**May 3, 1966** W. F. POWELL, JR **3,249,799**

SYSTEMS AND APPARATUS FOR OPERATING ELECTRIC DISCHARGE DEVICES

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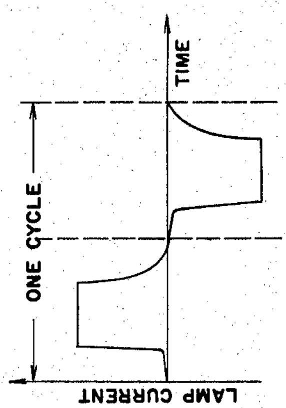


FIG. 2

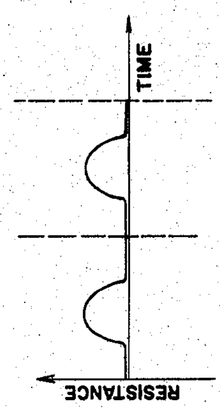


FIG. 3

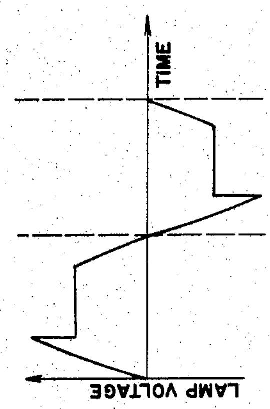


FIG. 4

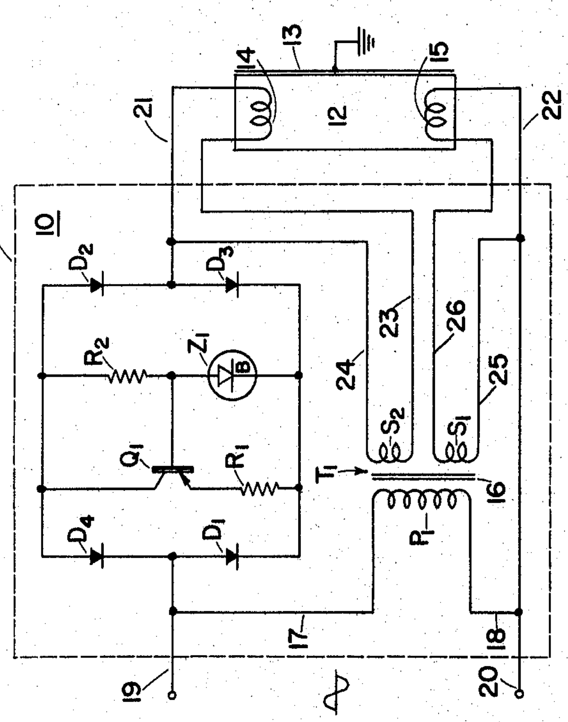


FIG. 1

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FIG. 5

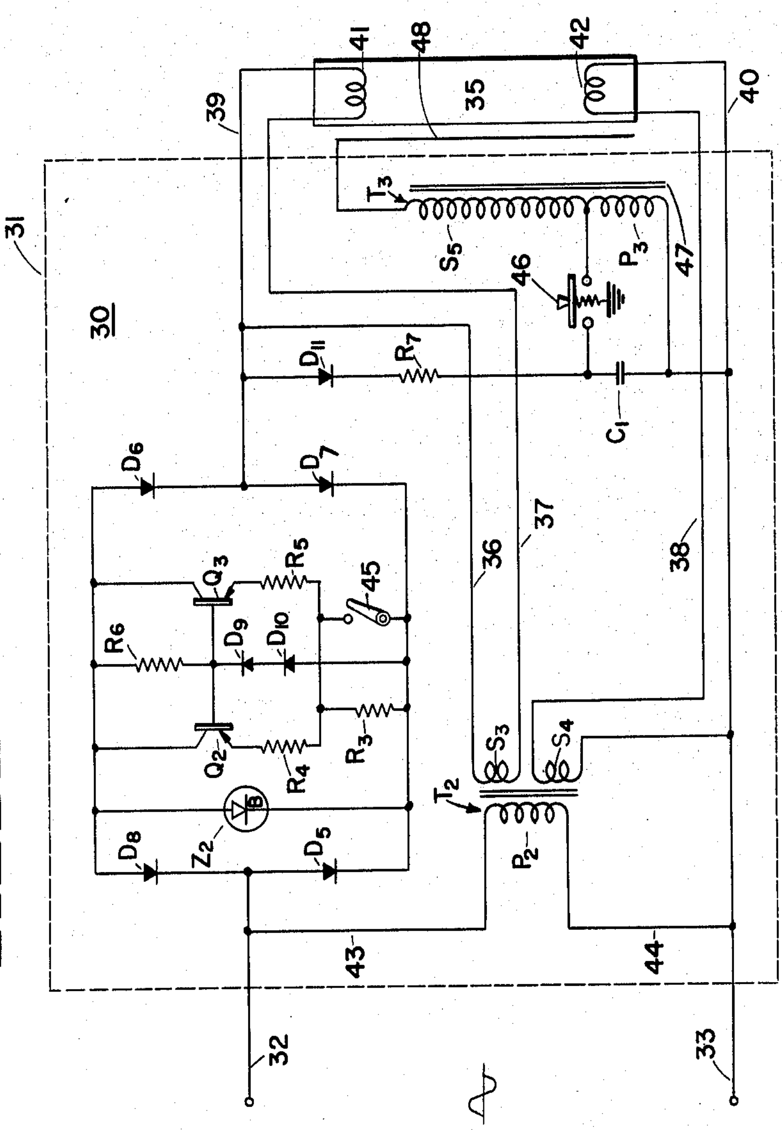


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FIG. 6

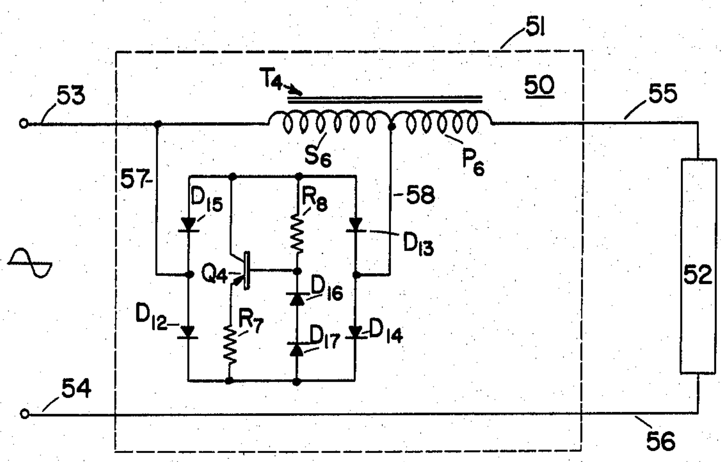


FIG. 7

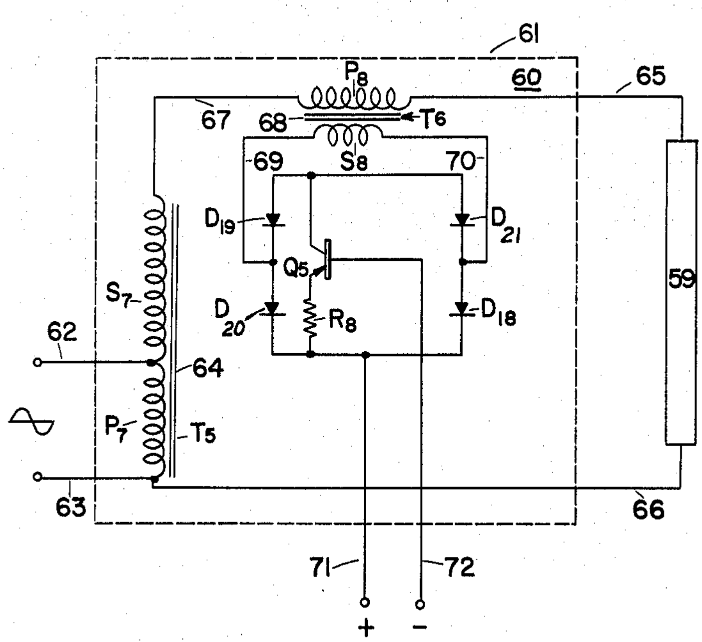


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FIG. 8

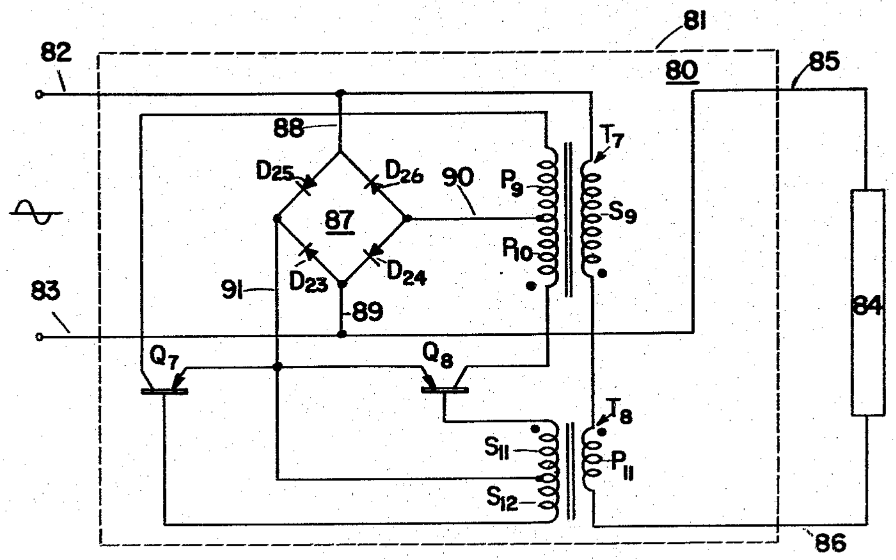
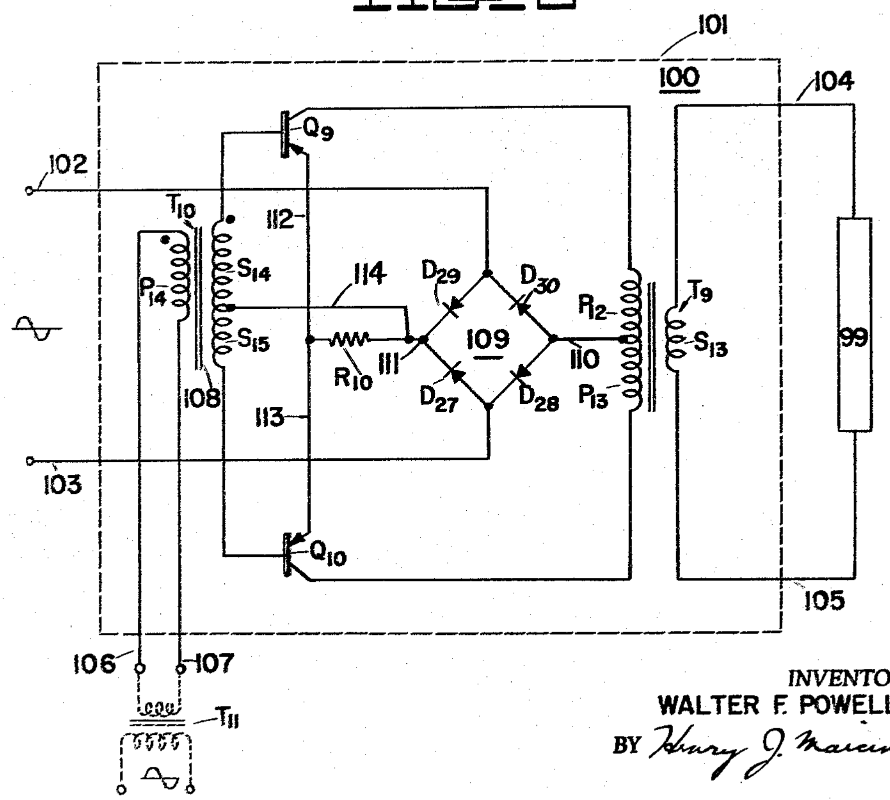



FIG. 9

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3,249,799

# SYSTEMS AND APPARATUS FOR OPERATING ELECTRIC DISCHARGE DEVICES

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Filed July 23, 1962, Ser. No. 211,554
4 Claims. (Cl. 315—98)

This invention relates generally to systems and apparatus for operating electric discharge devices, such as fluorescent lamps, with alternating current. More particularly, it relates to an improved ballasting and operating arrangement for such apparatus.

The voltage required to initiate current flow in an electric discharge lamp varies with the length and type of electric discharge lamp operated. Usually the voltage required to operate the electric discharge lamp when normal lamp current is flowing through the lamp is less than the starting voltage. If the lamp current increases during operation, the voltage drop across the lamp will decrease as lamp current increases. This tendency of the lamp voltage to vary inversely with the lamp current is generally referred to as its negative resistance characteristic.

It is, therefore, a requirement of an apparatus for operating electrical discharge lamps that it provide some means for limiting the current supplied to the lamp. If the current supplied to the lamp is not limited by some means, the current will continue to build up until the lamp is destroyed. A well-known way of limiting the current supplied to an electric discharge device, such as a fluorescent lamp, is to provide a ballasting resistor in series with the lamp.

The fluorescent lamp may be operated in a series loop arrangement which includes the ballasting resistor, the power source, and the lamp. In order to provide for stable operation and appropriate regulation of the lamp, the voltage drop across the ballasting resistor generally is about equal to the normal operating voltage of the fluorescent lamp. If the difference between the starting voltage and the normal operating voltage of the lamp in such a resistive ballasting arrangement is small, slight changes in the supply voltage would produce appreciable variations in the light output of the lamp. It is, therefore, necessary in applications where a resistor is used as a ballasting element to provide a voltage drop across the ballasting resistor that is about equal to the normal operating voltage of the lamp.

When the fluorescent lamp is operated in a series loop arrangement with a ballasting resistor, it will be appreciated that the vector sum of the voltage drop across the ballasting resistor and the voltage drop across the lamp is equal to the supply voltage. Since the supply voltage is generally maintained at a substantially constant level, as the lamp current builds up because of the inherent negative resistance characteristic of the lamp, the current through the ballasting resistor increases. This results in a proportional increase in the voltage drop across the ballasting resistor thereby causing the voltage across the lamp to decrease. Conversely, when the lamp current decreases, the voltage across the ballasting resistor decreases thereby causing the lamp voltage to increase. In this manner, the current supplied to the lamp is effectively limited.

Resistive elements have not been generally used in alternating current ballasting systems since they dissipate an appreciable amount of power. Reactive type of ballasting devices have been widely used since they consume less power than a ballasting resistor. Since reactive devices do not impede the flow of direct current, reactive ballasting elements have not been used in direct current systems for ballasting. However, resistors have been used in direct current systems despite the relatively large power losses occurring in the resistor.



A principal disadvantage of conventional resistor ballasting systems is that the power consumed by the ballasting resistor is generally about the same as that required to operate the lamp. Thus, the efficiency of the system is about fifty percent. It is desirable, therefore, to reduce the power losses in a resistive type of ballast while achieving satisfactory regulation and stability. Further, is is desirable to provide an apparatus for operating electric discharge lamps that does not require a large difference between the lamp starting voltage (open circuit voltage) and the lamp operating voltage. It will be appreciated that as the difference between the starting voltage and the operating voltage is reduced, less energy is required to be dissipated or stored in the ballasting elements. Consequently, the components in the system can be smaller in size and weight, and where a ballasting resistor is employed, less power is dissipated in the resistor.

Accordingly, it is a general object of the present invention to provide an improved apparatus and system for operating electric discharge devices.

A more specific object of the present invention is to provide an improved system and apparatus for operating electric discharge lamps, such as fluorescent lamps, wherein the lamp can be operated with a relatively smaller difference between the lamp starting voltage and the lamp operating voltage.

It is another object of the present invention to provide an improved apparatus for operating a fluorescent lamp that utilizes a resistive type of ballasting and can be operated at relatively greater efficiency than conventional ballasting systems employing resistors as ballasting elements.

In accordance with one form of my invention, I have provided an improved apparatus for operating at least one electric discharge lamp, such as a fluorescent lamp, from an alternating power source that employs a variable impedance network arrangement. The network arrangement provides an instantaneously varying impedance during a portion of each half cycle to control the current supplied to the electric discharge lamp in order to prevent the lamp from destroying itself because of its negative resistance characteristic. In the preferred form of my invention, the variable impedance network includes at least one transistor that is driven to provide an instantaneously variable impedance to control the lamp current, and a relatively low impedance is provided during an early and late portion of each half circle. The emitter and collector electrodes are connected in circuit with the output terminals of a full-wave bridge rectifier. Base drive for the transistor may be obtained from the full-wave bridge rectifier or may be obtained from a separate source, such as a feedback source, a variable D.C. supply or a fixed D.C. supply. The input terminals of the bridge rectifier may be placed directly in the lamp circuit, or if it is desired to employ transistors having relatively lower voltage ratings, a transformer may be interposed between the bridge rectifier and the lamp circuit.

In another form of my invention, I have provided a variable impedance bridge network for controlling the current supplied to a fluorescent lamp which is comprised of a full-wave rectifier, a pair of transistors, and a transformer. One the windings of the transformer is connected in circuit with at least one output lead and input lead of the apparatus to place the variable impedance bridge network in series circuit with the lamp during operation. The other of the transformer windings is connected in circuit with the collector electrodes of the transistors and has a tap connected in circuit with the output terminals of the full-wave rectifier. Further, a resistor may be connected in circuit with the other of the output terminals and in circuit with the emitter electrode of the transistors to function as a current measuring element. A bias supply means is connected in circuit with the base electrodes of the transistors. The transistors are driven by the bias supply means to provide an instantaneously variable impedance in the primary circuit of the transformer whereby the current supplied to the lamp is regulated.

According to another aspect of the invention, the bias supply means is comprised of a transformer having a primary and a center tapped secondary winding. The primary winding is connected to a suitable signal source. For example, the transformer may be connected across the output leads of the apparatus where is is desired to sense the voltage or in series with the lamp where it is desired to sense the lamp current or to a separate source having a predetermined wave shape where is is desired to provide a lamp current with a corresponding wave shape. Further, the center tap of the secondary winding is connected to one of the output leads of the full-wave bridge rectifier, and the ends of the secondary winding are connected to the base electrodes of the pair of transistors to supply base drive current thereto.

The subject matter which I regard as my invention is set forth in the appended claims. The invention itself, however, together with other objects and advantages may be better understood by referring to the following description taken in conjunction with the accompanying drawings in which:

FIGURE 1 is a schematic circuit diagram illustrating one embodiment of my invention for operating a fluorescent lamp from an alternating current source;

FIGURE 2 is an illustration of the lamp current waveform of an arbitrary cycle of the lamp current supplied by the apparatus illustrated in FIGURE 1;

FIGURE 3 illustrates the instantaneous variation in the resistance provided by variable impedance circuit shown in FIGURE 1 in one cycle corresponding to the cycle of the lamp current waveform illustrated in FIGURE 2;

FIGURE 4 represents an oscillogram of the lamp voltage corresponding to the lamp current waveform illustrated in FIGURE 2;

FIGURE 5 is a schematic circuit diagram of another embodiment of the invention;

FIGURE 6 illustrates a schematic circuit diagram of another form of my invention incorporating an arrangement for reducing the voltage requirements of the transistor or transistors employed in the variable impedance bridge network;

FIGURE 7 is a schematic circuit diagram of a ballast apparatus of the invention adapted for dimming one or more fluorescent lamps from a variable D.C. source;

FIGURE 8 is a schematic circuit diagram of an apparatus embodying another form of my invention wherein the variable impedance bridge network provides the bucking voltage to stabilize the lamp and is activated in response to feedback signal from lamp circuit; and

FIGURE 9 illustrates another embodiment of my invention in which the variable impedance bridge network of my invention also supplies the voltage to operate a fluorescent lamp.

Referring now more particularly to the schematic circuit diagram shown in FIGURE 1, the apparatus **10** embodying one form of my invention is shown enclosed in a dashed rectangle **11** and is connected in circuit with a hot cathode fluorescent lamp **12**. The fluorescent lamp **12** is disposed in capacitive relationship with a grounded conductive plate **13** to aid in starting the lamp **12**. The grounded conductive plate **13** is usually placed in circuit with the lead **20** which is adapted for connection to the low potential or grounded side of the power supply.

When the apparatus **10** is energized, the lamp cathodes



**14, 15** are supplied continuously with heating current by a small filament transformer $T_1$.

The filament transformer $T_1$ includes a pair of secondary windings $S_1$, $S_2$ which are inductively coupled on a magnetic core **16** with the primary winding $P_1$ connected by leads **17, 18** across a pair of input terminal leads **19, 20**. The input terminal leads **19, 20** are provided for connection to a suitable alternating power source, such as a 120 volt, 60 cycle supply. The output of the apparatus **10** is supplied to lamp **12** by a plurality of leads including a pair of output leads **21, 22** and leads **23, 24** and **25, 26** which provide the connections for supplying the cathode heating current to the lamp cathodes **14, 15**.

A full wave bridge rectifier having the diodes $D_1$, $D_2$, $D_3$ and $D_4$, a PNP transistor $Q_1$, resistors $R_1$, $R_2$, and Zener diode $Z_1$ functions as a variable impedance bridge network in accordance with the invention to provide an instantaneously variable impedance in series circuit with the lamp **12** in each half cycle of the alternating supply. The resistor $R_1$ is a current measuring resistor and the voltage across the resistor $R_1$ is applied to the emitter electrode of the transistor $Q_1$. The resistor $R_2$ is selected to provide a resistance sufficiently low so that at low value of lamp current, below the limiting level, transistor $Q_1$ is driven to a low impedance state. This situation occurs during the early portion and late portion of each half cycle of the power supply. The voltage across the Zener diode $Z_1$ is applied at the base electrode of transistor $Q_1$. Thus, the transistor $Q_1$ serves as an emitter-follower and controls the current passing through the transistor $Q_1$ by passing a current which will maintain the voltage drop across the resistor $R_1$ nearly equal to the breakdown voltage of the Zener diode $Z_1$.

When the alternating power source is of such polarity that the voltage at input terminal lead **19** is positive with respect to the voltage at input terminal lead **20**, it will be seen that the current flow through apparatus **10** takes a path which includes input terminal lead **19**, diode $D_1$, resistor $R_1$, transistor $Q_1$, diode $D_2$, output lead **21**, the fluorescent lamp **12**, output lead **22** and input lead **20**. It will be appreciated that when the polarity of the alternating supply reverses, the current flow through the apparatus **10** also reverses and takes a path which includes input lead **20**, output lead **22**, fluorescent lamp **12**, output lead **21**, diode $D_3$, resistor $R_1$, transistor $Q_1$, diode $D_4$, and input lead **19**. From the foregoing description of the flow of current through the apparatus **10**, it will be seen that the transistor $Q_1$ in conjunction with the diodes $D_1$, $D_2$, $D_3$, $D_4$ exercises control of the current in each half cycle.

Referring now to FIGURES 1, 2, 3 and 4, the operation of the apparatus **10** will now be more fully described. Let us assume that the alternating voltage applied across input leads **19, 20** is beginning its positive swing at the start of an arbitrary cycle. As will be seen from the lamp current waveform shown in FIGURE 2, at the start of the positive half cycle there is no significant current flow to the lamp **12**. From the waveform shown in FIGURE 3, it will be seen that at the start of the half cycle and during the early portion of each half cycle the resistance in series with the lamp **12** presented by the variable impedance circuit is low relative to impedance of the lamp **12**. This impedance is relatively small since the transistor $Q_1$ is in a low impedance state. As will be seen from the lamp voltage waveform shown in FIGURE 4, the supply voltage is applied across the lamp **12** during the early portion of the half cycle since the lamp impedance is substantially greater than the impedance across the rectifiers $D_1$, $D_2$, $D_3$, $D_4$ and transistor $Q_1$.

As the instantaneous voltage applied across the lamp **12** reaches a value in the half cycle where it is sufficient to ignite lamp **12**, the lamp will begin to conduct. This is evidenced in FIGURE 2 by the rapid rise of the instantaneous lamp current and in FIGURE 4 by a sharp drop in the lamp voltage. The instantaneous lamp current rises rapidly until the voltage drop across the current measuring resistor $R_1$ nearly equals the reverse breakdown voltage developed across the Zener diode $Z_1$. At this point, the transistor $Q_1$ seeks to maintain the current flow through the current measuring resistor $R_1$ connected to the emitter electrode at a level to maintain the voltage at the emitter electrode approximately equal to the breakdown voltage of the Zener diode $Z_1$.

As the instantaneous supply voltage increases in the half cycle, the junction resistances of the transistor $Q_1$ varies, as will be seen in FIGURE 3, to limit or clamp the current at a substantially constant level until the instantaneous value of the supply voltage falls off in the later portion of the half cycle to a point where the supply voltage cannot maintain the clamped current level. Hence, the resistor $R_1$ cannot provide a voltage drop nearly equal to the breakdown voltage of the Zender diode $Z_1$. During this portion of the cycle, as will be seen in FIGURE 3, the variable impedance circuit provides a relatively small resistance to the flow of current and the supply voltage is applied across lamp **12** as will be seen from the lamp voltage waveform shown in FIGURE 4.

From the foregoing description of the operation of the circuit, it will be apparent that during the early portion and the later portion of each half cycle, the variable impedance circuit presents a relatively insignificant amount of impedance to current flow, and consequently a negligible amount of instantaneous power is dissipated in the apparatus **10**. However, during the middle portion of the cycle, as will be seen in FIGURE 3, a varying resistance is provided by the variable impedance circuit to limit the lamp current at some preselected value as determined by the resistive value of the current measuring resistor $R_1$ and the voltage level selected for the Zener diode $Z_1$. Accordingly, power is consumed only when it is necessary in each half cycle to limit the current supplied to lamp **12** to a preselected value. It will be appreciated that in conventional resistive ballasting systems, the resistance provided by the ballasting resistor presents an impedance of constant magnitude. As a result, in such systems, power is instantaneously dissipated by the ballasting resistor during the entire cycle and particularly, in the late portion of the cycle.

An important advantage of the present invention is that improved efficiencies can be achieved. With a circuit that actively controls the resistance it is possible to operate a fluorescent lamp at an operating voltage that more closely approaches the supply voltage than was heretofore possible with conventional resistive type of ballasts. Further, less power is dissipated in the ballast circuit since resistance is instantaneously introduced in the circuit when it is needed.

The apparatus **10** shown in FIGURE 1 was constructed and used to operate a 30 watt rapid start lamp and a 40 watt rapid start fluorescent lamp. The following circuit components used in the variable impedance bridge network are given by way of an example of a "reduction to practice" of the invention and are not intended to limit the invention in any way:

| | |
|---|---|
| Full wave bridge rectifier | Mallory bridge rectifier FW 600. |
| Transistor $Q_1$ | 2N1073B. |
| Zener diode $Z_1$ | Motorola 1N3016B with a reverse breakdown voltage of 6.8 volts. |
| Resistor $R_1$ | 10 ohms, 5 watts. |
| Resistor $R_2$ | 1000 ohms, 2 watts. |

In Table I, I have tabulated the lamp voltage, the lamp current, the D.C. bridge voltage, and efficiency corresponding to input voltages of 90, 100, 110 and 120 volts when the apparatus **10** employing the aforedescribed circuit components was used to operate a 30 watt rapid start fluorescent lamp.



*Table I*

| | | | | |
|---|---|---|---|---|
| Input voltage (Volts, R.M.S.) | 90 | 100 | 110 | 120 |
| Lamp voltage (Volts, R.M.S.) | 74 | 72 | 72 | 72 |
| Lamp current (Amperes, R.M.S.) | .350 | .430 | .470 | .500 |
| Bridge voltage (Volts, D.C.) | 12 | 22 | 30 | 39 |
| Efficiency (percent) | 74 | 72 | 65 | 60 |

In Table II, I have summarized the lamp voltage, lamp current, the D.C. bridge voltage, and efficiency corresponding to supply voltages of 115, 120 and 125 volts when the apparatus **10** was used to operate a 40 watt rapid start lamp.

*Table II*

| | | | |
|---|---|---|---|
| Input voltage (Volts, R.M.S.) | 115 | 120 | 125 |
| Lamp voltage (Volts, R.M.S.) | 100 | 99 | 97 |
| Lamp current (Amperes, R.M.S.) | .375 | .425 | .460 |
| Bridge voltage (Volts, D.C.) | 11.5 | 18 | 23 |
| Efficiency (percent) | 87.0 | 82.6 | 77.6 |

From the data presented in Tables I and II, it will be apparent that as the operating voltage more nearly approaches the supply voltage, the efficiency of the apparatus **10** improves. It will be understood that it is possible with the variable impedance bridge network arrangement to operate fluorescent lamps with satisfactory regulation and stability at voltages that are closer to the supply voltage than was heretofore possible in comparable resistive ballasts of the prior art. When the 30 watt fluorescent lamp was operated by apparatus **10**, the efficiency was increased from 60 percent to 74 percent as the input voltage was decreased from 120 volts to 90 volts. For the 40 watt rapid start lamp, it will be noted that the efficiency of the apparatus **10** was increased from 77.6 percent to 87.0 percent when the input voltage was decreased from 125 volts to 115 volts. It will be appreciated that conventional resistive ballasts have efficiencies of approximately 50 percent corresponding to a 2 percent change in current for a 1 percent change in line voltage. It will be noted from Table II that this regulation is readily achieved at 80% efficiency with the variable impedance bridge network.

Referring now to FIGURE 5, I have illustrated therein another embodiment of my invention wherein a pair of transistors $Q_2$ and $Q_3$ are connected in parallel within a full wave bridge in a variable impedance bridge arrangement. The apparatus is generally identified by reference numeral **30** and is shown enclosed in a dashed rectangle **31**. A pair of input leads **32, 33** are brought externally of the apparatus **30** for connection to a suitable alternating power supply, such as a 120 volt, 60 cycle supply. The apparatus **30** is connected in circuit with a fluorescent lamp **35** by means of a plurality of electrical leads **36, 37, 38** and output leads **39, 40**. A small filament transformer $T_2$ having a primary winding $P_2$ and secondary windings $S_3$, $S_4$ was employed to provide a cathode heating current for cathodes **41, 42** of fluorescent lamp **35**. The primary winding $P_2$ is connected across input leads **32, 33** by leads **43, 44**.

It will be seen that the full wave bridge is comprised of diodes $D_5$, $D_6$, $D_7$ and $D_8$. Transistors $Q_2$ and $Q_3$ are connected across the output of the full wave bridge so that a unidirectional current flows through the parallel branches of the variable impedance bridge network that include transistor $Q_2$ and transistor $Q_3$. In each half cycle of the alternating supply, the main path of current flow within the variable impedance bridge network is through resistor $R_3$, or through switch **45** when it is closed, and through the parallel branches which include current measuring and balancing resistors $R_4$, $R_5$ and transistors $Q_2$, $Q_3$.

Switch **45** is in a closed position when it is desired to operate the fluorescent lamp **35** at its normal light output level and is opened when it is desired to operate the lamp **35** at a lower level of illumination. When switch **45** is opened, the resistor $R_3$ is connected in series with the resistors $R_4$ and $R_5$, and the transistors $Q_2$ and $Q_3$ clamp the current at a lower current level in each half cycle.

A Zener diode $Z_2$ is connected in parallel with the transistors $Q_2$ and $Q_3$ to protect the transistors from excessive transient voltages. The resistive valve of resistor $R_6$ is selected so that at low bridge currents the base drive current is sufficient to drive the transistors $Q_2$ and $Q_3$ into a near saturated condition. This occurs usually in the early and late portion of each half cycle of the alternating power supply. A pair of diodes $D_9$ and $D_{10}$ serve substantially the same purpose as the Zener diode $Z_1$ in the variable impedance bridge network shown in FIGURE 1. The sum of the junction drops of the diodes $D_9$ and $D_{10}$ was approximately 1.6 volts and provided the reference voltage at which the transistors $Q_2$ and $Q_3$ were clamped. Where a lower reference voltage is provided, it will be appreciated that the resistance of the current measuring resistors $R_4$, $R_5$ can be reduced in order to clamp the transistors $Q_2$ and $Q_3$ at a given current level. An advantage of the present arrangement employing two diodes in place of a Zener diode is that a pair of ordinary diodes is less expensive than a single Zener diode.

In the apparatus **30** shown in FIGURE 5, I have included a starting circuit to aid in the initial ignition of the lamp **35**. The starting circuit includes a tuned network which is comprised of a capacitor $C_1$, a resistor $R_7$, a diode $D_{11}$, a transformer $T_3$, and momentary switch **46**. The transformer $T_3$ includes a primary winding $P_3$ and a secondary winding $S_5$ inductively coupled therewith on a magnetic core **47**. One end of the secondary winding $S_5$ is connected to the primary winding $P_3$ and the other end is connected to a conductive plate **48**, which may be a lamp fixture, a conductive strip in the proximity to the lamp **35**, or a conductor wound around the lamp **35**. It will be seen that the starting circuit is connected across the output leads **39**, **40** of the apparatus **30** and that the starting circuit is energized in alternate half cycles since it is forward biased only during the alternate half cycles of the alternating power supply.

Essentially, the operation of the apparatus **30** shown in FIGURE 5 is the same as the apparatus **10** of FIGURE 1. During operation the variable impedance bridge network provides a low impedance in series circuit with the lamp **35** during the early and later portions of each half cycle when a current limiting action is not needed because the instantaneous values of the lamp current are below the clamping value. During the middle portion of each half cycle when the alternating voltage rises to its peak value and falls off from the peak value, a variable resistance or impedance is introduced in series circuit with the lamp impedance to limit the current supplied to the lamp **35**.

Initially, when the apparatus **30** is energized by connecting the input leads **32**, **33** in circuit with an alternating power source, lamp **35** is started by actuating the switch **46**. An oscillatory pulse is applied across the primary winding $P_3$ thereby causing an oscillatory voltage to be induced across the secondary winding $S_5$. Since the conductive strip **48** is capacitively coupled with lamp **35**, current flows between the conductive strip **48** and the electrodes **41**, **42** to aid in starting ionization within the lamp **35**. When lamp **35** is ignited, the momentary switch **46** is released, and the starting circuit becomes ineffective in the operating circuit.

At the instant lamp **35** conducts, the transistors $Q_2$ and $Q_3$ are in a low impedance state since the base electrodes are negatively biased by the voltage drop across the diodes $D_9$ and $D_{10}$. When switch **45** is closed, the lamp current rises rapidly to a level determined by the resistive value of the current measuring resistors $R_4$ and $R_5$. The lamp current rises until the voltage drop across each of the current measuring resistors $R_4$, $R_5$ approximates the sum of the junction drops across diodes $D_9$ and $D_{10}$. The transistors $Q_2$ and $Q_3$ function as emitter-followers to maintain the emitter current at a level so that the voltage drops across the resistors $R_4$ and $R_5$ do not exceed the sum of the junction drops of the diodes $D_9$ and $D_{10}$.

When the switch **45** is in the open position, the resistor $R_3$ is introduced into the emitter circuit, and the transistors $Q_2$ and $Q_3$ clamp the current at a lower level. Consequently, the current supplied to the fluorescent lamp **35** is reduced. It will be apparent, therefore, that the fluorescent lamp **35** can be readily operated at a high and a low light output level by the addition of the switch **45** and the resistor $R_3$. If a wider dimming range is desired, this can be readily accomplished by connecting a variable resistor in circuit with the emitter electrodes of transistors $Q_2$ and $Q_3$ or by varying the reference voltage applied at the base electrodes.

Taking an arbitrary half cycle of the supply voltage and assuming that the polarity of the supply voltage is such that its polarity at lead **32** is positive with respect to input lead **33**, I will now describe the main current flow through the apparatus **30**. Starting with the input lead **32**, the current from the power source traverses a path which includes diode $D_5$, the switch **45** when it is closed, the parallel branches which include resistors $R_4$, $R_5$ and transistors $Q_2$, $Q_3$, respectively, diode $D_6$, output lead **39**, the fluorescent lamp **35**, output lead **40** and input lead **33**. During the negative half cycle, the path of the main current flow through the apparatus reverses, and the diodes $D_7$ and $D_8$ of the variable impedance bridge circuit conduct the lamp current through the variable impedance bridge network.

The apparatus **30** shown in FIGURE 5 was constructed to operate a four foot high output rapid start fluorescent lamp. The fluorescent lamp required a current of 800 milliamperes at normal light output. The following circuit components used are given as an example of a specific exemplification of the invention:

| | |
|---|---|
| Zener diode $Z_2$ | Mallory FW 600 bridge. |
| Transistors $Q_2$, $Q_3$ | 100 volts, 1 watt. |
| Resistors $R_4$, $R_5$ | Bendix transistors 2N1653. |
| Resistor $R_3$ | 3 ohms, 1 watt. |
| Resistor $R_6$ | 5 ohms, 2 watts. |
| Diodes $D_9$, $D_{10}$, $D_{11}$ | 1000 ohms, 5 watts. |
| Capacitor $C_1$ | 1N2070. |
| Transformer $T_3$ | .01 microfarad, 600 volts. |
| Full wave bridge diodes $D_5$, $D_6$, $D_7$, $D_8$. | Universal wound, 200 turns with tap brought out at 20 turns, ferrite core. |

It was found that the apparatus employing the foregoing circuit components operated the four foot rapid start lamp on both the bright and dim positions when the supply voltage was varied from 115 volts to 130 volts R.M.S.

It will be understood that a voltage equal to the difference between the instantaneous supply voltage and the lamp voltage appears across the transistors $Q_1$, $Q_2$, $Q_3$ used in the variable impedance networks shown in FIGURES 1 and 5. For example, when apparatus **30** of FIGURE 5 was used to operate a 40 watt rapid start fluorescent lamp from a 120 volt, 60 cycle alternating supply, the voltage developed across the transistors $Q_3$, $Q_3$ was as high as 80 volts. Since transistors having high current and low voltage ratings are presently more economical to use, I have shown in FIGURE 6 an embodiment of my invention in which transistors of lower voltage ratings may be used as compared with the transistor used in the embodiments shown in FIGURES 1 and 5. I have found that it is possible to reduce the voltage ratings of the transistor used in a variable impedance network by connecting the input terminals of the bridge across a secondary winding of a transformer and connecting the transformer in series circuit with the electric discharge lamp.

Having more specific reference to FIGURE 6, I have shown therein an apparatus **50** for operating a fluorescent lamp **52** wherein the variable impedance network is connected across a secondary winding $S_6$ of an autotransformer $T_4$. In the embodiment of the invention shown in FIGURE 6, as well as in embodiments shown in FIGURES 7, 8 and 9, I have not included a starting aid circuit and cathode heating connections. It will be understood, of course, that a starting aid circuit and cathode heating connections, such as I have shown in FIGURES 1 and 5 and other arrangements may be used, if required, in conjunction with the operating circuits which I have schematically illustrated in FIGURES 6, 7, 8 and 9.

The apparatus **50** for operating the fluorescent lamp **52** is shown enclosed in a dashed rectangle **51**, which represents the housing means for the apparatus **50**. A pair of input leads **53**, **54** are provided for connection to a suitable alternating current supply. Output leads **55**, **56** are connected in circuit with the lamp **52** and supply the output of the apparatus to the lamp **52**. The autotransformer winding $P_6$ of transformer $T_4$ is connected in circuit with input lead **53** and the output lead **55**. The secondary winding $S_6$ is connected with the input of a full wave bridge comprised of diodes $D_{12}$, $D_{13}$, $D_{14}$ and $D_{15}$ by leads **57**, **58**.

The variable impedance network includes a transistor $Q_4$, a current measuring resistor $R_7$, a resistor $R_8$ that sets the base drive current, and a pair of diodes $D_{16}$, $D_{17}$. The sum of the junction drops of the diodes $D_{16}$, $D_{17}$ provides a reference voltage at which the current through the transistor $Q_4$ will be clamped at a predetermined level. When the current through the current measuring resistor $R_7$ is sufficient in magnitude to cause the voltage drop thereacross to be nearly equal to the reference voltage, the transistor $Q_4$ attempts to limit the current at this level and therefore also limits the current through the autotransformer winding $P_6$. A principal advantage of this arrangement is that the voltage rating of the transistors can be appreciably reduced.

During operation, as the supply voltage begins its positive swing, the impedance of the fluorescent lamp **52** is much greater than the impedance of the transformer $T_4$. At the start of the positive half cycle of the supply voltage, the transistor $Q_4$ is in a low impedance state and essentially the bridge impedance appears across the secondary winding $S_6$ of the transformer $T_4$. Consequently, the secondary winding $S_6$ is in effect short circuited, and all of the supply voltage will appear across the lamp **52**. When the fluorescent lamp **52** ignites, current flow is initiated through the autotransformer winding $P_6$. The lamp current rises sharply since a very low impedance is presented to current flow at this particular instant. When the current reaches a point where the voltage drop across the current measuring resistor $R_7$ approximates the reference voltage (the sum of the junction voltage drops of the diodes $D_{16}$, $D_{17}$), the transistor $Q_4$ begins its regulating action and provides a varying impedance to current flow.

Thus, the current during this portion of the cycle in the secondary winding $S_6$ and the autotransformer winding $P_6$ is limited. Hence, the current supplied to lamp **52** is limited. When the current falls off in the later portion of the half cycle, the transistor $Q_4$ again presents a very low impedance so that essentially all of the supply voltage is applied across lamp **52**.

Turning now to FIGURE 7, I have illustrated therein another embodiment of the invention in which a transformer $T_5$ is provided to supply a stepped-up voltage to operate a fluorescent lamp **59**. An isolated step-down transformer $T_6$ serves as a part of the variable impedance bridge network to provide the required ballasting action for lamp **59** in accordance with the invention. The apparatus of FIGURE 7 is generally identified by reference numeral **60** and is enclosed in a dashed rectangle **61** representing the housing means for the apparatus **60**.

The input transformer $T_5$ is comprised of a primary winding $P_7$ connected across a pair of input leads **62**, **63** and a secondary winding $S_7$ inductively coupled with the primary winding $P_7$ on a magnetic core **64**. The output of apparatus **60** is applied across the fluorescent lamp **59** by output leads **65**, **66**.

In order to permit a transistor of a lower voltage rating to be used, the transformer $T_6$ is provided. The transformer $T_6$ includes a primary winding $P_8$ connected in circuit with a lead **67** and output lead **65**, a magnetic core **68** and secondary winding $S_8$. The secondary winding $S_8$ is connected by leads **69**, **70** across the input of a bridge rectifier comprised of the diodes $D_{18}$, $D_{19}$, $D_{20}$ and $D_{21}$. A transistor $Q_5$ and a current measuring resistor $R_8$ are connected across the output of the bridge rectifier. It will be noted that in this exemplification of the invention base drive current is obtained from a separate variable D.C. source and is applied to the base electrode of transistor $Q_5$. A terminal lead **72** is provided for connection to the negative side of the variable D.C. source and terminal lead **71** is provided for connection to the positive side of the D.C. source.

The apparatus **60** shown in FIGURE 7 is particularly adaptable to applications where it is desired to dim a large number of fluorescent lamps. To control the luminous output of the fluorescent lamps, it is only required to provide a variable D.C. supply to the base electrode of the transistors in each of apparatuses used to operate fluorescent lamps. By varing the D.C. voltage to the transistors, the level at which the transistor will clamp the current can be readily varied. In Table III below, I have presented the data taken for the apparatus **60** shown in FIGURE 7, when the apparatus **60** was used to operate a 40 watt rapid start lamp at normal light output and at a 10:1 dimming ratio, or in other words, when normal operating current and $1/10$ of the normal operating current was supplied to the lamp **59**:

*Table III*

| | Normal Light Output | 10:1 Dimming Ratio |
|---|---|---|
| Input volts (R.M.S.) | 139 | 139 |
| Lamp volts (R.M.S.) | 98 | 123 |
| Lamp current (milliamperes) | 450 | 45 |
| Bridge current (milliamperes) | 880 | 110 |
| Bridge volts (peak) | 38 | 30 |
| Bias volt (D.C.) | 9.9 | 1.8 |

From the data shown in the Table III, it will be apparent that a 40 watt rapid start lamp can be readily dimmed and operated by reducing the bias voltage supplied to transistor $Q_5$ from 9.9 volts D.C. to 1.8 volts D.C.

The apparatus **60** shown in FIGURE 7 operates in a similar manner as the apparatus **50** shown in FIGURE 6 to regulate the lamp current. The voltage of the D.C. source connected across terminal leads **71**, **72** provides the reference voltage for the transistor $Q_5$. As this voltage is decreased, the level at which the current through the transistor $Q_5$ is clamped also proportionally decreases.

In FIGURE 8, I have illustrated another form of my invention in which a variable impedance bridge network is employed to dynamically vary the primary voltage of a bucking transformer $T_7$ connected in the lamp circuit. The impedance introduced in the circuit is high during a portion of each half cycle so that the bucking transformer presents no appreciable impedance to lamp current flow. During the portion of each half cycle when the electric discharge lamp conducts current, one of the pair of transistors $Q_7$ or $Q_8$ provides a varying impedance in the primary circuit of the bucking transformer $T_7$ to vary its voltage and thus regulate the lamp current, as will hereinafter be more fully described.

The apparatus **80** embodying this form of my invention is shown enclosed in a dashed rectangle **81** which substantially represents the enclosure for the apparatus

80. A pair of input terminal leads 82 and 83 is provided for connection to a suitable alternating current supply. The output of the apparatus 80 is applied across the lamp 84 by means of output leads 85 and 86.

A bucking voltage is introduced into the lamp circuit during operation by a variable impedance network. This network is comprised of a transformer $T_7$ having a pair of primary windings $P_9$, $P_{10}$ and a secondary winding $S_9$, a full wave rectifier 87 including diodes $D_{23}$, $D_{24}$, $D_{25}$ and $D_{26}$, transistors $Q_7$, $Q_8$ and a current transformer $T_8$ having a primary winding $P_{11}$ and secondary windings $S_{11}$, $S_{12}$ inductively coupled therewith. The secondary winding $S_9$ of transformer $T_7$ is closely coupled with the primary windings $P_9$, $P_{10}$ so that transformer $T_7$ has a low magnetizing reactance and does not impede the current in the lamp circuit when transistors $Q_7$ and $Q_8$ are not conducting. The input terminals of the full wave rectifier 87 are connected across input leads 82, 83 by leads 88, 89 and the output terminals of the full wave rectifier 87 are connected in circuit with the primary windings $P_9$, $P_{10}$ by lead 90 and with the transistors $Q_7$, $Q_8$ by lead 91 and the connections to the emitter electrodes.

It will be seen that the current transformer $T_8$ provides voltages across the secondary windings, $S_{11}$ and $S_{12}$ that are applied across the emitter-base junctions of transistors $Q_7$ and $Q_8$. In each half cycle of the alternating current supply one of the transistors $Q_7$, $Q_8$ will be forward biased and the other will be reverse biased. When one of the transistors $Q_7$, $Q_8$ conducts, a portion of the output of the full wave rectifier 87 is applied across one of the primary windings $P_9$ or $P_{10}$ to induce a voltage across the secondary winding $S_9$ that is in an opposing or bucking relation with the instantaneous voltage applied across the input terminal leads 82, 83.

Operation of the apparatus 80 is initiated by connecting the input terminal leads 82, 83 in circuit with a suitable power supply, such as a 120 volt, 60 cycle alternating current supply. During the open circuit condition, all of source voltage is applied across output leads 85, 86, and lamp 84 will ionize and conduct current. When lamp 84 conducts current, current will also flow through the primary winding $P_{11}$ of the current transformer $T_8$.

Let us take an arbitrary alternation of the alternating current supply when the polarity of the voltage is such that the input terminal lead 83 is positive with respect to input terminal lead 82. The path of current flow will be from input terminal lead 83, to output lead 85, the lamp 84, the primary $P_{11}$, the secondary $S_9$ and input terminal lead 82. The current flow through the primary winding $P_{11}$ causes a voltage to be applied across the winding $P_{11}$, and the polarity of this voltage will be such that the lower end of the winding $P_{11}$, as seen in FIGURE 8, is positive with respect to the upper end. Accordingly, a voltage is induced across the secondary windings $S_{11}$ and $S_{12}$ that causes the base electrode of transistor $Q_8$ to be negative or forward biased and that causes the base electrode of transistor $Q_7$ to be positive with respect to its emitter electrode. As a result, transistor $Q_7$ is in a high impedance state, while transistor $Q_8$ is switched into conduction. A part of the full wave rectified voltage output of the rectifier 87 is applied across primary winding $P_9$ depending upon the magnitude of the current in primary winding $P_{11}$. The base current drive to transistors $Q_7$, $Q_8$ can be balanced if necessary by sliding the tap which divides the secondary into windings $S_{11}$ and $S_{12}$ or by connecting a resistor in series with each base electrode of transistors $Q_7$, $Q_8$.

Current will now flow through lead 89, the diode $D_{23}$, lead 91, transistor $Q_8$, primary winding $P_{10}$, lead 90, diode $D_{26}$, lead 88 and to input terminal lead 82. As a result, a bucking voltage is induced across the secondary winding $S_9$ of transformer $T_7$. The polarity of this bucking voltage is such that the lower end is positive with respect to the upper end of the winding as will be seen in FIGURE 8.

During the positive alternation of the power supply, the bucking voltage is controlled in the following manner: If the feedback signal or drive current supplied by current transformer $T_8$ to the "on" transistor $Q_8$ is insufficient to drive it to saturation, a voltage drop appears across the emitter and collector electrodes of the transistor $Q_8$. As the current through the primary winding $P_{11}$ of the current transformer $T_8$ increases, the base drive current to transistor $Q_8$ also increases. Hence, as the base drive current increases, the impedance of transistor $Q_8$ decreases, and also the voltage drop across the transistor $Q_8$ decreases. Consequently, the voltage across the primary winding $P_{10}$ increases and causes the bucking voltage across secondary $S_9$ to increase. Thus, an increase in lamp current results in an increase in the bucking voltage, and the current supplied the lamp 84 is reduced. Similarly, a decrease in the current flow through the primary winding $P_{11}$ brings about a decrease in the bucking voltage across the secondary winding $S_9$. In this manner, regulation and control of the current supplied to the lamp 84 is achieved by varying the impedance connected in circuit with the primary winding $P_{10}$ of the bucking transformer $T_7$.

During the negative alternation of the power supply, the secondary winding $S_{12}$, the transistor $Q_7$ and the primary winding $P_9$ come into play since the polarity of the voltage induced across the secondary windings $S_{11}$, $S_{12}$ is reversed. The polarity of this voltage is such that the lower end of secondary winding $S_{12}$ is negative, and consequently the transistor $Q_7$ is now forward biased.

Under normal operating conditions of the apparatus 80 the base drive current supplied to the transistor $Q_7$ is insufficient to drive it to saturation. Thus, the output voltage of the bridge rectifier 87 is proportionally divided across transistor $Q_7$ and the primary winding $P_9$. As the current through the primary winding $P_{11}$ increases, the base drive current to transistor $Q_7$ increases. Accordingly, the voltage drop across the emitter and collector electrodes of transistor $Q_7$ decreases thereby causing the voltage across the primary winding $P_9$ of transformer $T_7$ to increase. As during the positive half cycle, the voltage appearing across the secondary $S_9$ increases in response to an increase in lamp current and decreases with a decrease in lamp current thereby controlling the current supplied to the lamp 84.

Referring now to FIGURE 9, I have shown therein another form of my invention embodying a variable impedance network for controlling and supplying the current required for operation of an electric discharge lamp 99. The apparatus for operating the electric discharge lamp 99 is generally identified by reference numeral 100 and is shown enclosed in a dashed rectangle 101. The apparatus 100 is energized by connecting a pair of input lead 102 and 103 across a suitable alternating current source. The output of the apparatus 100 is supplied to the electric discharge lamp 99 by output leads 104 and 105.

As will hereinafter be more fully explained, the variable impedance bridge network arrangement in the exemplification of the invention shown in FIGURE 9 will reproduce across output leads 104, 105 a current corresponding in waveshape to the waveshape of a feedback signal applied across a pair of feedback leads 106, 107 or, in other words, across the primary winding $P_{14}$ of transformer $T_{10}$. The transformer $T_{10}$ has a pair of secondary windings $S_{14}$ and $S_{15}$ inductively coupled with the primary winding $P_{14}$ on a magnetic core 108.

It will be noted that the input leads 102 and 103 are connected with the input terminals of a full wave bridge rectifier 109 which includes diodes $D_{27}$, $D_{28}$, $D_{29}$ and $D_{30}$. One of the output terminals of the bridge rectifier 109 is connected by lead 110 to the tap to which primary windings $P_{12}$ and $P_{13}$ of transformer $T_9$ are joined. The other output terminal of bridge rectifier **109** is connected in circuit with the emitter electrodes of transistors $Q_9$ and $Q_{10}$ through a resistor $R_{10}$ and leads **111**, **112** and **113** and is also connected with secondary windings $S_{14}$, $S_{15}$ by lead **114**.

Continuing with the descripition of apparatus **100** shown in FIGURE 9, the operation will now be more fully described. In order to start the operation of the apparatus **100**, the input terminal leads **102** and **103** were connected to an A.C. power source and the feedback leads **106** and **107** were also connected with an A.C. power supply through a small filament transformer $T_{11}$ to apply a sinusoidal signal across the feedback leads **106** and **107**.

Let us abritrarily assume that the voltage across the primary winding $P_{14}$ at a given instant is such that the upper end of the winding $P_{14}$, as seen in FIGURE 9, is negative with respect to the lower end. As a result, the voltage induced across the secondary windings $S_{14}$ and $S_{15}$ is such that the upper end is negative with respect to the lower end. A negative voltage is now applied at the base electrode of the transistor $Q_9$ to switch transistor $Q_9$ into conduction. At this instant, substantially the entire output volatage of the bridge rectifier **109** is applied across primary $P_{12}$, and a voltage is induced across the secondary winding $S_{13}$ of the transformer $T_9$. Assuming that this instantaneous voltage is sufficient to ionize lamp **99**, lamp **99** will begin to conduct. Consequently, current begins to flow in the loop which includes lamp **99**, output lead **104**, secondary winding $S_{13}$ and output lead **105**.

A current flow through the secondary winding $S_{13}$, in effect, lowers the resistance reflected to the primary winding $P_{12}$. Consequently, more current is supplied by the power source through the bridge rectifier **109**. However, the increased current flow produces a voltage drop across resistor $R_{10}$. This current is allowed to build up until the voltage drop across the resistor $R_{10}$ approximately equals the potential applied at the base of transistor $Q_9$, at which time the base drive on the transistor $Q_9$ wil be insufficient to support additional current flow. When this occurs, the voltage across the resistor $R_{10}$ will in effect track the voltage applied at the base electrode of transistor $Q_9$. Also, transistor $Q_9$ has a voltage drop that is substantially equal to the difference between the supply voltage and voltage developed across the transformer $T_9$.

If lamp **99** tries to draw more current than the value corresponding to the limited voltage developed across the resistor $R_{10}$, the transistor impedance increases and the voltage drop across the collecter and emitter electrodes of transistor $Q_9$ will increase thereby causing the voltage applied to the primary winding $P_{12}$ to decrease. Similarly, when the lamp current decreases, this voltage drop will decrease and cause the voltage across the secondary winding $S_{13}$ to increase. In this manner, the current to lamp **99** is dynamically controlled by the varying impedance introduced by the transistor $Q_9$. If the secondary winding $S_{13}$ is short circuited, the current in the circuit is still effectively limited by the voltage drop across the resistor $R_{10}$ and by the voltage available at the base electrode of transistor $Q_9$. In this case, the voltage developed across transformer $T_9$ is zero. On the other hand, when output leads **104**, **105** are open circuited, the full rectified output of the power source is made available across the primary winding $P_{12}$ to provide the maximum voltage across the secondary winding $S_{13}$.

When the voltage across the primary winding $P_{14}$ reverses, it will be understood that the lower end of the secondary winding $S_{15}$ is now negative with respect to the upper end, as seen in FIGURE 9, and a negative voltage now appears at the base electrode of transistor $Q_{10}$. During this alternation of the power source, primary winding $P_{13}$ provides the driving voltage for transformer $T_9$, and the loop which includes transistor $Q_{10}$, resistor $R_{10}$ and the primary winding $P_{13}$ come into play. In the same manner as during the previous alternation of the power supply, a decreasing current flow through the secondary winding $S_{13}$ has the effect of lowering the resistance reflected into the primary winding $P_{13}$ and thereby causing more current to be supplied thereto from the power source through bridge rectifier **109**. As this current flow in the loop increases, the voltage drop across the resistor $R_{10}$ increases. The current is allowed to build up until the voltage drop across the resistor $R_{10}$ is nearly equal to the potential at the base electrode of transistor $Q_{10}$. At this point, the base drive on transistor $Q_{10}$ will be insufficient to support additional current flow through the transistor $Q_{10}$. If the lamp circuit now attempts to draw more current, the voltage drop across the collector and emitter electrode of transistor $Q_{10}$ will increase. Thus, the voltage across the primary winding $P_{13}$ will decrease, and lamp operating voltage across the secondary winding $S_{13}$ decreases. In this way, the lamp current is limited by the varying impedance of the transistor $Q_{10}$.

Although, in the above described exemplification of the invention, the feedback signal was an alternating signal having a substantially sinusoidal waveshape, and in phase with the power source, it will be appreciated that other signals of different waveshapes may be provided to drive the variable impedance bridge circuit of the apparatus **100**. For example, if the voltage across the transformer secondary winding $S_{13}$ is fed back to the feedback leads **106** and **107**, the signal will have the waveshape of the lamp voltage, and the lamp current waveshape will be controlled to correspond with the lamp voltage waveshape. With such an arrangement, it will be apparent that unity lamp power factor can be achieved. Further, it will be appreciated that with the variable impedance bridge network arrangement shown in FIGURE 9, any desired waveshape of the lamp current can be obtained since the apparatus **100** will essentially provide a current in the secondary winding $S_{13}$ having a waveshape corresponding to the waveshape of the voltage signal applied across the primary winding $P_{14}$.

From the foregoing description of the various exemplifications of the invention, it will be apparent that the ballasting action for one or more fluorescent lamps is provided by a variable impedance network. This network introduces an instantaneously variable impedance which may directly regulate lamp current as in the embodiments shown in FIGURES 1 and 5 or indirectly as in the embodiments shown in FIGURES 6, 7, 8 and 9. An important advantage of the invention is that the variable impedance network makes it possible to minimize losses in the circuit that would otherwise result if a linear resistor were used as the ballasting element. Also, the variable impedance network arrangement makes it possible to design an apparatus for operating electric discharge lamps with a smaller difference between the supply voltage and the operating voltage of the lamp than would be the case if conventional ballasting elements were employed in the circuit to provide the current limiting action for the electric discharge lamps. Further, the variable impedance network of the invention is readily adaptable to control by a signal responsive to the lamp operating condition. A signal sensing an operating condition or a signal from an independent source may be employed to control the waveshape of the lamp current.

Although a variable impedance network utilizing a bridge has been employed in the exemplifications of my invention, it will be apparent to those skilled in the art that variable impedance networks employing bilateral semiconductor devices or unidirectional devices in an inverse arrangement may be used in the practice of the invention. It will be understood that the specific exemplifications of the invention which I have described herein are intended for illustrative purposes only and that many modifications may be made. It is, therefore, intended by the appended claims to cover all such modifications that fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A system for operating an electric discharge lamp, said system comprising an alternating power source, an electric discharge lamp, a variable impedance network comprising a full-wave rectifier circuit having alternating current input terminals and direct current output terminals, a transistor having an emitter, a collector, and a base, a current indicating impedance coupled in series with the emitter-collector path of said transistor, means coupling said serially coupled impedance and transistor between said direct current output terminals, a reference voltage device, means coupling said reference voltage device between said base and at least one of said direct current output terminals, circuit means including input leads connected in electrical circuit with the alternating power source and at least a pair of output leads connected in electrical circuit with the electric discharge lamp to supply operating potential to said electric discharge lamp, and means connecting one of said alternating current input terminals of said network to one of said input leads and the other of said alternating current input terminals of said network to one of said output leads and connecting the other of said input leads to the other of said output leads to place said variable impedance network in series circuit relation with the electric discharge lamp during operation thereof, said variable impedance network responding to the current magnitude in said current indicating impedance to provide an instantaneously varying impedance during a portion of each half cycle of the alternating power source to control the current supplied to the electric discharge lamp and clamping the lamp current at a predetermined level.

2. The system set forth in claim 1 wherein a filament transformer is provided having a primary winding and at least one secondary winding, said primary winding being connected in circuit with said input leads and said secondary winding being connected in circuit with the output leads for supplying a continuous cathode heating current to the lamp during operation.

3. An apparatus for operating at least one electric discharge lamp from an alternating power source comprising a variable impedance network, said variable impedance network including a bridge rectifier having input and output terminals, a transistor having an emitter, a collector and a base electrode, a current measuring resistor connected in circuit with the emitter electrode of said transistor, said current measuring resistor and said transistor being connected across the output of said bridge rectifier, diode means connected in circuit with the base electrode of said transistor and in parallel relation with said current measuring resistor, said diode means providing a reference voltage for said transistor, a resistor connected in circuit with the base electrode and one of the output terminals of said bridge rectifier to supply base drive current thereto, said transistor during operation passing a current during a portion of each half cycle whereby the voltage drop across said current measuring resistor is maintained nearly equal to the reference voltage of said diode means to clamp the current at a substantially constant level, and circuit means including at least a pair of output leads for connection with the electric discharge lamp to supply the output of the apparatus to said electric discharge lamp, said circuit means connecting one of said input leads and one of said output leads in circuit with said variable impedance bridge network to place said variable impedance circuit in series circuit relation with the electric discharge lamp during operation thereof.

4. A system for operating fluorescent lamps, said system comprising: a source of alternating current operating potential, at least one fluorescent lamp, control means including a full-wave bridge rectifier having input terminals and output terminals, a first impedance, a transistor having an emitter, a collector, and a base, means coupling said first impedance and the emitter-collector path of said transistor in series between said output terminals of said rectifier, a reference voltage breakdown device, a second impedance, means coupling said reference voltage breakdown device between said base and one of said output terminals of said rectifier and coupling said second impedance between said base and the other of said output terminals of said rectifier, and means coupling said lamp to said source of operating potential serially through said input terminals of said rectifier for providing an instantaneously varying impedance during a portion of each half cycle of said source of operating potential to control the current supplied to said fluorescent lamp.

**References Cited by the Examiner**

UNITED STATES PATENTS

| | | | |
|---|---|---|---|
| 2,935,674 | 3/1958 | Hohne | 307—88.5 |
| 3,047,746 | 7/1962 | Berkery | 307—88.5 |
| 3,089,980 | 5/1963 | Neusbaum | 315—97 |
| 3,114,872 | 12/1963 | Allard | 323—4 |

FOREIGN PATENTS

| | | |
|---|---|---|
| 1,061,438 | 7/1959 | Germany. |
| 897,828 | 5/1962 | Great Britain. |

GEORGE N. WESTBY, *Primary Examiner.*

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# UNITED STATES PATENT OFFICE
# CERTIFICATE OF CORRECTION

Patent No. 3,249,799 May 3, 1966

Walter F. Powell, Jr.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 2, line 4, for "resistor" read -- resistive --; line 11, for "is", first occurrence, read -- it --; column 3, lines 3 and 4, for "electrode" read -- electrodes --; lines 16 and 19, for "is", first occurrence, each occurrence, read -- it --; column 8, line 34, beginning with "Zener diode $Z_2$" strike out all to and including "core." in line 50, same column 8, and insert instead the following:

| | |
|---|---|
| Full wave bridge diodes $D_5$, $D_6$, $D_7$, $D_8$... | Mallory FW 600 bridge |
| Zener diode $Z_2$ .......................... | 100 volt, 1 watt |
| Transistors $Q_2$, $Q_3$ ......................... | Bendix trans-sistors 2N165 |
| Resistors $R_4$, $R_5$ ........................ | 3 ohm, 1 watt |
| Resistor $R_3$ ............................ | 5 ohms, 2 wat |
| Resistor $R_6$ ............................ | 1000 ohms, 5 watt |
| Diodes $D_9$, $D_{10}$, $D_{11}$ ...................... | 1N2070 |
| Capacitor $C_1$ ............................ | .01 micro-farads, 600 volt |
| Transformer $T_3$ .......................... | Universal wound, 200 turns with ta] brought out a 20 turns, fer rite core |

column 10, line 29, for "varing" read -- varying --; column 10, Table III, first column, line 6 thereof, for "volt" read -- volts --; column 11, line 34, strike out "the", second occurrence; column 12, line 56, for "lead" read -- leads --.

Signed and sealed this 5th day of September 1967.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

EDWARD J. BRENNER
Commissioner of Patents