

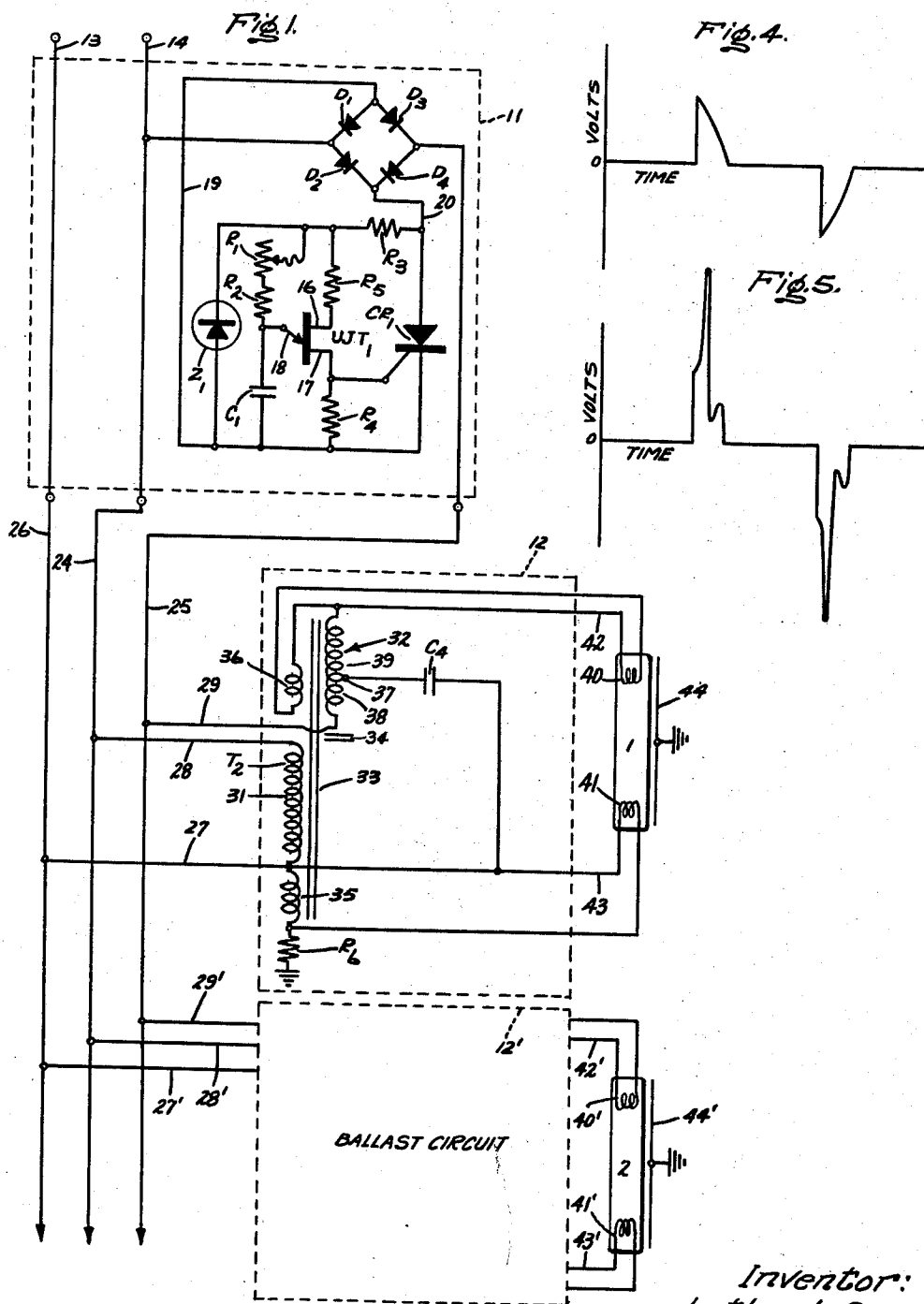
Feb. 16, 1965

L. L. GENUIT
BALLAST CIRCUIT AND SYSTEM FOR DIMMING
GASEOUS DISCHARGE LAMPS

3,170,085

Filed April 19, 1961

3 Sheets-Sheet 1



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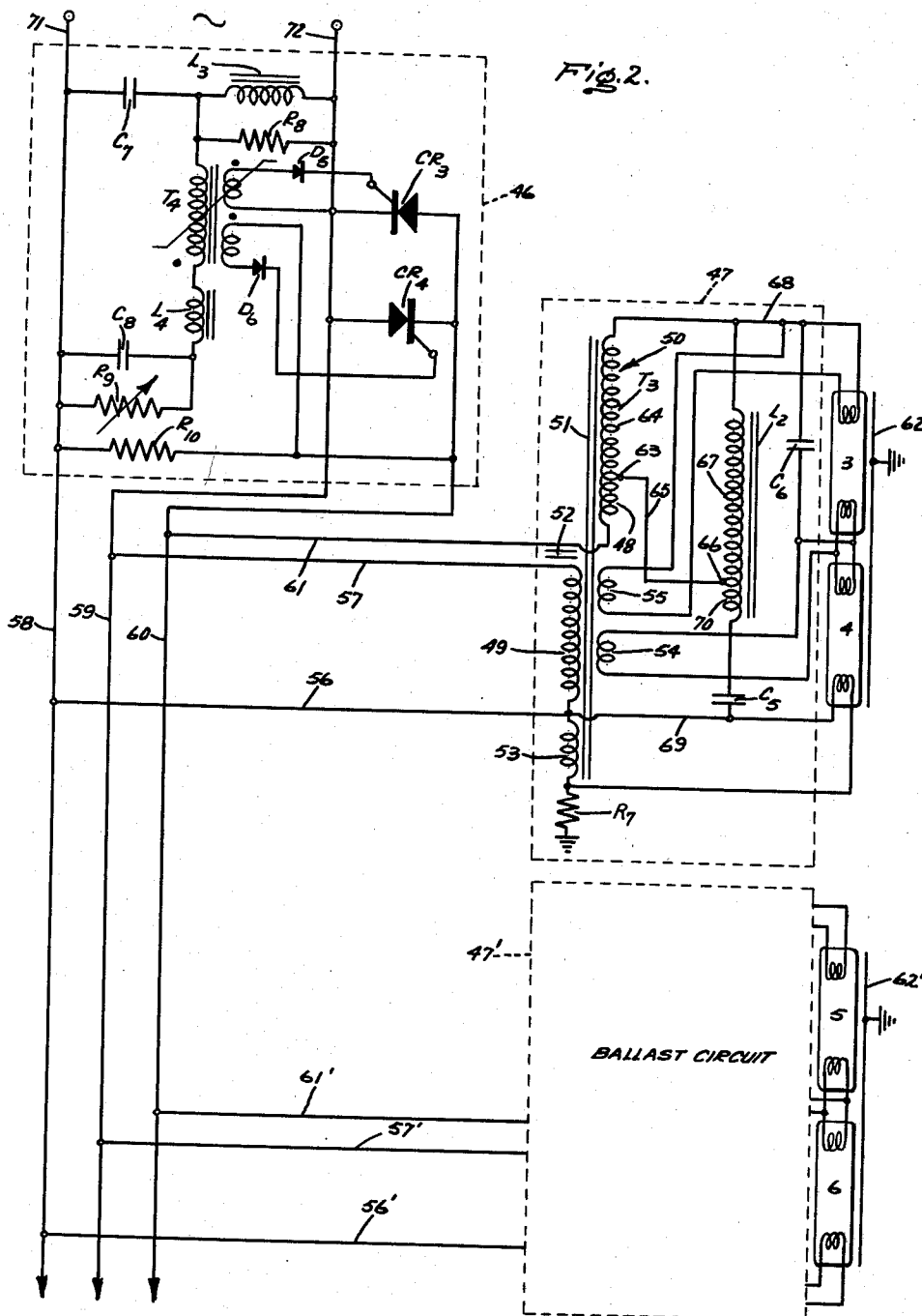
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3 Sheets-Sheet 2



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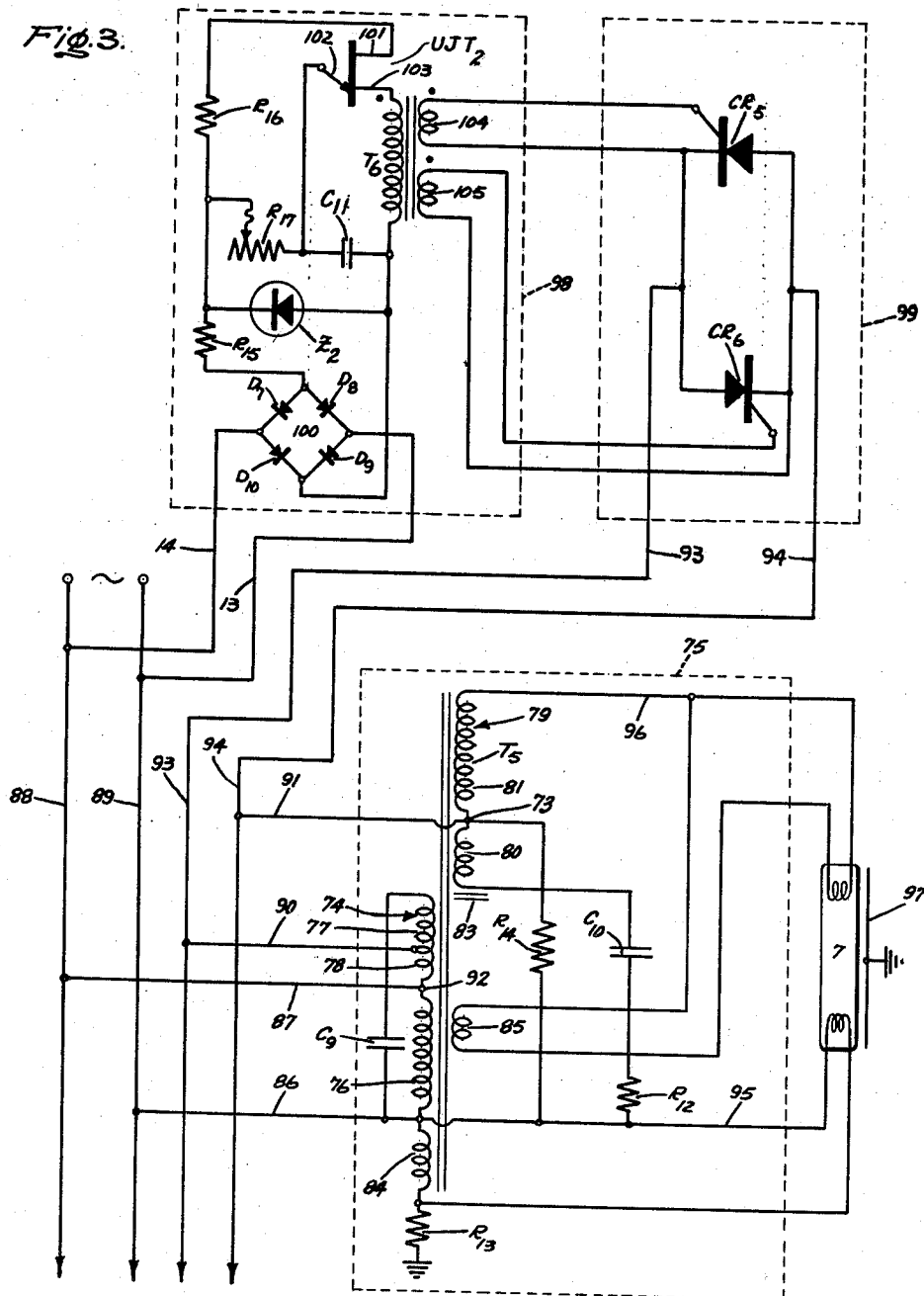
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3 Sheets-Sheet 3

Fig. 3.



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3,170,085

BALLAST CIRCUIT AND SYSTEM FOR DIMMING GASEOUS DISCHARGE LAMPS

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Filed Apr. 19, 1961, Ser. No. 104,107
11 Claims. (Cl. 315-227)

This invention relates to ballast circuits and systems for dimming gaseous discharge lamps and more particularly to ballast circuits and systems for dimming of fluorescent lamps wherein such dimming is achieved by regulating the interval of current conduction to the lamps during each half cycle of the alternating current supply by means of controlled rectifiers.

In order to provide for stable operation of a fluorescent lamp at various levels of luminous intensity, it is necessary that the voltage drop across the ballast apparatus must be maintained at some predetermined value so that sufficient ionization voltage is provided for starting the lamps at low brightness levels. If the voltage of the power supply is decreased, it will be seen that the voltage drop across a conventional reactor ballast circuit will decrease with the current. As this voltage drop decreases to a certain point, the fluorescent lamp becomes unstable in operation and eventually extinguishes approximately at a point where the lamp brightness is about one-half of its normal luminous output. Also, at this point, insufficient ionization voltage is available to start the lamp. Because of the complex characteristics of the fluorescent lamp and the ballast circuit, simple control of the line voltage does not provide a satisfactory dimming range that makes such systems practicable in many applications.

In applications where dimming of fluorescent lamps is accomplished by controlling the interval of current conduction during each half cycle of the alternating current supply by means of a controlled rectifier switching network, the dimming range of fluorescent lamp dimming systems has been appreciably extended. However, due to inherent characteristics of the controlled rectifiers and the complex characteristics of the arc discharge lamps and its associated ballast, difficulties have been encountered in controlling the luminous intensity of the lamps at low brightness levels. In such systems a pair of inversely connected controlled rectifiers are generally connected so that one of the rectifiers will conduct current in the positive half cycle of the alternating current supply and the other controlled rectifier in the negative half of the cycle. The controlled rectifiers are switched on at a predetermined point in each half cycle to supply current to the lamps. It will be appreciated that the voltage applied to the lamps at a particular conduction point in the half cycle must be sufficient to reignite the lamp in order to prevent the lamp from going out or flickering. At low brightness levels, this requirement poses a problem since the system must provide some means for maintaining a sufficient ionization voltage to reignite the lamp. It is, therefore, desirable that a system be provided wherein the luminous intensity of the fluorescent lamp can be effectively controlled at low brightness levels.

A principal difficulty heretofore encountered in fluorescent lamp dimming systems has been instability at low dimming levels. Fluorescent lamps when operated at low dimming levels from normal commercial power supplies flicker at random frequencies. In many applications this flickering is objectionable and has been a factor that has limited the use of fluorescent lamp dimming systems. This flickering has in some applications been associated with the normal fluctuations in the voltage of the power supply. Clearly, there is a need for a ballast circuit and dimming system for operating fluorescent lamps wherein the lamps will not flicker at low levels of luminous in-

tensity in response to normal fluctuations of a commercial power supply. It is, of course, desirable that this be accomplished without the use of voltage stabilizers or regulators.

Accordingly, an object of this invention is to provide an improved ballast circuit and system wherein gaseous discharge lamps such as fluorescent lamps can be effectively dimmed at low brightness levels by controlling the interval of current conduction to the lamps during each half cycle of the power supply.

Another object of the present invention is to provide a ballast circuit and system for the operation of a plurality of fluorescent lamps wherein sufficient ionization voltage is provided for starting the lamps at low brightness levels.

It is still another object of the invention to provide an improved ballast circuit and system for operating a plurality of fluorescent lamps stably at low levels of luminous intensity without need for voltage stabilizers or regulators.

The foregoing and other objects and advantages of the invention are realized by a fluorescent lamp dimming system employing a phase control and switching circuit utilizing controlled rectifiers wherein the ballast circuit includes a capacitor connected in circuit with a portion of the secondary winding forming therewith an oscillatory circuit which under open circuit conditions provides a transient voltage that maintains the luminous intensity of the lamps at low intensity levels.

In another aspect of my invention, I have provided a ballast circuit having a high reactance transformer with a primary winding and a high reactance secondary winding divided into a first winding portion and a second winding portion by a tap. In this modification of the ballast circuit of the invention, I have included a reactor having a tap and a capacitor connected in series circuit relationship with the reactor which are connected across the output leads of the ballast circuit. One end of the first winding portion of the high reactance secondary is connected in circuit with the tap on the reactor. The tap on the reactor divides the reactor into a first and a second winding, the first winding of the reactor and the capacitor forming a resonant circuit under open circuit conditions whereby a transient voltage is developed when the current conduction to the ballast circuit is switched on.

It will be understood that the term "resonant" as used herein is not limited to a condition of pure resonance but includes conditions at or near resonance, i.e., a resonant effect, whereby an increase in voltage is produced by oscillations in the circuit as compared with identical circuits which do not employ a resonant effect.

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

FIG. 1 is a schematic circuit diagram of a dimming system and a ballast apparatus illustrating one embodiment of the invention;

FIG. 2 is a schematic circuit diagram of a dimming system and a ballast apparatus illustrating another embodiment of the invention;

FIG. 3 is a schematic circuit diagram of a ballast apparatus and dimming system illustrating an embodiment of the invention in which an autotransformer is employed in the switching network;

FIG. 4 illustrates the wave form of the open circuit voltage of a ballast apparatus similar to the one shown in FIG. 1 in which a capacitor has not been connected in circuit with the secondary winding in accordance with the invention; and

FIG. 5 illustrates the waveform of the open circuit voltage of the ballast circuit of FIG. 1 in which the ca-

pacitor and the secondary winding portion form an oscillatory circuit under open circuit conditions in accordance with the invention.

The dimming system illustrated in FIG. 1 includes a phase control and switching circuit identified generally by reference numeral 11, as shown enclosed in the dashed rectangle 11. Ballast circuits are identified generally by the reference numerals 12, 12' and shown enclosed in dashed rectangles 12, 12'. Although two ballast circuits 12, 12' and fluorescent lamps 1, 2 are shown, it will be appreciated that the system will operate a plurality of such ballast circuits and lamps. Since all the ballast circuits are identical, the internal circuit connections are illustrated only for ballast circuit 12. A pair of input terminal leads 13, 14 are provided for connecting the phase control and switching circuit 11 to a suitable power source (not shown) such as a 118 volt, 60 cycle power supply.

As shown in FIG. 1, the phase control and switching circuit 11 includes a bridge rectifier having the diodes D_1 , D_2 , D_3 and D_4 , a control rectifier CR_1 and a firing circuit including a Zener diode Z_1 and a unijunction transistor UJT₁. The type of phase control and switching network shown in FIG. 1 is well-known in the art and is described in the General Electric Controlled Rectifier Manual, first edition, 1960, at pages 94-96. With this type of a phase control and switching circuit, it is possible to achieve full wave phase control with a single controlled rectifier CR_1 .

It will be seen that the phase control circuit 11 is energized by the full wave rectified output of the bridge rectifier 15 and is connected across the bridge rectifier 15 by electrical leads 19, 20. Resistor R_3 is provided in order to limit the current of the phase control circuit. A capacitor C_1 is connected across the emitter electrode 18 and base-one electrode 17 of the unijunction transistor UJT₁. The capacitor C_1 is charged by a variable resistor R_1 which serves as the dimming control for the entire fluorescent lamp system. The variable resistor R_1 may be located at a remote control station depending upon the specific application. The resistor R_3 is connected in circuit with base-two electrode 16 in order to limit the current thereto. The voltage across resistor R_4 is applied across the gate and cathode of the controlled rectifier CR_1 .

In the circuit arrangement shown in FIG. 1, controlled rectifier CR_1 when switched on in one half cycle permits current to flow in one direction to switching line 25 and when switched on in the next half cycle permits a current flow in an opposite direction to switching line 25. Thus, the current in one direction follows a path starting with the input terminal lead 14 through diode D_2 , lead 20, controlled rectifier CR_1 , lead 19, diode D_3 , and to switching network line 25. In the opposite direction, starting with the switching network line 25, the current follows a path through diode D_4 , lead 20, controlled rectifier CR_1 , lead 19, diode D_1 and to input terminal lead 14.

The controlled rectifier CR_1 is a PNP semiconductor having three terminals, an anode represented by the arrow symbol, the cathode represented by the line drawn through the apex of the arrow symbol and a gate represented by the diagonal line extending from the cathode. Preferably, silicon controlled rectifiers may be used as switching elements since the operating characteristics of a silicon controlled rectifier are such that it conducts in a forward direction with a forward characteristic very similar to that of an ordinary rectifier when a gate signal is applied. Thereafter, the controlled rectifier continues conduction even after the gate signal is removed, provided that a minimum holding current is supplied to the controlled rectifier CR_1 .

The supply lines 24, 26 and switching line 25 provide power and switching connections for the individual ballast circuits 12, 12'. Additional ballast circuits or ballasts may be connected to the supply lines 24, 26, the total number being limited by the volt-ampere rating of

the controlled rectifier CR_1 employed in the switching network.

Continuing with the detailed description, the ballast circuits 12, 12' shown in FIG. 1 are connected to supply lines 24, 26 and switching line 25 by ballast input leads 27, 27', 28, 28' and switching network lead 29, 29', respectively. Referring now to the internal circuit connections, ballast circuit 12 includes a high reactance transformer T_2 , having a primary winding 31, a secondary winding 32, a magnetic core 33, magnetic shunts 34, and filament windings 35, 36. The primary winding 31 is connected across the ballast input leads 27, 28 which are connected to supply lines 24, 26. It will be seen therefore that the supply voltage is applied across the primary winding 31 and that the switching action of controlled rectifier CR_1 does not affect the applied voltage across the primary winding 31. The secondary winding 32 has a tap 37 which divides the secondary winding 32 into a first winding portion 38 and a second winding portion 39.

In the exemplification of the invention to be hereinafter more fully described, tap 37 was brought out so that 320 turns were provided in the first secondary portion 38 and 960 turns were provided in the second winding portion 39.

In the dimming system shown in FIG. 1, preferably rapid start fluorescent lamps may be used. Each of the lamps 1, 2 is comprised of an elongated tubular cylindrical envelope, having sealed into the ends thereof, filamentary cathodes 40, 40', 41, 41'. The lamps 1, 2 are connected across output leads 42, 42' and 43, 43', respectively. Cathode heating windings 35, 36 of ballast circuit 12 are connected in circuit with cathodes 40, 41 and supply a heating current to the cathodes 40, 41. A grounded conductive plate 44, 44', such as a fixture may be located in proximity to lamps L_1 , L_2 . As shown in circuit diagram of ballast circuit 12, the grounded plate 44 serves in conjunction with a grounded resistor R_6 as a starting aid to apply a starting potential to one of the cathodes 40, 41.

In order to stabilize the operation of the ballast circuit 12, I have provided a capacitor C_4 connected in circuit with the first secondary portion 38 and output lead 43. It will be understood that although as shown in FIG. 1 the capacitor C_4 is connected to the tap 37 or one end of the first winding portion 38, it also may be connected to the other end of the first secondary portion 38. In such a circuit arrangement the switching network lead 29 would be connected to the tap 37. When the switching network lead 29 and the lead connecting with capacitors C_4 are reversed in this manner, the polarity of the initial peak of transient voltage produced by the damped oscillation is of such polarity that it is additive to the secondary voltage. In either circuit arrangement, the transient voltage is sufficient to provide the stabilizing action at low dimming levels in accordance with the invention. The capacitor C_4 serves in conjunction with the secondary winding portion 38 of transformer T_2 to form an LC oscillatory circuit which under open circuit condition resonates at a predetermined frequency above the line frequency. The autotransformer action of secondary winding portion 39 augments the transient voltage produced by the LC oscillatory circuit. Therefore, ballast 12 develops sufficient ionization voltage so that the lamp L_1 is reignited at low brightness levels and the lamp operation at low dimming levels is not rendered unstable by normal fluctuations in the power supply. Thus, the system and ballast circuit of the present invention makes it possible to obtain satisfactory dimming of fluorescent lamps at low levels of luminous intensity. It will be appreciated that although only a single lamp 1 is shown connected across the output leads 42, 43 of the ballast circuit 12, the circuit can be very readily redesigned to provide an increased open circuit voltage required for two-lamp operation.

In FIG. 2, I have illustrated another embodiment of the

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invention illustrating a fluorescent lamp dimming system wherein a phase control and switching circuit 46 and ballast circuit 47 are shown. In ballast circuit 47 it will be noted that a separate inductor L_2 is utilized in conjunction with the capacitor C_5 and winding portion 48 to serve as an oscillatory circuit under open circuit conditions to provide a transient voltage at low brightness levels sufficient in magnitude to reignite lamps 3, 4 during each half cycle.

The ballast circuit 47 includes a high reactance transformer T_3 having a primary winding 49, a secondary winding 50, a magnetic core 51, magnetic shunts 52, and filament heating windings 53, 54, 55. Primary winding 49 is connected by input terminal leads 56, 57 to supply lines 58, 59, respectively. Switching network lead 61 is brought out from one end of the secondary winding 50 and connected in circuit with switching network line 60. A grounded resistor R_7 in conjunction with a conductive plate 62 serve to apply a potential across one of the lamp electrodes and ground during starting. A starting capacitor C_6 is connected across lamp L_3 to sequentially start the lamps L_3 , L_4 in a manner that is well-known in the art. A tap 63 divides the secondary winding 50 into two winding portions 48, 64, respectively. Tap 63 is connected by a means of conductor 65 to a tap 66 on the winding 67 of inductor L_2 serially connected with capacitor C_5 across ballast output leads 68, 69. Winding portion 70 of inductor L_2 provides the additional inductive reactance required to tune the oscillatory circuit comprised of winding portion 48, winding portion 70 and capacitor C_5 in order to provide an ionization voltage of sufficient magnitude to start the lamps at low brightness levels during each half cycle.

An additional ballast circuit 47', the internal connections of which have been omitted, is represented by the dashed rectangle 47'. It will be noted that the additional ballast circuit 47' is connected in the system by connecting the input leads 56', 57' across the supply lines 58, 59 and the switching network lead 61' in circuit with switching network lead 61 in circuit with switching network line 60. Ballast circuit 47' has the identical internal circuit components and connections as shown in dashed rectangle 47 and functions in the same manner to provide voltage required to start and operate lamps 5 and 6. Conductive plate 62' is a part of the starting aid circuit and functions in the same manner as the conductive plate 62.

Having reference now to the phase control and switching circuit generally identified in FIG. 2 by the reference numeral 46 and enclosed in the dashed rectangle, I have illustrated therein an improved modification of a phase control and switching circuit which is particularly adaptable to the ballast circuits of the invention. This circuit is described in my copending application Serial Number 104,108, filed Apr. 19, 1961, and assigned to the same assignee as the present invention. The phase control and switching circuit 46 includes a pair of input terminal leads 71, 72, a serially connected inductor L_3 , capacitors C_7 , C_8 , resistors R_8 , R_9 , R_{10} , a serially connected inductor L_4 and saturable transformer T_4 , diodes D_5 , D_6 and controlled rectifiers CR_3 , CR_4 . The variable resistor R_9 connected across the capacitor C_8 varies the phase angle of the voltage applied to the saturable transformer T_4 .

Controlled rectifiers CR_3 and CR_4 are connected in inverse parallel relationship across supply line 59 and the switching network line 60. Resistor R_{10} is connected in circuit across the supply line 58 and switching network line 60. It will be seen that by virtue of this connection only a proportional part of the total ballast voltage is applied across the controlled rectifiers CR_3 , CR_4 . Resistor R_{10} also provides a resistive load in circuit with the conducting controlled rectifier so that a holding current is supplied to it during the ionization period of the lamps 3, 4 to prevent the rectifier from being prematurely turned off in the half cycle.

Referring now to FIG. 3, the ballast circuit is generally identified by reference numeral 75 and is shown enclosed

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in the dashed rectangle 75. A high reactance ballast transformer T_5 is comprised of a primary winding 76, an extension winding 74 having a first extension winding portion 77 and a second extension winding portion 78, a high leakage reactance secondary 79, a tap 73 dividing the high leakage resistance secondary winding 79 into a first winding portion 80 and a second winding portion 81, a magnetic core 82, magnetic shunts 83, and cathode heating windings 84, 85. A pair of input terminal leads 86, 87 are connected across primary winding 76 and are connected to supply line 88, 89 which are connected to an alternating current source (not shown).

In order to correct for power factor, a capacitor C_9 is connected across the primary winding 76 and the secondary extension winding 74. Extension winding portion 77 of the secondary extension winding 74 is provided to increase the voltage applied across the power factor capacitor C_9 above the source voltage and the voltage across the extension winding portion 78 so that the size and the cost of the power factor capacitor C_9 can be reduced. Switching network leads 98, 91 are brought out from a tap 92 on the extension winding 74 and from tap 73 on secondary winding 79 and are connected to switching network lines 93, 94.

As shown in FIG. 3, one ballast output lead 95 is connected in circuit with the input lead 86 and supply line 89 which is provided for connection to the grounded side of the power supply. The other output lead 96 is connected to one end of the secondary winding 79. Output leads 95, 96 are also connected across a fluorescent lamp 7. Although in the exemplification of the invention shown in FIG. 3, only one lamp 7 of one ballast circuit 75 is illustrated therein, it will be readily apparent that additional ballast circuits can be connected in circuit with supply lines 88, 89 and switching network lines 93, 94. Cathode heating windings 84, 85 are closely coupled with the primary winding 76 so as to provide a continuous supply of heating current to lamp 7 when the ballast circuit 75 is energized.

A grounded conductive plate 97 positioned in proximity to lamp 7 and a grounded resistor R_{13} function as a starting aid circuit. Resistor R_{14} connected across tap 73 and output lead 95 provides controlled rectifiers CR_5 , CR_6 with a resistive load during the ionization period of lamp 7 in order that the conducting controlled rectifiers CR_5 , CR_6 may be supplied with a suitable holding current.

Capacitor C_{10} is connected in series circuit relationship with the first winding portion 80 of secondary winding 79 and forms therewith an oscillatory circuit. This circuit arrangement under open circuit conditions produces a resonant oscillation that provides a transient voltage having a polarity in the initial half cycle of the oscillation that is in additive relationship to the voltages across the primary winding 76 and secondary winding 79. This results in the advantage that a starting circuit can be designed with a lower circuit quality. The circuit quality is the ratio of the energy stored to the energy lost in the oscillatory circuit and is equal to the ratio of the capacitive reactance to the total effective series resistance of the circuit. It will be appreciated that further adjustments in the oscillatory circuit quality can be made by connecting a resistor R_{12} in series with the capacitor C_{10} . Since damping does not appreciably affect the magnitude of the first half cycle of the oscillatory transient voltage provided by this circuit arrangement, the starting circuit can be designed with a lower circuit quality. It was found that lower circuit quality results in more stable operation at low dimming levels.

Continuing with the description of the system shown in FIG. 3, the phase control circuit and switching circuit are shown enclosed in the dashed rectangles and are generally identified by numerals 98, 99, respectively.

In order to control the points during each half cycle at which the controlled rectifiers CR_5 , CR_6 are fired, the phase control circuit 98 is employed and is particularly

adaptable for use in connection with the ballast circuits of the invention. It will be seen that the phase control circuit 98 is energized from the alternating supply lines 88, 89 by leads 13, 14 through a full wave bridge rectifier 100 having diodes D_7, D_8, D_9, D_{10} . The phase control circuit 98 utilizes a unijunction transistor UJT_2 and a Zener diode Z_2 in a well-known firing circuit configuration.

In order to limit the maximum interbase voltage of the unijunction transistor UJT_2 , the Zener diode Z_2 and a resistor R_{15} are connected in circuit with the bridge 100. With such an arrangement, a clipped pulsating voltage is applied across unijunction transistor UJT_2 . The Zener diode Z_2 is a semiconductor diode, preferably a silicon diode, having a predetermined reverse breakdown voltage. For voltages below the breakdown value, the Zener diode Z_2 acts as a rectifier and only negligibly small current can flow in the reverse direction. However, when the reverse voltage exceeds the breakdown value, the Zener diode Z_2 presents a very low resistance and permits current to flow freely in the reverse direction with no substantial increase in voltage. A resistor R_{16} is connected in circuit with the base-two electrode 101 to limit the current thereto. A capacitor C_{11} is connected across the emitter electrode 102 and base-one electrode 102 of unijunction transistor UJT_2 . Capacitor C_{11} is charged through a variable resistor R_{17} which serves as the dimming control for the entire fluorescent lamp system. A pulse transformer T_6 provides A.C. coupling and D.C. isolation between the phase control circuit 98 and the switching circuit 99. Secondary windings 104, 105 are in a one-to-one turns ratio with primary winding 106. Identical positive pulses are induced in the secondary winding 104, 105 which during operation trigger the controlled rectifier CR_5, CR_6 which has a positive anode voltage during the half cycle.

Although I have illustrated only one ballast circuit 75 in the dimming system shown in FIG. 3, it will be appreciated that a plurality of similar ballast circuits may be connected in the circuit by connecting the input terminal leads thereof across the supply lines 88, 89 and the switching terminal leads across the switching network lines 93, 94. In this embodiment of the invention as in the others, the number of such ballasts that may be employed in a given application will depend upon the volt-ampere rating of the controlled rectifiers CR_5, CR_6 .

Having reference now to the schematic diagram shown in FIG. 1, the operation of the dimming system illustrated therein will now be more fully described. Operation is initiated by energizing the input lead terminals 13, 14 and thereby energizing the phase control and switching circuit 11 and the ballast circuits 44, 44'. The full wave bridge 15 converts the alternating current supplied to the phase control and switching circuit 11 to a full wave rectified voltage that is clipped by Zener diode Z_1 and applied to unijunction transistor UJT_1 . At the start of the first instantaneous rectified current wave, capacitor C_1 begins charging. The setting of the variable resistor R_1 determines the rate at which capacitor C_1 is charged to the peak emitter voltage of unijunction transistor UJT_1 and consequently the point at which unijunction transistor UJT_1 is fired during each half cycle. Until unijunction transistor UJT_1 is fired at some point in the half cycle, controlled rectifier CR_1 is in a blocking state and no current flows in the secondary winding 32 even though the primary winding 31 of the high reactance ballast transformer T_2 is energized.

Assuming that silicon controlled rectifier CR_1 is fired in the positive half cycle and that lamp 1 is ignited, the instantaneous current follows a path which may be traced from input terminal lead 14 through diode D_2 , lead 20, controlled rectifier CR_1 , lead 19, diode D_3 , switching network line 25, switching terminal lead 29, secondary winding 32, output lead 42, lamp 1, output lead 43, input terminal lead 27, supply line 26 and to

input terminal lead 13, the lead provided for connection to the grounded side of the power supply. In the next half cycle, when CR_1 is again triggered and lamp 1 is ignited, the path of instantaneous current flow is in a reverse direction. It may be traced from input terminal lead 13, supply line 26, ballast input terminal lead 27, output lead 43, lamp 1, output lead 42, secondary winding 32, switching terminal lead 29, switching network line 25, diode D_4 , lead 20, controlled rectifier CR_1 , lead 19, diode D_1 and to input terminal lead 14, the lead provided for connection to the ungrounded side of the power supply.

During the portion of the half cycle when lamp 1 presents an open circuit condition in the ballast circuit 12 and CR_1 is switched on, the instantaneous current path during an arbitrarily selected half cycle follows a path which may be traced from input terminal lead 14 through diode D_2 , lead 20, controlled rectifier CR_1 , switching network line 25, switching input lead 29, secondary winding portion 38, capacitor C_4 , output lead 43, ballast input terminal lead 27, supply line 26 and to input terminal lead 13. During this portion of the half cycle, capacitor C_4 is effective in the circuit and functions in conjunction with the secondary winding portion 38 as an oscillatory circuit to provide a transient voltage when controlled rectifier CR_1 is switched on that will cause lamp 1 to reignite thereby maintaining the luminous intensity of the lamp at low dimming levels. It will be seen that if controlled rectifier CR_1 is fired early in the half cycle, the open circuit voltage of the secondary winding is sufficient to cause reignition of lamp 1.

In FIGS. 4 and 5, I have shown the voltage waveforms for the open circuit voltage at the lamp terminals when the controlled rectifier is fired late in each half cycle. The voltage waveform shown in FIG. 4 represents the open circuit voltage for a comparable ballast circuit without the oscillatory circuit arrangement of the present invention. In FIG. 4 the voltage peaks shown are the sum of primary and secondary voltages during the last few degrees of each half cycle following the firing of the controlled rectifier.

Referring now to the voltage waveform illustrated in FIG. 5, this waveform represents the open circuit voltage at the output terminals of the ballast circuit 12 shown in FIG. 1. Although this description of the operation of the ballast circuit refers to the ballast circuit 12 of FIG. 1, it will be appreciated that the ballast circuits shown in FIGS. 2 and 3 operate in a substantially similar manner. It will be observed that in the waveform shown in FIG. 4, the effective voltage available when the switching action occurs late in the half cycle, is considerably less than the voltage available when switching occurs earlier in the half cycle. This imposes a limitation on the continuous dimming range of the system since the voltage provided when the controlled rectifiers are switched on late in the half cycle is insufficient to cause reignition of the lamps.

As shown in FIG. 5, the resultant instantaneous open circuit voltage obtained at the instant of switching is appreciably greater than the peak voltage of the sinusoidal voltage. The resultant transient voltage at the instant of switching is stepped-up by the autotransformer action in the secondary winding portion 39 of the ballast circuit 12. Thus, during the transient condition at the instant of switching the secondary winding 32 in effect functions as an autotransformer to provide an instantaneous open circuit voltage sufficient to ignite the lamp during low brightness levels. When lamp 1 is ignited, it conducts current and presents less impedance to the flow of current than the capacitor C_4 . Thus, the capacitor C_4 is ineffective in the circuit during the portion of the cycle during which lamp 1 is ignited. Capacitor C_4 is effective in the circuit under open circuit conditions and makes it possible to extend the dimming

range of a plurality of fluorescent lamps to a substantially zero brightness level since sufficient starting voltage is provided when the controlled rectifier CR₁ is fired late in each half cycle.

Further, it was found that this circuit arrangement provided stability of lamp operation at low intensity levels and eliminated lamp flicker caused by fluctuations in the power supply.

To operate a plurality of 40 watt fluorescent lamps, the ballast circuit shown in FIG. 1 employed the following circuit components which are identified below and are cited to illustrate a specific reduction to practice of the invention:

Primary winding 31	-----turns---	790
Secondary winding 32	-----do-----	960
First winding portion 38	-----do-----	320
Second winding portion 39	-----do-----	640
Capacitor C ₄	-----microfarads---	.01

An improved phase control circuit is shown in FIG. 2. The resistor R₉ connected in parallel circuit relationship with capacitor C₈ serves as the dimming control for the system and by adjusting the dimming control, the phase angle of the voltage appearing across the serially connected pulse transformer T₄ and inductor L₄ is varied. The pulse transformer T₄ in this circuit arrangement is a saturating reactor and inductor L₄ is a linear reactor. The impedance of L₄ is considerably less than the unsaturated impedance of T₄ but considerably greater than the saturated impedance of T₄. The volt-second rating of T₄ is such that it can only support a voltage spike at the magnitude of the impressed voltage. The voltage appearing across the primary winding of the pulse transformer is thus, a spike of voltage taken from the center of each half cycle of the voltage applied across the serially connected inductor L₄ and pulse transformer T₄.

The phase control and switching circuit 46 shown in FIG. 2 provides the advantage that the phase angle of the voltage across the serially connected saturable reactor or nonlinear pulse transformer T₄ and inductor L₄ is not appreciably affected by normal variations in voltage supplied to input terminal leads 71, 72. Further, the phase control portion of the circuit 46 uses relatively inexpensive static control elements and does not require the use of semiconductor elements.

Dimming of fluorescent lamps 3, 4, 5, 6, in the system shown in FIG. 2 is essentially achieved in the same manner as in the systems illustrated in FIGS. 1 and 3. By firing one of the controlled rectifiers CR₃, CR₄ at a predetermined point during each half cycle of the alternating current supply, the interval of current conduction to the lamp circuit and the luminous intensity of the lamps 3, 4, 5, 6 is controlled. Two controlled rectifiers CR₃, CR₄ are connected back-to-back so that one conducts during the negative half of the cycle and the other during the positive half of the cycle. When variable resistor R₉, the dimming control, is set so that the controlled rectifiers CR₃, CR₄ are fired early in each cycle, it will be seen that the conduction period to the lamps is greater than would be the case if they were fired late in the cycle. Consequently, as the firing of the controlled rectifiers CR₃, CR₄ is delayed by the phase control circuit, the lamps are progressively dimmed. The minimum brightness level occurs when variable resistor R₉ is in its minimum resistance position.

Controlled rectifiers CR₃, CR₄ are turned off at the end of each half cycle of the lamp current due to the voltage reversal that takes place at the end of each half cycle. During the conduction period in each half cycle when the lamps are ignited, the path of instantaneous current flow during one arbitrarily selected half cycle can be traced from input terminal lead 72 through controlled rectifier CR₄, switching network line 60, switching terminal lead 61, secondary winding 50, output lead 68, lamps 3, 4, output lead 69, ballast input terminal lead 56, supply

line 58 and input terminal lead 71 of the phase control and switching circuit 46.

During the portion in the half cycle when the lamps 3, 4, are not ignited and controlled rectifier CR₄ is switched on, an open circuit condition exists and the current flow through the circuit may be traced from input terminal lead 72 through controlled rectifier CR₄, switching network line 60, switching terminal lead 61, secondary winding portion 48, connecting line 65, winding portion 70 of inductor L₂, capacitor C₆, output lead 69, ballast input terminal lead 56, supply line 58 and input terminal lead 71. During this open circuit condition, it will be noted that the transient voltage produced by the oscillatory circuit when a controlled rectifier is switched on is augmented by the autotransformer action of the inductor L₂. A principal advantage of this arrangement is that higher voltages for reigniting the lamps 3, 4 are provided by the ballast circuit 47 and a pair of lamps 3, 4 can be progressively dimmed to a substantially zero brightness level. Also, the lamps 3, 4 are prevented from being extinguished at low brightness levels due to insufficient ionization voltage being applied to the lamps 3, 4 to cause reignition in each half cycle.

Having reference now to the operation of the phase control circuit 98 and switching circuit 99 shown in FIG. 3, it will be seen that the phase control circuit 98 is substantially similar in operation to the circuit shown in FIG. 1. When the phase control circuit 98 is energized, bridge rectifier 100 converts the alternating current to a full wave rectified voltage that is clipped by a Zener diode Z₂. This clipped full wave rectified voltage is applied to unijunction transistor UJT₂.

Capacitor C₁₁ begins charging at the start of the first instantaneous rectified alternating current wave and the rate at which it is charged to the peak emitter voltage is determined by the setting of the variable resistor R₁₇. Assuming that silicon controlled rectifier CR₅ has positive anode voltage during an arbitrarily selected half cycle, it will be triggered by the firing pulse induced across the secondary winding 104 of pulse transformer T₆ when capacitor C₁₁ is discharged by unijunction transistor UJT₂. When triggered, the controlled rectifier CR₅ functions like an ordinary diode. In the next half cycle, controlled rectifier CR₆ has a positive anode voltage and it is triggered by the firing pulse induced across the secondary winding 105.

Dimming of fluorescent lamp 7 is achieved by firing one of the silicon controlled rectifiers CR₅, CR₆ at a predetermined point during each half cycle of the alternating current in order to control the interval of current conduction to lamp 7. Two controlled rectifiers CR₅, CR₆ are required since one conducts during the negative half of the cycle and the other during the positive half of the cycle. If controlled rectifiers CR₅, CR₆ are fired early in each cycle, it will be seen that the conduction time of the controlled rectifier is greater than would be the case if they were fired late in the cycle. Consequently, as the firing of the controlled rectifiers CR₅, CR₆ are delayed by the phase control circuit 98 the lamps are progressively dimmed. A minimum brightness level is achieved when the variable resistance R₁₇ is in its maximum resistance position, since with this setting the charging rate of the capacitor C₁₁ is such that the voltage across it does not reach the peak emitter value of the unijunction transistor UJT₂. Consequently, the unijunction transistor UJT₂ is not fired during the half cycle but is only fired when the unijunction inner base voltage drops momentarily to zero during the voltage reversal which takes place at the end of each half cycle. This conduction period which takes place near the end of the cycle amounts to a very brief interval and does not have any appreciable effect on the luminous output of the lamp 7.

Since at the end of each half cycle the rectified voltage at base-two electrode 101 of unijunction transistor UJT₂ drops to zero, the capacitor C₁₁ is discharged thereby

starting a new firing cycle. In this manner, the timing of the unijunction transistor pulse is always synchronized with the alternating current supply voltage. Thus, after unijunction transistor UJT_2 is fired, the voltage of capacitor C_{11} remains at a low level until the voltage builds up at the beginning of the next half cycle.

The operation of the ballast circuit 75 shown in FIG. 3 is substantially similar to the circuits shown in FIGS. 1 and 2. The switching action of the controlled rectifiers CR_5 and CR_6 are utilized to resonate an oscillatory circuit to provide the required voltage to reignite the lamps at low luminous levels. During an arbitrarily selected half cycle when CR_5 is conducting and lamp 7 is ignited, it will be seen that the current follows a path which may be traced from ballast input terminal lead 87 through secondary winding portion 78, switching terminal lead 90, switching network line 93, controlled rectifier CR_6 , switching network line 94, switching input lead 91, secondary winding portion 81, output lead 96, lamp 7, output lead 95 and input terminal lead 86. In the next half cycle, instantaneous current flow follows a reverse path through CR_5 when it is triggered.

Under open circuit conditions, secondary winding portion 80, capacitor C_{10} and resistor R_{12} are effective in the circuit and function as an RLC oscillatory circuit until the lamp 7 is reignited. During the starting period of lamp 7, the resistor R_{14} provides a resistive load in order that a suitable holding current is supplied to the controlled rectifiers CR_5 , CR_6 . It will be noted that as shown in the ballast circuit 75 illustrated in FIG. 3, the upper plate of capacitor C_{10} is preferably connected to one end of the secondary winding 79 and not to a tap as in the other ballast circuits. In such an arrangement the polarity of the initial half cycle of the resonant oscillation is such that it adds to the voltage across the primary winding 76 and across the secondary winding 79. This results in the advantage that the system operates with greater stability at low brightness levels and that the oscillatory portion of ballast circuit 75 can be designed with a lower circuit quality.

It will be understood that the system and various ballast circuits described herein are intended as illustrative examples of the invention and that the invention is not limited to such embodiments thereof. Further, it will be apparent that many modifications of the particular embodiments of the invention described herein may be made. It is to be understood, therefore, that I intend by the appended claims to cover all such modifications that fall within the true spirit and scope of the invention.

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

1. A ballast circuit for starting and operating at least one fluorescent lamp at various levels of luminous intensity from an alternating current supply in conjunction with a phase control and switching circuit adapted to connect one side of the alternating current supply in circuit with a switching network line at a predetermined point in each half cycle, said ballast circuit comprising a first and second input terminal lead for connection across the alternating current supply, a high reactance transformer having a primary winding connected across said input terminal leads, a high leakage reactance secondary winding, at least one switching terminal lead for connection to the switching network line, a tap provided on said secondary winding and dividing said secondary winding into a first winding portion and a second winding portion, said switching terminal lead being connected to one end of said first winding portion, circuit means including at least a pair of output leads for connection to the fluorescent lamp to supply the output of the high reactance transformer thereto, a capacitor connected in circuit with the other end of said first winding portion and one of said output leads, at least said first winding portion and said capacitor forming an oscillatory circuit under open circuit conditions to provide a transient volt-

age to aid the ignition of said lamp and said second winding portion of said secondary winding augmenting said transient voltage by autotransformer action.

2. A ballast circuit for operating and starting at least one fluorescent lamp from an alternating current supply and for use in conjunction with a phase control and switching network adapted to control in each half cycle the flow of current from the ungrounded side of the power supply to a switching network line, said ballast circuit comprising a pair of input terminal leads for connection across the alternating current supply, a high reactance transformer having a primary winding connected across said input terminal leads and a secondary winding inductively coupled therewith on a magnetic core, said secondary winding being divided into a first winding portion and a second winding portion, a first circuit means including a pair of output leads for connecting the output of said high reactance transformer across said lamp, a switching terminal lead for connection with the switching network line of the phase control and switching network, one end of said first winding portion being connected in circuit with said switching terminal lead and a second circuit means including at least a capacitor connecting the other end of said first winding portion in circuit with one of said output leads, said capacitor and said first winding portion functioning as an oscillatory circuit to provide a transient voltage under open circuit conditions during operation of said circuit when the current is switched on to said switching terminal lead whereby said lamp is ignited during each half cycle to stably operate said lamp at low levels of luminous intensity.

3. A ballast circuit for starting and operating at least one fluorescent lamp at various levels of luminous intensity and for use in conjunction with a phase control and switching circuit employing controlled rectifiers adapted to control the interval of current conduction from the ungrounded side of the power supply to a switching network line, said ballast circuit comprising a first and second input terminal lead for connection across said alternating current supply, a high reactance transformer having a primary winding connected across said input leads, a secondary winding inductively coupled therewith on a magnetic core, said secondary winding being divided into a first and a second winding portion, a first and second output lead for connection across at least one fluorescent lamp, said first output lead being connected in circuit with said first input lead and said second output lead being connected in circuit with one end of said secondary winding, a switching terminal lead connected in circuit with the one end of said first winding portion, a capacitor connected in circuit with the other end of said first winding portion and said first output lead, at least said capacitor and said first winding portion forming an oscillatory circuit during operation whereby when the current conduction to said switching terminal lead is switched on in each half cycle, a transient voltage produced in said oscillatory circuit under open circuit condition to cause reignition of said lamp in each half cycle to operate the fluorescent lamp at low luminous levels.

4. A ballast circuit for starting and operating a pair of fluorescent lamps from an alternating current supply at various levels of luminous intensity and for use in conjunction with a phase control and switching circuit employing controlled rectifiers to control the interval of current conduction in each half cycle between one side of the power supply and a switching network line, said ballast circuit comprising a first and a second input terminal lead for connection across the alternating current supply; a high reactance transformer having a primary winding connected across said input terminal leads and a secondary winding inductively coupled therewith on a magnetic core; a first and a second output lead for connection across a pair of fluorescent lamps; a starting capacitor connected in circuit with said second output lead for connection across one of said lamps, said first output lead

being connected in circuit with said first input lead and said second output lead being connected in circuit with one end of said secondary winding; a switching terminal lead connected in circuit with the other end of said secondary winding; a tap on said secondary winding dividing said secondary winding into a first and a second winding portion; a reactor and a capacitor connected in series circuit across said first and second output lead; a tap on said reactor connected in circuit with said tap on said secondary winding, said tap on said reactor dividing said reactor into a first and second winding; said first winding portion of said secondary winding, said first winding of said reactor and said capacitor all forming a resonant circuit under open circuit conditions during the operation of said circuit whereby a transient voltage is developed when the current conduction to said switching terminal lead is switched on to cause reignition of said pair of lamps during each half cycle whereby said lamps are stably operated at low levels of luminous intensity.

5. A ballast circuit for starting and operating at least one fluorescent lamp from an alternating current supply at various levels of luminous intensity and for use in conjunction with a phase control and switching circuit employing controlled rectifiers that control the interval of current conduction from a first switching network line to a second switching network supply line, said ballast circuit comprising: a first and second input terminal lead for connection across the alternating current supply; a high reactance transformer having a primary winding connected across said input leads, an extension winding and a secondary winding inductively coupled with said primary winding on a magnetic core; a first and a second output lead, said first output lead being connected in circuit with said first input terminal lead and said second output lead being connected in circuit with one end of the secondary winding; a first switching terminal lead for connection in circuit with one of said switching network lines and connected in circuit with said extension winding; said secondary winding being divided into a first winding portion and a second winding portion, a second switching terminal lead for connection to the other of said switching network supply lines and connected in circuit with one end of said first winding portion, a capacitor connected in circuit with the other end of said first winding portion and said first output lead, at least said capacitor and said first winding portion of said secondary winding forming an oscillatory circuit during operation under open circuit conditions whereby a transient voltage is provided to cause reignition of said lamps during each half cycle at low levels of luminous intensity.

6. The ballast circuit set forth in claim 5 wherein a resistor is connected across said second switching terminal lead and said first output lead so as to provide a holding current for said controlled rectifiers during the ionization period of the lamps and to provide a voltage divider action so as to limit the voltage which appears across the controlled rectifiers during operation.

7. A ballast circuit for starting and operating at least one fluorescent lamp at various levels of luminous intensity from an alternating current supply in conjunction with a phase control and switching circuit adapted to connect one side of the alternating current supply in circuit with a switching network line at a predetermined point in each half cycle of said supply, said ballast circuit comprising a first and second input terminal lead for connection across the alternating current supply, a high reactance transformer including a magnetic core, a primary winding connected across said input terminal leads and a secondary winding inductively coupled therewith on said magnetic core, a tap on said secondary winding dividing said secondary winding into a first winding portion and a second winding portion, a first circuit means including a pair of output leads for connecting the output of said high reactance transformer across said lamp, a switching terminal lead for connection with the switching network line

of the phase control switching network and connected in circuit with the tap on said secondary winding, a capacitor connected in circuit with one end of said first winding portion and one of said output leads, at least said capacitor and said first winding portion of said secondary winding forming a resonant circuit during operation under open circuit conditions whereby a transient voltage is provided to cause reignition of the lamp during each half cycle at low levels of luminous intensity.

8. A ballast circuit for starting and operating at least one fluorescent lamp at various levels of luminous intensity and for use in conjunction with a phase control and switching circuit adapted to connect one side of the alternating current supply in circuit with a switching network line at a predetermined point in each half cycle of said supply, said ballast circuit comprising a first and a second input lead for connection across the alternating current supply, a high reactance transformer including a primary winding connected across said input terminal leads and a high leakage reactance secondary winding inductively coupled therewith on a magnetic core, a tap provided on said secondary winding and dividing said secondary winding into a first winding portion and a second winding portion, a switching terminal lead for connection to the switching network line, a pair of output leads, one of said output leads being connected with one end of said secondary winding and the other of said output leads being connected in circuit with one end of the primary winding, said switching terminal lead being connected to the other end of said secondary winding, a capacitor connected in circuit with said tap and one of said output leads, at least said first winding portion and said capacitor forming a resonant circuit under open circuit conditions to provide a transient voltage to aid the ignition of said lamp and said second winding portion of said secondary winding augmenting said transient voltage by autotransformer action.

9. A system for starting and operating gaseous discharge lamps at predetermined levels of luminous intensity from an alternating current supply, said system comprising a plurality of fluorescent lamps; a plurality of ballast circuits, each of said ballast circuits having a pair of output leads connected across at least one of said plurality of lamps and in circuit with a high reactance transformer so as to apply the output of said transformer across said lamp; each of said high reactance transformers having a primary winding, a pair of input terminal leads connected across said primary winding, a high reactance secondary winding, a tap on said secondary winding dividing said secondary winding into a first winding portion and a second winding portion, a switching terminal lead connected in circuit with one end of said first winding portion, a capacitor connected in circuit with the other end of said first winding portion and one of said output leads of said ballast circuit, at least said first winding portion and said capacitor forming a resonant circuit under open circuit conditions to provide a transient voltage to aid the ignition of said lamp; a phase control and switching means connected in circuit with each of the switching terminal leads and in circuit with one side of the alternating current supply so as to control the interval of current conduction during each half cycle of the alternating current supply.

10. A system for controlling the luminous intensity of a plurality of fluorescent lamps comprising: a plurality of fluorescent lamps; a plurality of ballast circuits, each of said ballast circuits comprising a high reactance transformer including a primary winding for connection across the alternating current supply and a high leakage reactance secondary winding, a tap on said secondary winding dividing said secondary winding into a first winding portion and a second winding portion, a pair of switching terminal leads, a first and second output lead connected across at least one of said lamps, circuit means connecting said output leads, said second winding portion, said

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lamp, said primary winding in series circuit relationship across said switching terminal leads, and a capacitor connected in circuit with one end of said high reactance secondary winding and said second output lead, the other end of said secondary winding being connected to said first output lead; a switching circuit means including at least a controlled rectifier connected in circuit with said switching terminal leads to control the current supplied in each half cycle to said ballast circuits; a phase control means for controlling the phase angle at which said controlled rectifiers are fired during each half cycle of the alternating current supply and connected in circuit with said controlled rectifier; at least said first portion of said high reactance secondary and said serially connected capacitor forming an oscillatory circuit and said oscillatory circuit providing a transient voltage under open circuit conditions sufficient in magnitude to maintain the luminous intensity of said lamps at low brightness levels.

11. A system for dimming and operating a plurality of gaseous discharge lamps from an alternating current supply, said system comprising: a plurality of gaseous discharge lamps; a plurality of ballast circuits, each of said ballast circuits comprising an autotransformer having a primary winding for connection across said alternating current supply, a high leakage reactance secondary winding, a pair of output leads connected across at least one of said plurality of lamps and in circuit with said autotransformer so as to apply at least the voltage induced in said high reactance secondary winding across said lamp, a capacitor, a reactor connected in series circuit rela-

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tionship with said capacitor across the output leads, a first tap provided on said high reactance secondary winding and dividing said secondary winding into a first winding portion and a second winding portion, a second tap provided on said reactor and connected in electrical circuit with said first tap, and switching network lead connected in circuit with one end of said secondary winding; switching circuit means including at least one controlled rectifier connecting one side of said alternating current supply in electrical circuit with each of said switching network leads during each half cycle of the alternating current supply; phase control means connected in circuit with said switching circuit means and adapted to vary the phase angle at which said controlled rectifier is fired in order to control the interval of conduction to said lamps; at least said capacitor, said first winding portion of said reactor and said first winding portion of said high reactance secondary winding of each of said ballast circuits forming an oscillatory circuit under open circuit conditions whereby as said controlled rectifier is switched on a transient voltage of sufficient magnitude results to cause reignition of said lamps during each half cycle.

References Cited by the Examiner

UNITED STATES PATENTS

3,037,147 5/62 Genuit et al. 315—289 X

DAVID J. GALVIN, *Primary Examiner*.

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