United States Patent

[11] **3,626,277**

[72] Inventor **Robert D. Munson**
St. Louis County, Mo.

[21] Appl. No. **58,235**
[22] Filed **July 27, 1970**
[45] Patented **Dec. 7, 1971**
[73] Assignee **Emerson Electric Co.**

[54] **CURRENT REGULATOR SUITABLE FOR MERCURY LAMP BALLAST**
13 Claims, 2 Drawing Figs.

[52] **U.S. Cl.** ..... **323/17,** 307/297, 315/194, 315/224, 315/311, 321/2, 321/45 C, 323/22 T, 323/DIG. 1
[51] **Int. Cl.** **H02m 7/24,** H05b 41/14, G05f 1/64
[50] **Field of Search** ..... 315/194, 224, 311; 323/4, 9, 17, 22 T, 25, 38, DIG. 1; 307/268, 297, 93, 252 J, 252 W; 321/2, 45 C

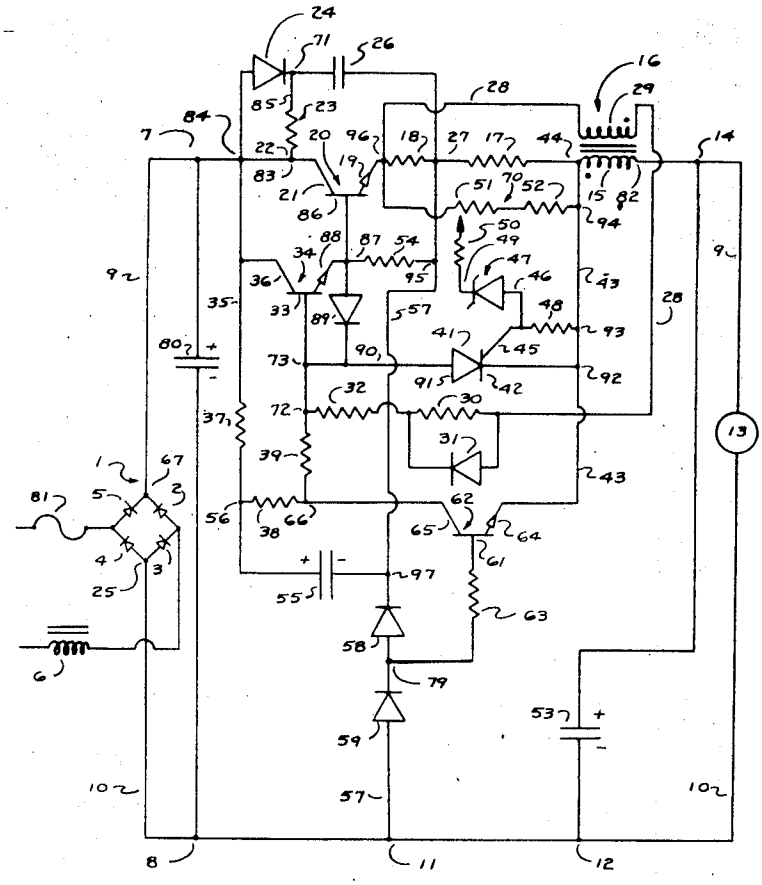
[56] **References Cited**

UNITED STATES PATENTS

3,462,643	8/1969	Turner et al.	323/22 T X
3,500,127	3/1970	Schiff	315/224
3,373,341	3/1968	Wattson	323/9
3,192,441	6/1965	Wright	323/22 T X
3,204,130	8/1965	Hickey	307/268
3,396,326	8/1968	Kisrow	323/9

Primary Examiner—Gerald Goldberg
Attorney—Polster and Polster

ABSTRACT: An electrical circuit has a quick-acting switch electrically connected in series between a variable load and a rectified power input. A switch control circuit is provided which connects the switch in its power on position when circuit current is a minimum and disconnects it as current reaches a predetermined maximum. A transformer primary winding is utilized to maintain current in the load during switch off times while its secondary winding is used to commutate a silicon-controlled rectifier in the switch control circuit. The switch is held in the off position until current in the transformer primary approaches zero, at which time the switch is recycled.



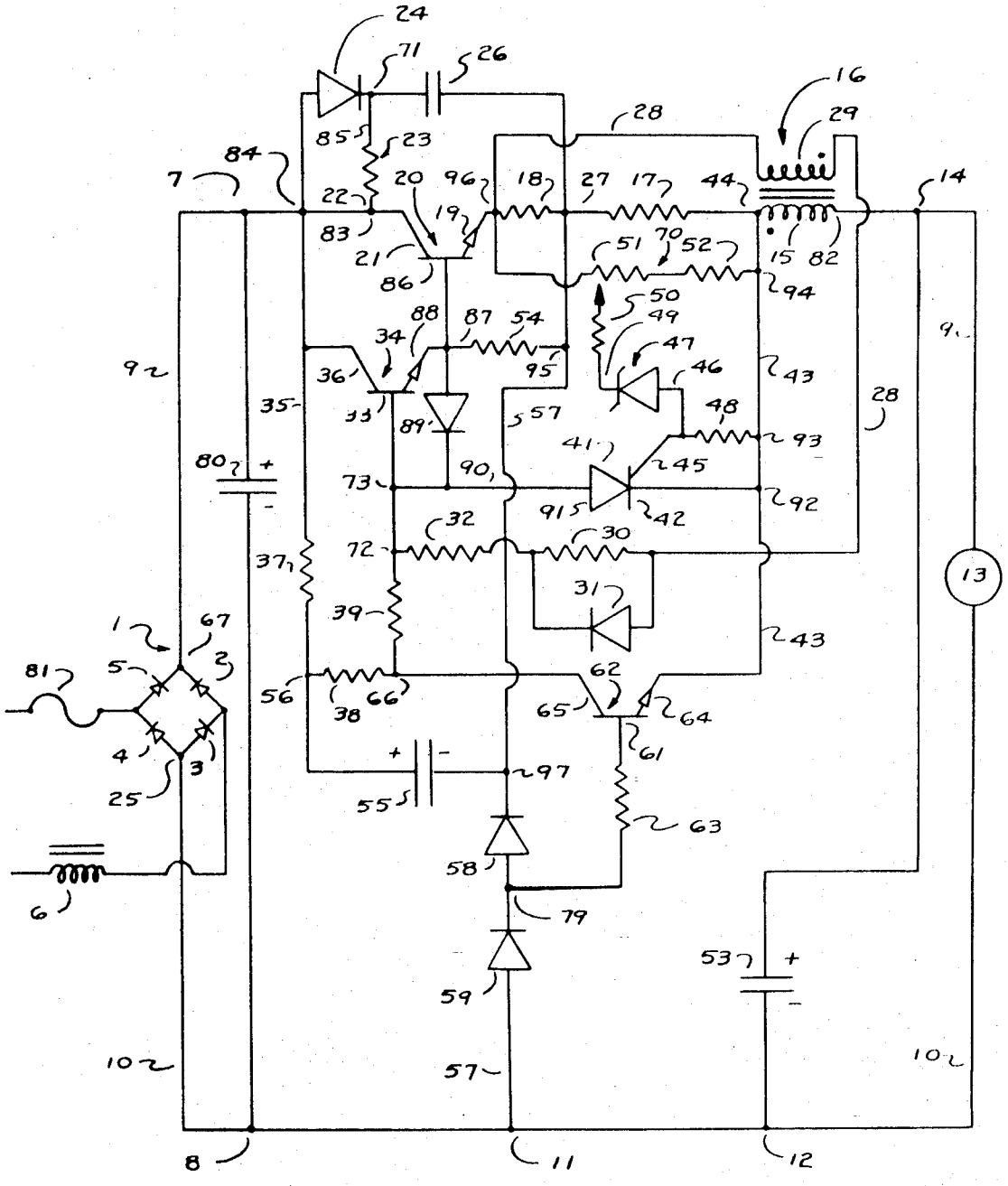


Fig-1

INVENTOR
ROBERT D. MUNSON

BY

ATTORNEYS

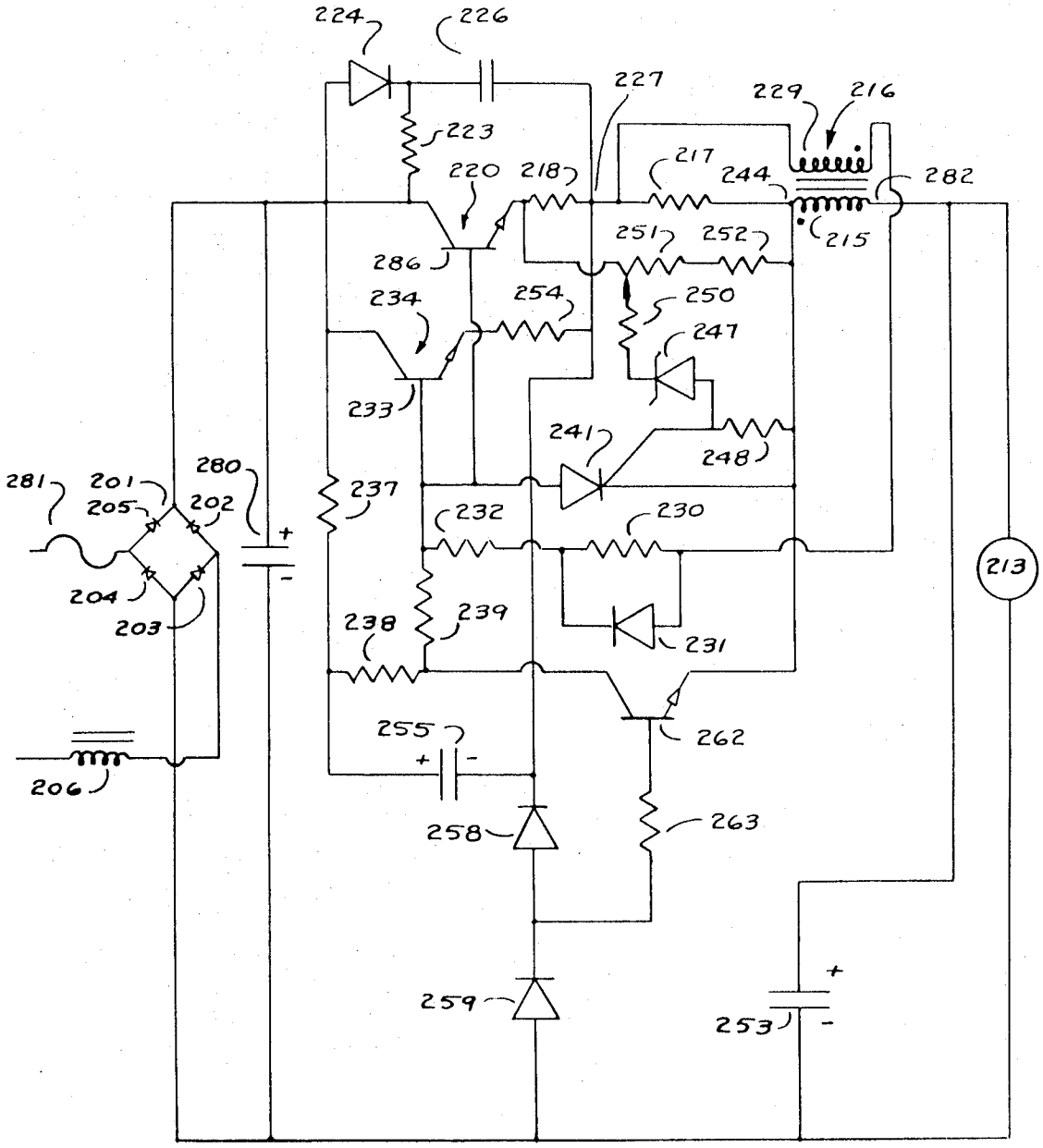


Fig-2-

INVENTOR
ROBERT D. MUNSON
By Cobb & Cobb
ATTORNEYS

CURRENT REGULATOR SUITABLE FOR MERCURY LAMP BALLAST

BACKGROUND OF THE INVENTION

This invention relates to control devices and in particular to solid-state ballasts for mercury-arc lamps. Those skilled in the art, however, will recognize the wide applicability of the design features in the circuit of this invention to other switching circuits.

A mercury-arc lamp is essentially a varying impedance. The arc tube generally contains argon in addition to mercury. The argon acts as a starting aid and requires the application of approximately 200 volts across the lamp's terminals before it ionizes. With argon ionization, current flow begins and the voltage drop across the lamp decreases rapidly to 18 volts. After the argon ionization, mercury droplets in the lamp evaporate and the mercury vapor enters the arc. The addition of mercury vapor in the arc causes a rise in lamp impedance to a stable operating area where voltage drop across the lamp terminals approximates 135 volts. Ideally, a mercury-arc lamp ballast should be a constant-current source. During the initial starting period the dramatic decrease in lamp impedance corresponds to an equally dramatic current demand. Unless some type of limiting circuit is provided, the lamp circuit destroys itself.

Numerous attempts have been made to provide current-limiting circuits for these lamps. A review of prior art, description of lamp operation, and one form of control circuit is given in the U.S. Pat. to Mahler, No. 3,486,069. The simplest and lowest cost ballast produced to date is the common reactor ballast. A major disadvantage of this conventional ballast is its inherent poor regulation of line voltage fluctuations. When circuit power regulation is improved, as by a saturating (constant-current) type ballasting reactor, circuit efficiency is reduced and the lamp requires longer warmup time. Solid-state ballasting circuits appear to offer the best solution in providing effective current-limiting circuits. Theoretically, these circuits meet all performance requirements. They offer excellent power regulation capability, operating efficiencies, and small size. Practically, solid-state ballasting circuits are not displacing reactor ballasts because of the present uneconomically high cost differential between the solid-state and reactor ballast. The circuit of this invention offers the advantages of solid-state ballast at a unit cost approximating a comparable reactor ballast. It accomplishes the current-limiting function through a simple, practical and novel component arrangement.

One of the objects of this invention is to provide a solid-state control device for mercury-arc lamps.

Another object of this invention is to provide a low-cost, easy-to-manufacture solid-state regulator.

Yet another object of this invention is to provide a solid-state circuit having reliable, long life under continuous operation.

Other objects will become apparent to those skilled in the art in view of the following description and accompanying drawings.

SUMMARY OF THE INVENTION

In accordance with this invention, generally stated, a control device providing constant current has a switch in series with a load. Current flowing through the circuit is sampled and the switch is opened when that current reaches a predetermined peak value. An inductor in the form of a transformer has a primary winding electrically connected in series with the load and a secondary winding that provides both regenerative feedback to the switch and commutation for a silicon-controlled rectifier in the sampling circuit. A sensor circuit follows decay current in the transformer primary, locking the switch in its off position until that current approaches a minimum value. A diode, capacitor, and resistor are electrically connected to the switch and act to reduce switching losses.

BRIEF DESCRIPTION OF THE DRAWING

In the drawings, FIG. 1 is a schematic representation of control circuit of this invention; and

FIG. 2 is a schematic representation showing a connection variation in the circuit of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1 for the preferred embodiment of the control circuit of this invention, reference numeral 1 indicates a full-wave bridge rectifier having diodes 2, 3, 4 and 5 as bridge elements. Input to bridge 1 is an AC source not shown and its output is connected via conductors 9 and 10 across a capacitor 80 at connection nodes 7 and 8. Capacitor 80 acts as a filter and stabilizes the waveform in the bridge output. An optional inductor 6 may be placed in the bridge 1 input circuit and when so placed acts to improve power factor and waveform in the control circuit of this invention. In the preferred embodiment, a fuse 81 also is connected electrically in the bridge input circuit and protects against excessive current demand by the control circuit.

Conductor 10 electrically connects a side 25 of rectifier through to one side of a mercury-arc lamp 13 and places connection nodes 8, 11 and 12 at the same potential as side 25. A second side of lamp 13 is connected by conductor 9 and a node 14 to a transformer 16 having a primary winding 15 with a first side 82. A second side 44 of winding 15 is electrically connected through a resistor 17, a node 27, a resistor 18, and a node 96 to an emitter 19 of transistor switch 20. A collector 21 of transistor transistor 20 is electrically connected to a first side 22 of a resistor 23 and to the anode side of a diode 24 through connection nodes 83 and 84 respectively, and via conductor 9 to node 7 and side 67 of bridge 1. A second side 85 of resistor 23 is electrically connected to the cathode side of diode 24 and to a first side of a capacitor 26 at a node 71. The second side of capacitor 26 is electrically connected to node 27 intermediate resistors 17 and 18.

Emitter 19 of transistor 20 also is electrically connected via a conductor 28 to a secondary winding 29 of transformer 16, through that winding to a resistor 30 and a diode 31 connected in parallel; through a series resistor 32 and a connection node 72 to a base 33 of a transistor 34.

An electrical conductor 35 connects a collector 36 of transistor 34 to node 84 and through a resistor 37, a node 56, a resistor 38, a node 66, a resistor 39, a node 72, and a node 73 to its base 33.

A base 86 of transistor 20 is electrically connected to a node 87. An emitter 88 of transistor 34 is electrically connected to transistor's 20 base 86 through node 87. Emitter 88 also is electrically connected from node 87 to a node 95 through a resistor 54. Node 95 and node 27 are connected by a conductor 57. Resistor 54 aids in quick turnoff of switch 20 by shunting a portion of the base drive from transistor 34, a procedure described fully hereinafter.

A diode 89 is electrically connected between node 87 and base 33 of transistor 34 and to an anode side 91 of a silicon-controlled rectifier 41 via a conductor 90. Silicon-controlled rectifier 41 has its cathode 42 electrically connected from a node 92 via a conductor 43 and nodes 93 and 94 to side 44 of primary winding 15.

A gate electrode 45 of silicon-controlled rectifier 41 is electrically connected to a zener diode 47 at its anode 46 and through a resistor 48 to node 93 and side 44 of winding 15.

A cathode 49 of diode 47 is electrically connected through a resistor 50 to a variable resistor 51 connected in series with a resistor 52. Resistors 51 and 52 are connected in parallel with resistors 17 and 18, between node 96 and side 44 of winding 15. Resistors 17, 18, 51 and 52 form a current sensor 70.

A capacitor 53 is electrically connected in parallel with lamp 13 between nodes 12 and 14.

A capacitor 55 is electrically connected between node 56 intermediate resistors 37 and 38 and conductor 57 at a node 97. Conductor 57 is connected between nodes 27, 95 and 97. Two freewheeling diodes 58 and 59 are electrically connected by conductor 57 between nodes 11 and 97.

A transistor 62 has a base 61, an emitter 64 and a collector 65. Base 61 is electrically connected through a resistor 63 to a node 79 between diodes 58 and 59. Conductor 43 electricallly connects emitter 64 to side 44 of winding 15 via nodes 92, 93 and 94. Collector 65 is connected to node 66 between resistors 38 and 39.

In operation, application of AC power to rectifier 1 provides a DC input across nodes 7, 8 and capacitor 80 which, as previously described, filters and shapes the current waveform. Current flow through resistors 37, 38 and 39 provides base drive for transistor 34 turning that transistor on. Conduction by transistor 34 in turn provides base drive for transistor switch 20. Application of base drive to transistor 20 drives that transistor into saturation, closes the circuit to current flow, charges capacitor 53 and applies a voltage across lamp 13.

The current inrush from bridge 1 passes through diode 24, charging capacitor 26. Capacitor 26 is discharged through resistor 23 each time switch 20 turns on. The charging and discharging of capacitor 26 is important as will be described fully hereinafter.

As transistor 20 turns on, current passes through the secondary winding 29 of transformer 16 via conductor 28, diode 31 and resistor 32, providing additional drive voltage to base 33, driving transistor 34, and thus transistor 20 into further saturation.

When the voltage buildup across nodes 12 and 14 approaches 200 volts, the argon starting gas in lamp 13 begins ionization, resulting in a decrease of load impedance and a corresponding increase in current through transistor 20. Unless checked, the current demand would destroy transistor 20. Sensor 70 provides signal means for checking this current demand. As current through resistor 17 and 18 increases the voltage across resistors 51 and 52 increases. A voltage across resistor 51 causes a current and corresponding voltage across resistor 50. This current is blocked by zener diode 47. However, diode 47 will conduct when the voltage across resistor 51 reaches a predetermined level. While resistor 51 is variable, its operation will be consistent for any one setting. Conduction of diode 47 causes a current and corresponding voltage across resistor 48. The voltage across resistor 48 provides a gate signal for silicon-controlled rectifier 41, turning that rectifier on. Conduction of silicon-controlled rectifier 41 rapidly removes base drive from both transistor 34 and transistor 20 through diode 89, turning those transistors off.

Current flow through resistor 18 decreases rapidly and the collapsing field in transformer primary winding 15 will tend to maintain current flow through lamp 13, as does discharge of capacitor 53. A return path for this current flow is provided through freewheeling diodes 58 and 59. During the nonconduction of transistor 20, capacitor 26 is free to provide some discharge current through primary winding 15, aiding the maintenance of current flow to the lamp. The operation of capacitor 26, as previously stated, is important. At initial circuit startup, capacitor 26 will charge quickly through diode 24. As transistor 20 turns on, any charge on capacitor 26 dissipates through resistor 23 and transistor 20 until there are approximately zero volts on the capacitor 20. When the transistor 20 turns off, capacitor 26 again begins to recharge through diode 24. During this time period capacitor 26 transfers energy to the load through node 27, resistor 17 and primary winding 15. Once capacitor 26 reaches a steady-state condition, it blocks further current flow and is ready to discharge through transistor 20 upon initiation of the succeeding cycle.

The voltage developed across diode 58 and resistor 17 causes a current flow through resistor 63 and this current biases transistor 62 to its on position. Transistor 62 remains conductive so long as there is substantial current flow through primary 15. Conduction by transistor 62 prevents application of base drive to transistor 34 and thus switch 20, effectively holding switch 20 off if substantial current flow through winding 15 is present. The current flow through resistors 37 and 38 is very small compared with the decay current of primary 15 and may be neglected when referring to current flow through primary 15. Diodes 58 and 59 are important. The circuit of this invention is designed to operate for a broad band of input voltages. The diodes of the preferred embodiment are necessary in order to obtain the proper voltage for transistor 62 conduction. However, at any one specific voltage, the circuit may be adjusted to operate effectively with a single flyback diode. Once commercial embodiment of this invention also uses a fast-switching semiconductor device for diode 59. In that application, transistor switch 20 operates at approximately 20,000 cycles per second with the circuit shown.

The quick dispersion of base drive from transistors 34 and 20 by silicon-controlled rectifier 41 is aided by the action of secondary winding 29, resistor 32 and resistor 30. Upon nonconduction of transistor 20 and the collapse of the primary field, voltage across secondary winding 29 reverses. Current flow through resistors 32 and 30 now aids rectifier 41 in turning switch 20 off. This circuit action is unusual from another standpoint. Voltage reversal of secondary 29 acts to commutate silicon-controlled rectifier 41. Commutation of rectifier 41 results in the rectifier's nonconduction. Nonconduction of silicon-controlled rectifier 41 ordinarily would allow the current flow through resistors 37, 38 and 39 to supply base drive to transistor 34. However, this current is shunted by transistor 62 conduction, and transistors 34 and 20 are maintained in their off condition. As decay current through primary winding 15 approaches zero, the voltage across diodes 58 and resistor 17 becomes insufficient to provide base drive for transistor 62 and that transistor turns off. Nonconduction of transistor 62 permits application of base drive to transistor 34. The cycle is then repeated.

Capacitor 55 serves two functions. It provides a delay in the conduction of transistor 20 until capacitor 80 is fully charged, and it stores energy so that base drive can be supplied through resistors 38 and 39 after the collector-emitter voltage of transistor 20 has decreased following transistor 20 conduction.

Resistor 32 limits the base current of transistor 34 to a safe value even with the regenerative feedback provided by secondary winding 29. Resistor 30 also provides resistance in series with secondary winding 29 of transformer 16 so that a small current through resistors 37, 38 and 39 will drive transistor 34 into saturation.

As the collector-emitter voltage of transistor switch 20 increases, that is, as switch 20 is turned off, capacitor 26 supplies current to the primary winding 15 of transformer 16 as described above and retards the rate of rise of the collector-emitter voltage. By retarding the collector-emitter voltage rise, capacitor 26 acts to reduce switching losses. Resistor 23 discharges capacitor 26 each time transistor 20 conducts. The addition of diode 24, capacitor 26 and resistor 23 has lowered operating temperature of transistor 20 by as much as 14° C.

Merely by way of example, the following components work well in the circuit shown in FIG. 1 and described above:

COMPONENT	RATING
Diodes 2, 3, 4 and 5	1,000 PIV, 3 amperes
Capacitor 80	160 microfarads, 450 volts
Resistor 37	27,000 ohms, 2 watts
Resistor 38	27,000 ohms, 2 watts
Resistor 39	2,200 ohms
Resistor 23	1,000 ohms, 10 watts
Diode 24	400 PIV, 1 ampere
Capacitor 26	0.02 microfarads, 600 volts
Transistor 20	2N3902
Transistor 34	2N3902
Diode 89	50 PIV, 1 ampere
Resistor 32	82 ohms, 5 watts
Capacitor 55	2 microfarads, 350 watts
Resistor 54	12 ohms, 1 watt
Resistor 18	1 ohm, 10 watts
Resistor 17	0.3 ohm, 10 watts
Resistor 51	10 ohms
Diode 47	1N752
Resistor 52	22 ohms
SCR 41	1 ampere, 25 volts
Resistor 50	12 ohms
Resistor 48	1,000 ohms

Resistor 30	220 ohms
Diode 31	100 PIV, 1 ampere
Transistor 62	2N5172
Resistor 63	1,000 ohms
Diode 58	400 PIV, 3 amperes
Diode 59	400 PIV, 3 amperes (fast switching)
Capacitor 53	20 microfarads, 450 volts
Transformer 16	10:1 turns ratio primary to secondary. Primary inductance 1 millihenry minimum.

FIG. 2 represents a slight modification in the connection diagram shown in FIG. 1. Circuit component values are designated with corresponding reference numerals commencing with numeral 201. Component values are equivalent in each diagrammatic representation with the exceptions of resistors 254 and 232, which have new values of 1 ohm and 39 ohms respectively. Transistors 234 and 220 are electrically connected in parallel so that base drive is supplied simultaneously to their respective bases 233 and 286 through resistors 237, 238 and 239. This connection method eliminates the need for diode 89 of FIG. 1. Secondary winding 229 of transformer 216 also is electrically connected to the node 227 side of resistor 218. Circuit operation remains the same as described above except that both transistors 234 and 220 share the load circuit demand.

Numerous variations in the circuits of this invention, within the scope of the appended claims, will occur to those skilled in the art in light of the foregoing description and accompanying drawings. Thus, varied component values may be substituted for those described or certain circuit elements eliminated, particularly where the circuit is to be used with a single input voltage. For example, at certain voltages resistor 30 and diode 31 may be eliminated without detrimental effect on circuit operation. Likewise, certain connection points may be varied. Thus, in FIG. 2, resistor 251 may be connected to the node 227 side of resistor 218. This connection requires other resistor changes in sensor 270 which may be chosen by conventional design considerations. Similarly, the circuit functions satisfactorily with the cathode of the SCR in either circuit electrically connected to side 82 or 282 of the transformer primary. This connection generally, however, leads to higher operating temperatures for the transistor switches. Certain standard modifications may be made permitting wider circuit application. The disclosed circuit works well as a ballast for mercury-arc lamps utilizing an AC input between 208 and 277 volts, plus or minus 10 percent. Where the AC input is below this range, for example, 120 volts, modification to the circuit must be made to enable the voltage across nodes 14 and 12 to reach the required 200 volts for argon ionization. A full-wave voltage doubler, wired to a separate starting electrode in the lamp itself works well, as does other voltage doubler circuit means with the more conventional lamp of the preferred embodiment. The circuit may be used for loads other than mercury-arc lamps. These variations are merely illustrative.

Having thus described the invention, what is claimed and desired to be secured by Letters Patent is:

1. A control device comprising:
a DC power input;
a switch electrically connected between said power input and a load;
means for sensing current to said load electrically connected in series with said switch and said load;
means for opening said switch responsive to said current-sensing means electrically connected to said current-sensing means and said switch;
a transformer having a primary winding electrically connected in series between said switch and said load and a secondary winding electrically connected to provide regenerative feedback to said switch during on times of said switch and electrically connected to said means for opening said switch so as to provide reversal of said opening means during off times of said switch;
a freewheeling diode current path connected in parallel with said load for discharging said transformer primary winding during off times of said switch; and
a capacitor connected in parallel with said load and said diode current path.

2. The control device of claim 1 wherein said switch comprises at least one transistor.

3. The control device of claim 2 wherein said means for sensing current is a resistor.

4. The control device of claim 3 wherein said means for opening said switch comprises a silicon-controlled rectifier with a gate circuit responsive to said current-sensing means

5. The control device of claim 4 wherein said freewheeling diode circuit comprises a first and second diode connected in series across said load.

6. In a control device having a rectified power input, a switch having an "on" and an "off" position electrically connected between said power input and a load, said switch having a first side and a second side; means for sensing current to said load electrically connected in series with said switch and said load, means for opening said switch responsive to said current-sensing means electrically connected between said current-sensing means and said switch, a freewheeling diode current path electrically connected in parallel with said load, and a capacitor electrically connected in parallel with said load and said diode current path, the improvement comprising a transformer, a diode, a resistor and a capacitor, said transformer having a primary winding electrically connected in series with said switch and said load and a secondary winding electrically connected to provide regenerative feedback to said switch during on times of said switch and electrically connected to said means for opening said switch so as to provide reversal of said opening means during off times of said switch, said diode and said resistor being electrically connected in parallel with said capacitor in series between said first and second switch sides whereby said switch discharges said capacitor whenever said switch is in its "on" position.

7. The improvement of claim 6 wherein said switch comprises at least one transistor.

8. The improvement of claim 7 wherein said means for sensing current to said load is a resistor.

9. The improvement of claim 8 wherein said means for opening said switch comprises a silicon-controlled rectifier with a gate circuit responsive to said current-sensing means.

10. The improvement of claim 9 wherein said freewheeling diode current path comprises a first and second diode connected in series across said load.

11. In a switching circuit utilizing a switch with an "on" and "off" position to interrupt circuit operation, said switch having a first side and a second side, the improvement comprising a diode, a capacitor and a resistor, said diode and said resistor being electrically connected in parallel with said capacitor in series between said first and second switch sides whereby said switch discharges said capacitor whenever said switch is in its "on" position.

12. The improvement of claim 11 wherein said switch comprises at least one transistor, said first switch side being a collector of said transistor and said second switch side being and emitter of said transistor.

13. A control device comprising:
a DC power input;
a switch electrically connected between said power input and a load;
means for sensing current to said load electrically connected in series with said switch and said load;
means for opening said switch responsive to said current-sensing means electrically connected to said current-sensing means and said switch;
a transformer having a primary winding electrically connected in series between said switch and said load and a secondary winding electrically connected to provide regenerative feedback to said switch during on times of said switch and electrically connected to said means for opening said switch so as to provide reversal of said opening means during off times of said switch;
a freewheeling diode current path connected in parallel with said load for discharging said transformer primary winding during off times of said switch;

a capacitor connected in parallel with said load and said diode current path; and

means for maintaining said switch in its off position while decay current flows through said transformer primary winding, said last-mentioned means comprising a transistor having a collector electrically connected so as to provide a shunt path around said switch during transistor conduction, an emitter electrically connected to a first side of said transformer primary winding, and a base electrically connected to said freewheeling diode current path so as to be responsive to current flow in said transformer primary winding.

* * * * *