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 APPARATUS INCLUDING A BUCKING TRANSFORMER FOR OPERATING
 ELECTRIC DISCHARGE LAMPS
 Original Filed July 23, 1962

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FIG. 1

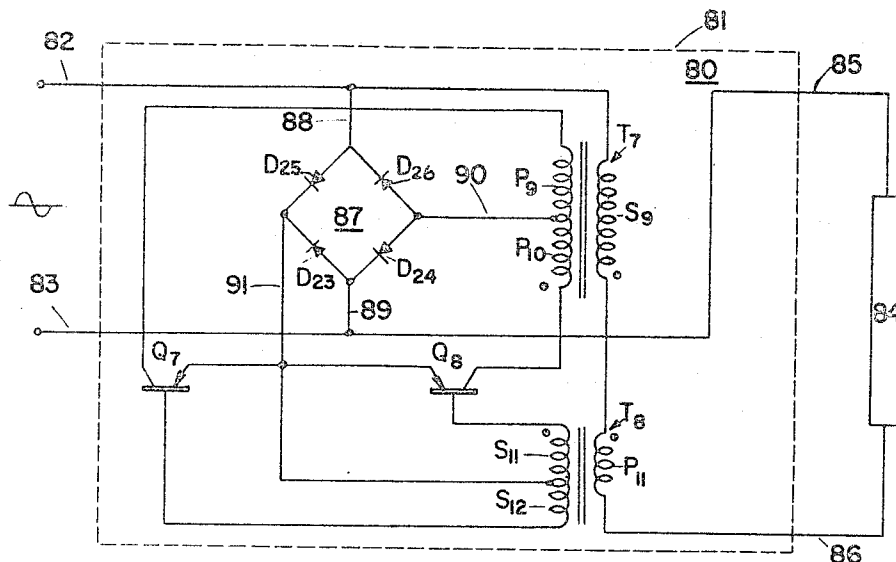
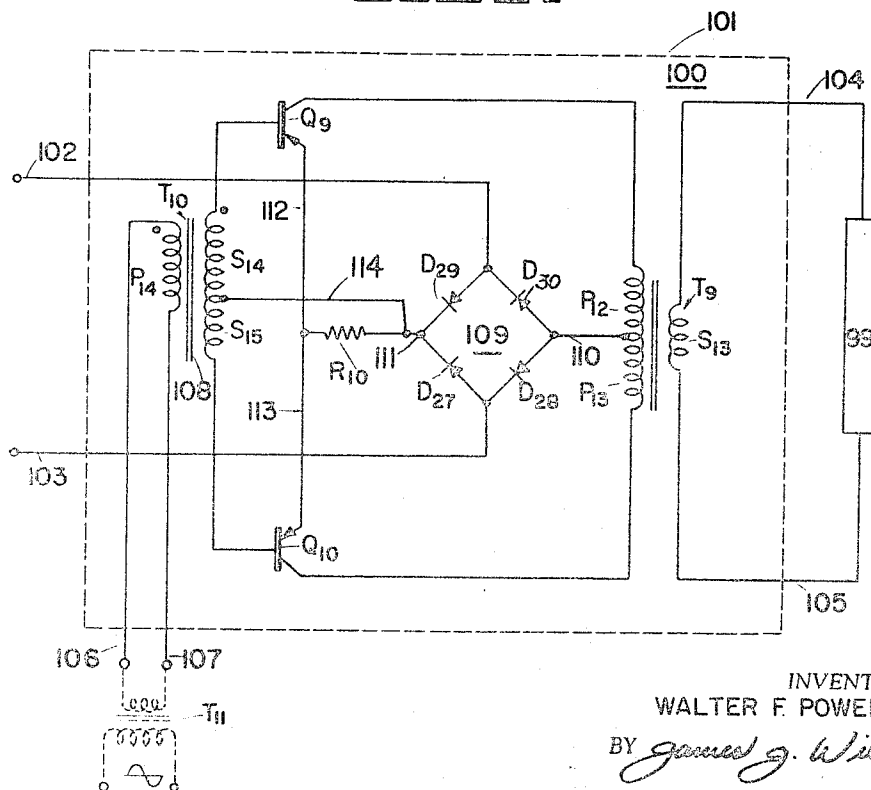


FIG. 2



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APPARATUS INCLUDING A BUCKING TRANSFORMER FOR OPERATING ELECTRIC DISCHARGE LAMPS

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Original application July 23, 1962, Ser. No. 211,554, now Patent No. 3,249,799, dated May 3, 1966. Divided and this application June 16, 1965, Ser. No. 464,517
3 Claims. (Cl. 315-206)

This invention relates generally to 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. This application is a divisional application of my copending application filed July 23, 1962, Ser. No. 211,554 which issued May 3, 1966 as Patent No. 3,249,799.

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.

Where 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 ballast-

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ing 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 resistive 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, it 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 for operating electric discharge devices.

A more specific object of the present invention is to provide an improved 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 cycle. 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 of 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 electrodes 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 it 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 it 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 of an apparatus embodying a 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 2 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.

In FIGURE 1, I have illustrated a 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 cur-

rent 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 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 1, 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_{10} 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 1.

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

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current results in an increase in the bucking voltage, and the current supplied to 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 2, 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 leads 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 2 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 description of apparatus 100 shown in FIGURE 2, 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 arbitrarily 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 2, is negative with respect to the lower end. As a result, the

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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 voltage 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 will 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 collector 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 2, 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 2, 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 regulate lamp current indirectly as in the embodiments shown in FIGURES 1 and 2. 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 exemplification 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 ballast apparatus comprising a pair of input leads for connection in circuit with an alternating power source, output leads for connection in circuit with at least one electric discharge lamp, a bucking transformer having a center tapped primary winding and a secondary winding, a current transformer having a primary winding and a center tapped secondary winding, said secondary winding of said bucking transformer and said primary winding of said current transformer being connected in circuit with one of said output leads and one of said input terminal leads for connection in series circuit relation with said lamp, a full wave bridge rectifier having input terminals and output terminals, said input terminals being connected in circuit with said input terminal leads for connection with the alternating power source, a pair of transistors, each of said transistors having a collector, an

emitter, and a base electrode, one of said output terminals of said bridge rectifier being connected in circuit with the tap of the primary winding of said bucking transformer, the other of said terminals being connected in circuit with the emitter electrodes of said transistors and the tap of said secondary winding of the current transformer, circuit means connecting the ends of the primary winding of said bucking transformer in circuit with the collector electrodes of said transistors and connecting the ends of the secondary winding of said current transformer in circuit with the base electrodes of said transistors, said transistors providing a variable impedance in the primary circuit of said bucking transformer to regulate the current flow through the secondary winding of the bucking transformer in response to changes in the current supplied at the output leads.

2. Ballast apparatus comprising a pair of input leads for connection to an alternating power source, a pair of output leads for connection to at least one electric discharge lamp, a bucking transformer having a primary winding and a secondary winding coupled thereto, current indicating means having input terminals and output terminals, means coupling said secondary winding of said bucking transformer and said input terminals of said current indicating means in circuit with one of said input leads and one of said output leads for connection in series circuit relations with said lamp, a rectifier having input terminals and output terminals, said rectifier input terminals being connected in circuit with said input leads for connection with said alternating power source, at least one transistor having an input electrode and output electrodes, means coupling one of said rectifier output terminals to said primary winding of said bucking transformer, means coupling the other of said rectifier output terminals to one of said output electrodes of said transistor, means coupling said primary winding of said bucking transformer to at least the other output electrode of said transistor, and means coupling said output terminals of said current indicating means to said input electrode of said transistor to regulate the current flow through said secondary winding of said bucking transformer in response to changes in current through said input terminals of said current indicating means as indicated by said output terminals of said current indicating means.

3. Ballast apparatus comprising a pair of input leads for connection to an alternating current power source, a pair of output leads for connection to at least one electric discharge lamp, a bucking transformer having a tapped primary winding and a secondary winding coupled thereto, current indicating means having input terminals and output terminals, means coupling said secondary winding of said bucking transformer and said input terminals of said current indicating means in circuit with one of said input leads and one of said output leads for connection in series circuit relation with said lamp, means coupling the other of said input leads to the other of said output leads, a full wave rectifier having input terminals and output terminals, said input terminals being connected in circuit with said input leads for connection with said alternating power source, a pair of transistors each having an input electrode and output electrodes, means coupling one of said output terminals of said rectifier to said tap on said primary winding of said bucking transformer, means coupling the other of said output terminals of said rectifier to corresponding output electrodes of said transistors, means coupling said primary winding of said bucking transformer to the other corresponding output electrodes of said transistors, and means coupling said output terminals of said current indicating means to said input electrodes of said transistors in degenerative fashion to regulate the current flow through said secondary winding of said bucking transformer in response to changes in current supplied to said lamp through said input terminals of said current indicating means as indi-

cated by said output terminals of said current indicating means.

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