is above a preselected value, ignition control means fed by said turn-on means to generate an ignition spark when said thermostat calls for heat, and turn-off means coupled to terminate the occurrence of an ignition spark upon occurrence of a flame and overload said circuit breaker to deactivate said solenoid operated valve upon absence of a flame.

2. A control system comprising a solenoid operated valve, a circuit breaker coupled in series with said solenoid operated valve, a diode coupled in shunt with said solenoid operated valve, a full wave rectifier coupled to feed said diode and said solenoid operated valve, a silicon controlled rectifier interposed between said source of electrical energy and said diode and solenoid operated valve, a thermostat, turn-on means interposed between said thermostat and said silicon controlled rectifier to initiate activation of said solenoid operated valve when said thermostat calls for heat, ignition control means fed by said turn-on means to generate an ignition spark when said thermostat calls for heat, and turn-off means coupled to terminate the occurrence of an ignition spark upon occurrence of a flame and overload said circuit breaker to deactivate said solenoid operated valve upon absence of a flame.

3. A control system comprising a solenoid operated valve, a circuit breaker coupled in series with said solenoid operated valve, a diode coupled in shunt with said solenoid operated valve, a full wave rectifier coupled to feed said diode and said solenoid operated valve, a silicon controlled rectifier interposed between said source of electrical energy and said diode and solenoid operated valve, a thermostat, turn-on means interposed between said thermostat and said silicon controlled rectifier to initiate activation of said solenoid operated valve when said thermostat calls for heat, temperature sensitive means positioned to detect the temperature of water in a boiler coupled to said turn-on means to inhibit the activation of said solenoid operated valve when said thermostat calls for heat during that period when the temperature of the water is above a preselected value, ignition control means fed by said turn-on means to generate an ignition spark when said thermostat calls for heat, and turn-off means coupled to terminate the occurrence of an ignition spark upon occurrence of a flame and overload said circuit breaker to deactivate said solenoid operated valve upon absence of a flame.

4. A control system comprising a solenoid operated valve, a circuit breaker coupled in series with said solenoid operated valve, a diode coupled in shunt with said solenoid operated valve, a source of electrical energy coupled to feed said diode, and said solenoid operated valve, a silicon controlled rectifier interposed between said source of electrical energy and said diode and solenoid operated valve, a thermostat, turn-on means interposed between said thermostat and said silicon controlled rectifier to initiate activation of said solenoid operated valve when said thermostat calls for heat, ignition control means fed by said turn-on means to generate an ignition spark when said thermostat calls for heat, turn-off means coupled to terminate the occurrence of an ig-

7. A control system comprising a solenoid operated valve, a circuit breaker coupled in series with said solenoid operated valve, a diode coupled in shunt with said solenoid operated valve, a full wave rectifier coupled to feed said diode and said solenoid operated valve, a silicon controlled rectifier interposed between said source of electrical energy and said diode and solenoid operated valve, a thermostat, turn-on means interposed between said thermostat and said silicon controlled rectifier to initiate activation of said solenoid operated valve when said thermostat calls for heat, temperature sensitive means positioned to detect the temperature of water in a boiler coupled to said turn-on means to inhibit the activation of said solenoid operated valve when said thermostat calls for heat during that period when the temperature of the water is above a preselected value, ignition control means fed by said turn-on means to generate an ignition spark when said thermostat calls for heat, and turn-off means coupled to terminate the occurrence of an ignition spark upon occurrence of a flame and overload said circuit breaker to deactivate said solenoid operated valve upon absence of a flame, and color sensitive means coupled to said turn-off means to initiate deactivation of said solenoid operated valve on occurrence of an undesired condition of combustion,

10. A control system comprising a solenoid operated valve, a circuit breaker coupled in series with said solenoid operated valve, a diode coupled in shunt with said solenoid operated valve, a full wave rectifier coupled to feed said diode and said solenoid operated valve, a silicon controlled rectifier interposed between said source of electrical energy and said diode and solenoid operated valve, a thermostat, turn-on means interposed between said thermostat and said silicon controlled rectifier to initiate activation of said solenoid operated valve when said thermostat calls for heat, temperature sensitive means adapted to be positioned to detect the temperature of water in a boiler coupled to said turn-on means to inhibit the activation of said solenoid operated valve when said thermostat calls for heat during that period when the temperature of the water is above a preselected value, ignition control means fed by said turn-on means to generate an ignition spark when said thermostat calls for heat, turn-off means coupled to terminate the occurrence of an ignition spark upon occurrence of a flame and overload said circuit breaker to deactivate said solenoid operated valve upon absence of a flame, color sensitive means coupled to said turn-off means to initiate deactivation of said solenoid operated valve on occurrence of an undesired condition

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of combustion, and blower control means coupled to the thermostat to activate a blower when said thermostat calls for heat.

11. A control system comprising a solenoid operated valve, a diode coupled in shunt with said solenoid operated valve, a source of electrical energy coupled to feed said diode and solenoid operated valve, a control means interposed between said source of electrical energy and said diode and solenoid operated valve, a thermostat, turn-on means interposed between said thermostat and said control means to initiate activation of said solenoid operated valve when said thermostat calls for heat, by cyclically activating the control means, ignition control means fed by said turn-on means to generate an ignition spark when said thermostat calls for heat, and turn-off means coupled to terminate the occurrence of an ignition spark upon the occurrence of a flame, to initiate deactivation of said solenoid operated valve upon absence of a flame and to cyclically deactivate the control means.

12. A control system comprising a solenoid operated valve, a circuit breaker coupled in series with said solenoid operated valve, a diode coupled in shunt with said solenoid operated valve, a source of electrical energy coupled to feed said diode and said solenoid operated valve, a silicon controlled rectifier interposed between said source of electrical energy and said diode and solenoid operated valve, a thermostat, turn-on means interposed between said thermostat and said silicon controlled rectifier to initiate activation of said solenoid operated valve when said thermostat calls for heat, by cyclically activating said silicon controlled rectifier, temperature sensitive means adapted to be positioned to detect the temperature of water in a boiler coupled to said turn-on means to inhibit the activation of said solenoid operated valve when said thermostat calls for heat during that period when the temperature of the water is above a preselected value, ignition control means fed by said turn-

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on means to generate an ignition spark when said thermostat calls for heat, and turn-off means coupled to cyclically deactivate said silicon controlled rectifier, to terminate the occurrence of an ignition spark upon occurrence of a flame, and to overload said circuit breaker to deactivate said solenoid operated valve upon absence of a flame.

13. A control system comprising a solenoid operated valve, a circuit breaker coupled in series with said solenoid operated valve, a full wave rectifier coupled to feed said diode and said solenoid operated valve, a silicon controlled rectifier interposed between said source of electrical energy and said diode and solenoid operated valve, a thermostat, turn-on means interposed between said thermostat and said silicon controlled rectifier to initiate activation of said solenoid operated valve when said thermostat calls for heat by cyclically activating the silicon controlled rectifier, ignition control means fed by said turn-on means to generate an ignition spark when said thermostat calls for heat, and turn-off means coupled to cyclically deactivate the silicon controlled rectifier, to terminate the occurrence of an ignition spark upon occurrence of a flame, and to overload said circuit breaker to deactivate said solenoid operated valve upon absence of a flame.

References Cited by the Examiner

UNITED STATES PATENTS

1,755,970	4/1930	Singleton.	
2,964,102	12/1960	Cassell et al.	158—28
3,051,813	8/1962	Busch et al.	
3,060,997	10/1962	Maney	158—28
3,097,314	7/1963	Harriman.	
3,113,610	10/1963	Sawyer et al.	158—28
3,174,528	3/1965	Staring	158—28

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