CONTROL CIRCUIT FOR PROVIDING REGULATED CURRENT TO LAMP LOAD

15 Claims, 8 Drawing Figs.

ABSTRACT: Control circuit for gaseous discharge lamps including a variable frequency inverter for driving a high-reactance transformer having a first capacitor in the transformer secondary tuned to a harmonic of the supply voltage to provide ignition voltage for the lamps, and a second capacitor in near series resonance with the fundamental frequency of the supply voltage to provide series impedance at the fundamental frequency for stable operation after ignition, and lamp current sensing means for providing a feedback signal to a variable reference comparator circuit which adjusts the frequency output of the inverter to provide regulated lamp current for changes in input voltage and lamp voltage.
CONTROL CIRCUIT FOR PROVIDING REGULATED CURRENT TO LAMP LOAD

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a control circuit for starting and operating gaseous discharge lamps which include circuit means for adjusting lamp current to provide automatic current regulation for changes in input voltage and lamp voltage.

2. Description of Prior Art

The electrical characteristics of fluorescent lamps are such that a high starting voltage is required for ignition, and a ballast (or series impedance) is required for stable operation thereafter. The light intensity output from an energized fluorescent lamp is proportional to the RMS current through the lamp. In certain prior art arrangements high-reactance ballast transformers are used to provide voltages required for starting and operating one or more fluorescent lamps. By connecting a shunting capacitor in parallel circuit relationship with the high-reactance transformer secondary, a circuit is provided which can be made to resonate with the fundamental or harmonic of the AC input voltage, and develop a high starting voltage to ignite the lamp. In addition a capacitor may be placed in series circuit relationship with the lamp to provide a net capacitive reactance in the lamp circuit during the period subsequent to lamp ignition.

While the above system is effective in starting and operating fluorescent lamps, it does not, by itself, provide an adjustable, regulated lamp current. In certain applications, as for example in photographic or electrostatic copying machines, a regulated lamp current is required to maintain constant light intensity. While various attempts have been made to incorporate regulation in the high-reactance transformer by saturation of the magnetic core, such attempts have been generally inefficient and the arrangement in general has been difficult to adjust.

SUMMARY OF THE INVENTION

It is the purpose of the present invention to provide a control circuit for gaseous discharge devices, such as fluorescent lamps, which has simple and efficient means for adjusting and regulating lamp current. In a preferred embodiment of such arrangement, a direct current input voltage is transformed to a variable frequency inverter which is operative to provide an AC voltage waveform containing a fundamental frequency component, plus one or more harmonics, to the primary of a tuned transformer. A first capacitor, which is connected across the secondary of the high-reactance transformer, has a value such that the capacitor resonates with the leakage reactance of the transformer primary at some selected harmonic which is present in the inverter output waveform. The harmonic resonant voltage across the transformer secondary, when added to the transformer fundamental voltage, is made sufficient to ignite the lamp which is connected to the transformer secondary.

A second capacitor connected in series with the lamp is selected to be near resonance with the leakage reactance of the transformer at the fundamental inverter frequency. Once the lamp is ignited the high harmonic voltage across the first capacitor is swamped out by the large fundamental current flowing through the second capacitor, the lamp and the secondary winding of the transformer. The equivalent series impedance at the fundamental inverter frequency provides the necessary ballast for stable operation.

Lamp current control is accomplished by taking advantage of the lamp current versus frequency characteristic of the tuned transformer configuration consisting of the transformer and the first and second capacitor. Lamp current is sensed and the sensing signal is compared to a preset reference level. If the lamp current attempts to exceed the reference level, an error signal is applied to a control input of the variable frequency inverter circuit, and the output frequency of the inverter is changed in a direction to reduce the lamp current. With decrease of the lamp current below the reference point, the output of the inverter frequency changes in a direction to increase the lamp current.

BRIEF DESCRIPTION OF THE DRAWINGS

With reference to the drawings, FIG. 1 is a showing of one embodiment of the novel lamp current control circuit of the invention;

FIG. 2 is a graph of the harmonic starting voltage versus frequency characteristics of a tuned transformer configuration in such a circuit where the lamp is not ignited;

FIGS. 3A and 3B are graphs of the lamp current versus frequency characteristics of a tuned transformer configuration in such a circuit;

FIG. 4 is an illustration of a reference and comparator circuit designed to produce the curve of FIG. 3B above; and

FIGS. 5–7 are illustrations of different tuned transformer configurations for use in the novel circuit arrangement.

DETAILED DESCRIPTION

With reference to FIG. 1, there is shown thereat a preferred embodiment of the invention. As there shown, a variable frequency inverter 3 has a pair of inputs 1, 2 connected to any applicable source of direct current input voltage. Variable frequency inverter 3 includes a saturable core oscillator 10 which drives a pair of switching transistors 4, 8 in a manner to be described, to supply a square wave output over conductors 13, 14 to a center tapped primary winding 16 wound with the indicated polarity on core 17 of a tuned transformer 15. The waveform output from inverter 10 will contain a fundamental frequency component plus one or more harmonics.

Transformer 15 includes a first, second and third secondary windings 19, 20, 21 respectively wound on core 17 with the polarities indicated by the dots adjacent the respective windings. The secondary windings 19, 20 of transformer 15 are connected in series with the filaments 30, 31 respectively of a gaseous device, such as illustrated fluorescent lamp 27. Secondary winding 21 is connected in series with capacitor 26, lamp 27, and the primary winding 35 on a current transformer 36 in lamp sensing circuit 34.

A second capacitor 25 is connected across the secondary 21 of the high-reactance transformer 15. During the “start up” condition capacitor 25 is made to resonate with the leakage reactance of transformer 15 at some selected harmonic present in the inverter output waveform. The harmonic resonant voltage across secondary winding 21, when added to the transformer fundamental voltage, is made sufficient to ignite the lamp (see FIG. 2). The output frequency of inverter 3 during this “start up” condition is denoted the “starting” frequency.

Capacitor 26 is selected to be near resonance with the leakage reactance of the winding of transformer 15 at the fundamental inverter frequency. Once the lamp 27 is ignited, the voltage across capacitor 25 is swamped out by a large fundamental current flowing through secondary winding 21, capacitor 26, lamp 27, and the primary winding 35 of current transformer 36. The equivalent series impedance of these components at the fundamental inverter frequency provides the necessary ballast for stable operation.

Lamp Current Regulation

In accordance with a novel concept of the invention, current to the lamp 27 is automatically regulated by utilization of the lamp current versus frequency characteristic of the tuned transformer configuration consisting of transformer 15, capacitor 25, and capacitor 26. If the current flows through lamp 27 attempts to exceed a reference level preset in reference and comparator circuit 45, the circuit 45 generates and feeds an error signal over conductor 60 to the saturable core oscillator 10 in the variable frequency inverter 3, and the inverter output frequency is changed in a direction to reduce lamp current.
More specifically, with capacitor 25 tuned with the leakage reactance of transformer 15 to be resonant at the third harmonic of the starting frequency, the high harmonic voltage across capacitor 25 is sufficient to ignite the lamp 27, and thereafter current at the fundamental square wave frequency begins to flow through capacitor 26, lamp 27, current transformer primary winding 35 of transformer 36 and transformer secondary winding 21. The lamp current through the primary winding 35 of current transformer 36 is transferred to the center tapped secondary 37 for rectification by diodes 38 and 40 and filtering by capacitor 41. The filtered DC voltage developed across resistor 42 is proportional to the lamp current through lamp 27, and is fed over conductor 43 to the base of comparison transistor 46 in the reference and comparator circuit 45.

FIG. 1 shows a reference and comparator circuit 45 for a device wherein the starting frequency, (the fundamental inverter frequency) is above the peak of the lamp current versus frequency curve, as shown in FIG. 3A. If the device were designed so that the starting frequency were below the peak of the curve, as shown in FIG. 3B, a reference and comparator circuit 45', such as shown in FIG. 4, would be used. The following description is of the reference and comparator circuit shown in Fig. 1.

Transistor 46 is connected to compare such signal with a preset reference voltage the value of which is determined by the setting on potentiometer 50, and to such end has an emitter connected through the adjustable arm 49 of potentiometer 50 to negative conductor 2. The collector of transistor 46 is connected to the base of the control transistor 47 to thereby vary the value of the control signal fed over conductor 60 to oscillator 10. More specifically, the emitter of transistor 47 is connected to a stable voltage point established at the junction of Zener diode 51 and resistance 52 which are series connected across the DC input conductors 1, 2. The variable current output from the collector of transistor 47 (as determined by the output of transistor 46) is fed over conductor 60 to the input for oscillator 10. The collector of transistor 47 is also connected through resistor 48 and resistor 50 to negative potential on conductor 2.

In operation, the starting frequency of the oscillator 10 is determined by the voltage of the reference Zener diode 51 minus the voltage drop across resistor 48. During the startup condition, transistor 47 is off. After startup, with variation of the lamp current above the preselected value, the input signal on conductor 60 will be adjusted to vary the frequency output of inverter 10. More specifically, if the lamp current across resistor 42 attempts to exceed the reference level established over adjustable resistor 50 at the emitter of transistor 46 by more than the emitter-base drop of transistor 46, collector current will begin to flow in transistor 46, and transistor 47 will be turned on to cause an increased voltage to appear on conductor 60 and the input for the saturating core oscillator 10. Consequently the frequency output of inverter 10 will increase, and in a system having the characteristics of Fig. 3A, lamp current will decrease to hold the lamp current constant at the value determined by the setting on potentiometer 50. Correspondingly, as the lamp current decreases, and the error signal provided across resistor 42 decreases, the conductivity of transistors 46 and 47 decreases to reduce the value of the control signal over conductor 60 to oscillator 10 to decrease the output frequency of inverter 3. Reduction of the frequency output of inverter 3 will result in the increase of lamp current, whereby current to the lamp tends to remain constant despite normal variations in DC input voltage and lamp voltage drop.

It is apparent that adjustment of potentiometer 50 of different values will vary the operating frequency range of the circuit. If the current is too high, the setting on potentiometer 50 is lowered so that the reference circuit will increase the voltage to the oscillator circuit 3 to control same to operate at a higher frequency and thereby reduce the current. Raising of the setting on potentiometer 50 effects a decrease of the voltage to the oscillator 3 and a decrease in the oscillator frequency to increase the current.

If the lamp were to extinguish, the current at input 43 to transistor 46 would go zero and transistor 46 would turn off to in turn effect turn off of inverter 47. The voltage on output path 60 will go to minimum value, and at minimum voltage the frequency of the oscillator drops back to f0, the harmonic frequency drops to f0 and the lamp will refire.

The position of the peak of the lamp current versus frequency curve (FIG. 3A) on the frequency axis is determined by the value of the leakage reactance 21 and capacitor 26. Thus by changing the value of capacitor 26 it is possible to shift the peak of the curve along the frequency axes.

If the circuit components (i.e., capacitor 26 and reactance 21) are selected so that the starting frequency is below the peak of the lamp current versus frequency curve (FIG. 3B), a reference and comparator circuit 45', such as shown in FIG. 4, would be used. With reference thereto, components similar to those shown in FIG. 1 are identified by a corresponding number. In such arrangement, the output on line 60 equals the voltage established by Zener diode 51' less the voltage across resistor 101. As the voltage across resistor 101 goes up, the voltage on line 60 goes down, and vice versa. The voltage drop across resistor 101 is dependent on the amount of current going through resistor 101, and the value of current through resistor 101 is dependent on the conductivity of transistor 100, which conductivity in turn is dependent on the conductivity of transistor 46.

Current on line 43 to the base of comparison transistor 46', and the related base voltage when compared to the present reference voltage determined by the setting on potentiometer 50', will determine the conductivity of transistor 46'. An increase in current, and a corresponding increase in voltage on line 43 will cause transistor 46' to become more conductive, causing transistor 100 to become more conductive, and an increased current flow through resistor 101. With the greater voltage drop across resistor 101 as the result of the increased current flow, there is a decreasing voltage on line 60 to the oscillator, causing a decrease in frequency and, as seen in Fig. 3B, a corresponding decrease in lamp current.

By the same analogy, a decreasing current on line 43 could cause an increased voltage on line 60 delivered to the oscillator causing an increased frequency and a corresponding increase in lamp current.

Adjustment of potentiometer 50 to a lower setting will lower the current range, and adjustment of potentiometer 50 to higher setting will raise the current range for the unit in an obvious manner. If the lamp current on line 43 were to be reduced to zero, then the voltage on line 60 would be at maximum and the oscillator frequency would be increased to f0 and the resulting harmonic frequency f0 would cause the lamp to fire.

With specific reference now to the variable frequency inverter 3 as shown in Fig. 1, it will be recalled that switching transistors 4, 8 are alternately switched on by the output signals from the saturating core oscillator 10 to provide a square wave AC voltage output to transformer 15 for energizing the lamp load. As shown in Fig. 1, oscillator 10 basically comprises a pair of switching transistors 61, 62, the collector outputs of which are connected to opposite ends of the primary winding 63 which is wound on a saturable core 69 of transformer 70. The center tap 64 of primary winding 63 is connected to negative input conductor 2. Feedback windings 66, 68 wound on saturable core 69, with the indicated polarities, are series connected through resistances 65, 67 to bases of transistors 61, 62 respectively and through their respective emitters to diode 74, and also through resistor 73 to negative input conductor 2. The emitters of transistors 61, 62 are connected common to one another and to the input of the control signals are received from the reference and comparator circuit 45.

The saturable core oscillator 10 is operative in a conventional manner to provide square wave signals across secondary
3,611,021  

windings 71, 72 of transformer 70 through current limiting resistors 75, 76 to the base circuits of switching transistors 4, 8 to effect alternate switching of transistors 4, 8, and the provision whereby of a square wave AC voltage at the primary winding of transformer 15 which waveforms have a frequency identical with that of the base drive signals output from transformer 70 of oscillator 10. Feedback diodes 5 and 11 connected between the collector of transistors 4, 8 and the negative conductor 2 permit feedback of reactive current to the DC input.

With reference once more to Fig. 3A, a typical characteristic is shown therefor a circuit in which the components are selected so that the resonant frequency of capacitor 26 and the leakage reactance of transformer 15 falls somewhat below the starting frequency. The values of the tuned transformer 15 and inverter 3 are selected so that the lamp current at the starting frequency is slightly higher than the maximum desired lamp current for the worst input case and worst lamp conditions, i.e., minimum DC input voltage across conductors 1, 2 and maximum voltage drop across lamp 27.

It will be apparent that in the circuit shown in Fig. 3A, the starting frequency for the lamp is at the lower end of the operating frequency range and that the lamp current is at the higher value at start. If lamp current tends to increase, the regulating system will cause the inverter frequency to increase (i.e., above the starting frequency) and the lamp current will be reduced. As the lamp current drops, the inverter frequency is decreased, and the lamp current is regulated to the desired value.

It should be obvious that by selecting the components so that the lamp current resonant peak after start falls below the starting frequency as shown in FIG. 3B, the operating frequency range could be made to occur below the starting frequency, and lamp current would decrease as inverter frequency was made less than the starting frequency. In either case the end result is the same, the lamp current tends to remain constant at the reference level despite normal variations in DC input voltage and lamp voltage drop. The value of current is of course readily adjusted by movement of potentiometer arm 49 to change the reference level. Should the lamp become extinguished for any reason the inverter frequency drops back to the starting frequency to reignite the lamp.

The feedback control technique depicted in FIG. 1 can utilize a number of different tuned transformer configurations as shown in Figs. 5 through 7, all of which have essentially the same starting and control characteristics. If the tuned transformer/lamp circuit shown in FIG. 1 is replaced by the circuit shown in FIG. 5, it will be apparent that the operation is essentially the same as that described previously except that harmonic resonance at "start" occurs between the leakage reactance of transformer 15 and the series combination of capacitors 25 and 26. Also the voltage available to ignite the lamp at start is the voltage across the secondary 21 reduced by the capacitance divider formed by capacitor 25 and 26.

The operation of the circuit shown in FIG. 6 is identical to that of the corresponding parts shown in FIG. 1 except that the shunting capacitor has been connected to a tap on the transformer secondary 21 instead of across the entire winding.

Fig. 7 shows a further alternate circuit to that shown in FIG. 1. In this case an auto transformer connection is used which places the primary voltage of winding 16 in series with the secondary voltage; otherwise operation is essentially the same as described previously.

Numerous advantages in the use of the foregoing arrangement include the fact that no electrical or mechanical switch is required to start the lamp while yet achieving wide current control with relatively small frequency change. A nearly sinusoidal current is provided by the series resonant circuit during stable operation and by starting the lamp with harmonic resonance (rather than fundamental resonance) the circulating energy and current supplied by the source is greatly reduced, whereby less stringent requirements are placed on the inverter which provides the voltage for the lamp.

Representative values, which are not to be considered limiting, could be as follows:

\[ f_0 = 0.5 \text{ to } 2 \text{amps} \]
\[ f_0 = 20 \text{ kHz.} \]
\[ f_0 = 60 \text{ kHz. (the third harmonic)} \]

In the use of the arrangement of FIG. 3A, a typical operating range might be 20-25 kHz. where \( f_0 \) is minimum. In the use of the arrangement of FIG. 3B, a typical operating range might be 15-20 kHz. where \( f_0 \) is maximum.

While what is described is regarded to be a preferred embodiment of the invention, it will be apparent that variations, rearrangements, modifications and changes may be made therein without departing from the scope of the present invention as defined by the appended claims.

1. A control circuit for providing regulated current to a gaseous lamp comprising an input circuit over which direct current power is supplied, a variable frequency inverter circuit connected to said input means including a control input for adjusting the frequency of the output signals from said inverter circuit, a high-reactance transformer having a primary and a secondary winding, means connecting said primary winding to the output of said variable frequency inverter, a further winding means on said transformer connected to energize the filaments of said lamp, a shunt capacitor connected in shunt of said secondary winding for providing harmonic resonance during start, a series capacitor connected in series with said secondary winding and said gaseous lamp to provide fundamental resonance for lamp energization subsequent to start, and lamp current regulating means for providing a control signal to said control input to adjust the frequency output of said variable frequency inverter circuit in a current regulating mode.

2. A circuit as set forth in claim 1 in which said lamp current regulating means includes a sensing circuit for providing a signal representative of the value of the lamp current, a reference circuit for providing a preset reference signal level, and means for providing a control signal to said variable frequency inverter circuit of a magnitude related to the differential of the sensed signal relative to said preset reference signal level.

3. A circuit as set forth in claim 2 in which said reference circuit includes means for adjusting said preset reference to different values.

4. A circuit as set forth in claim 1 in which said variable frequency inverter circuit includes an oscillator circuit and a pair of switching transistors driven by said oscillator circuit, and in which said control signal is fed to said control input to vary the output frequency of said inverter circuit to maintain a constant output current and thereby a constant light intensity from said lamp.

5. A control circuit as set forth in claim 4 in which said oscillator circuit is a saturable core oscillator.

6. A control circuit as set forth in claim 1 in which said series capacitor and secondary winding of said transformer have a value which establishes the operating frequency of the variable frequency inverter circuit to be above the starting frequency of the inverter circuit.

7. A control circuit as set forth in claim 6 in which said control signal to said variable frequency inverter circuit increases the inverter output frequency to reduce lamp current responsive to detection of an increase in lamp current by said lamp current regulating means.

8. A control circuit as set forth in claim 1 in which said series capacitor and said secondary winding of said transformer has a value which establishes the operating frequency to occur below the starting frequency of the variable frequency inverter circuit.

9. A control circuit as set forth in claim 8 in which said control signal to said variable frequency inverter circuit decreases the inverter output frequency to decrease the lamp current in response to the detection of an increase in lamp current by said lamp current regulating means.

10. A control circuit as set forth in claim 1 in which said shunt capacitor is connected across only a part of said secondary winding.
11. A control circuit as set forth in claim 1 in which said primary and secondary transformer windings are connected in an autotransformer configuration with the primary voltage in series with the secondary voltage, and said shunt capacitor is connected across the secondary winding and said series capacitor is connected in series with the parallel connected secondary winding and shunt capacitor.

12. A control circuit as set forth in claim 1 in which said transformer and frequency inverter circuit have components which provide a lamp current at the starting frequency which is slightly higher than the maximum desired lamp current for the minimum input voltage over said input circuit and the maximum drop across said lamp.

13. A control circuit as set forth in claim 1 in which the signal output of said adjustable frequency inverter current comprises an AC square wave having a fundamental frequency component plus one or more harmonics.

14. A control circuit as set forth in claim 1 in which said lamp current regulating means comprises a current transformer having a primary winding connected in series with said lamp, and a center tapped secondary winding, a rectifier circuit connected to the output of said secondary winding, and a resistor connected to the output of said rectifier circuit to develop a DC signal representative of the current in said lamp circuit.

15. A control circuit as set forth in claim 1 in which said frequency circuit operates at a first frequency for ignition of said lamp and a second frequency for operation of said lamp, and wherein a momentary interruption of lamp power during operation of said lamp and a resulting loss of lamp current causes said lamp current regulating means to provide a control input signal to return the variable frequency inverter circuit from said second operating frequency to said first starting frequency for reignition of said lamp.