

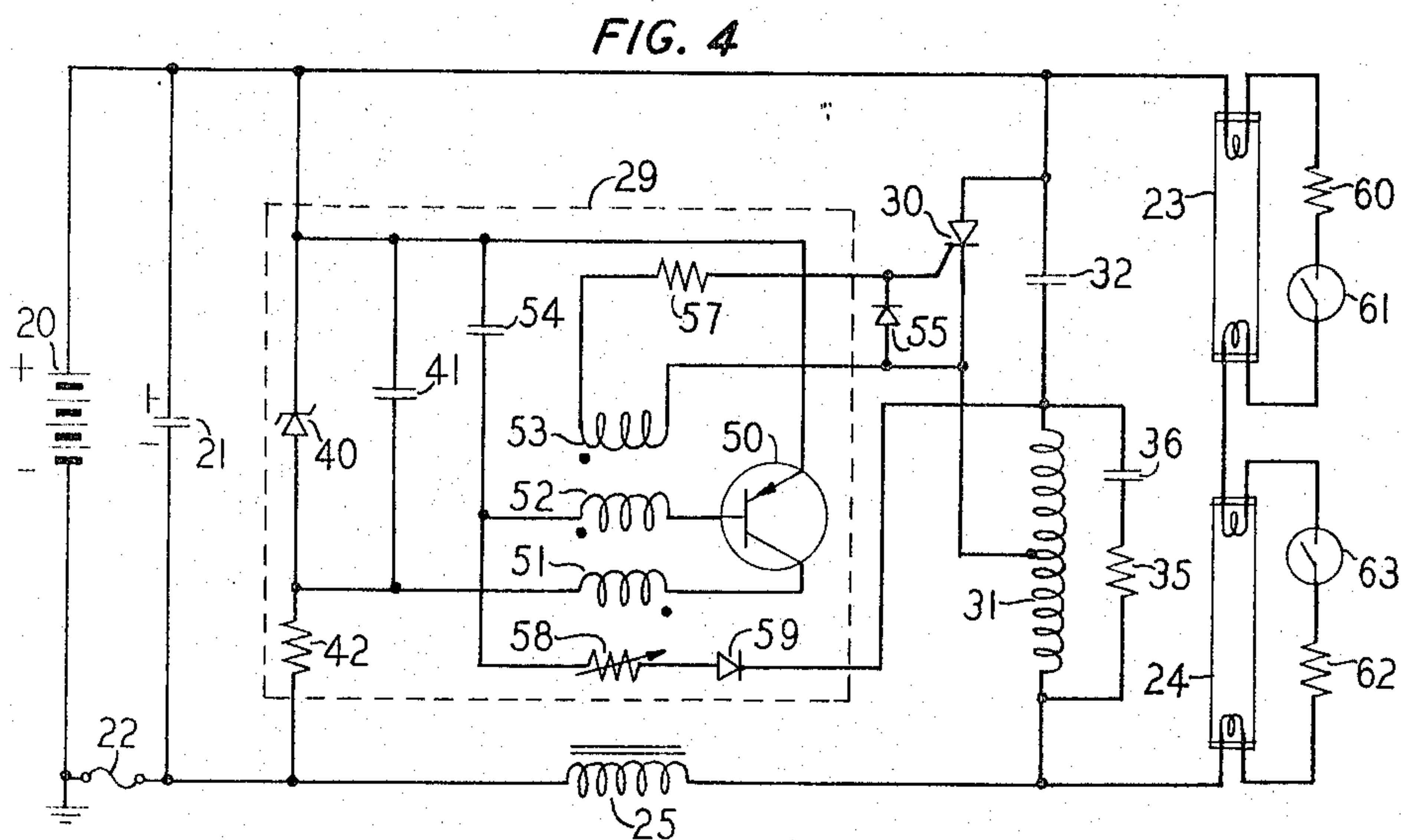
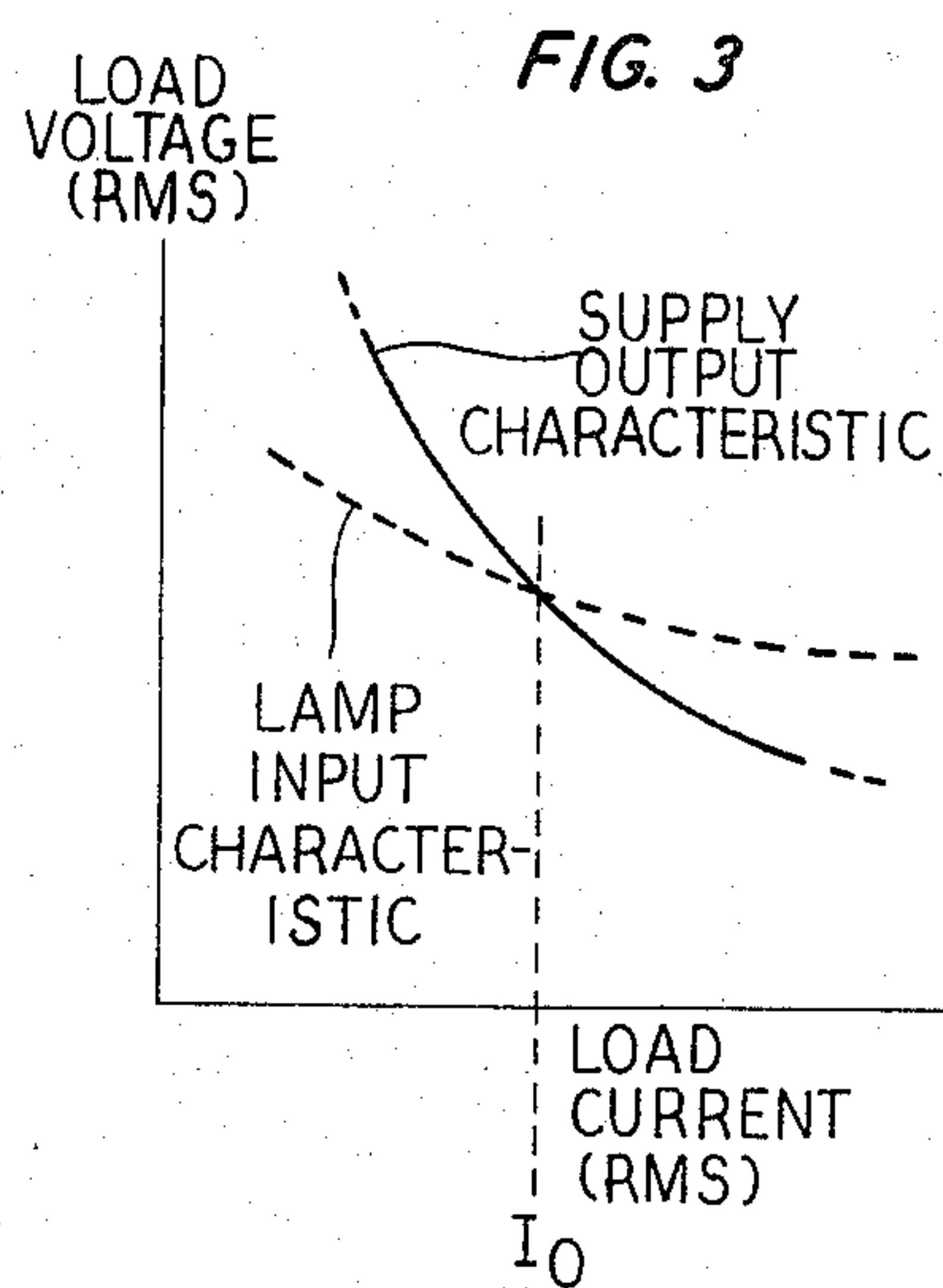
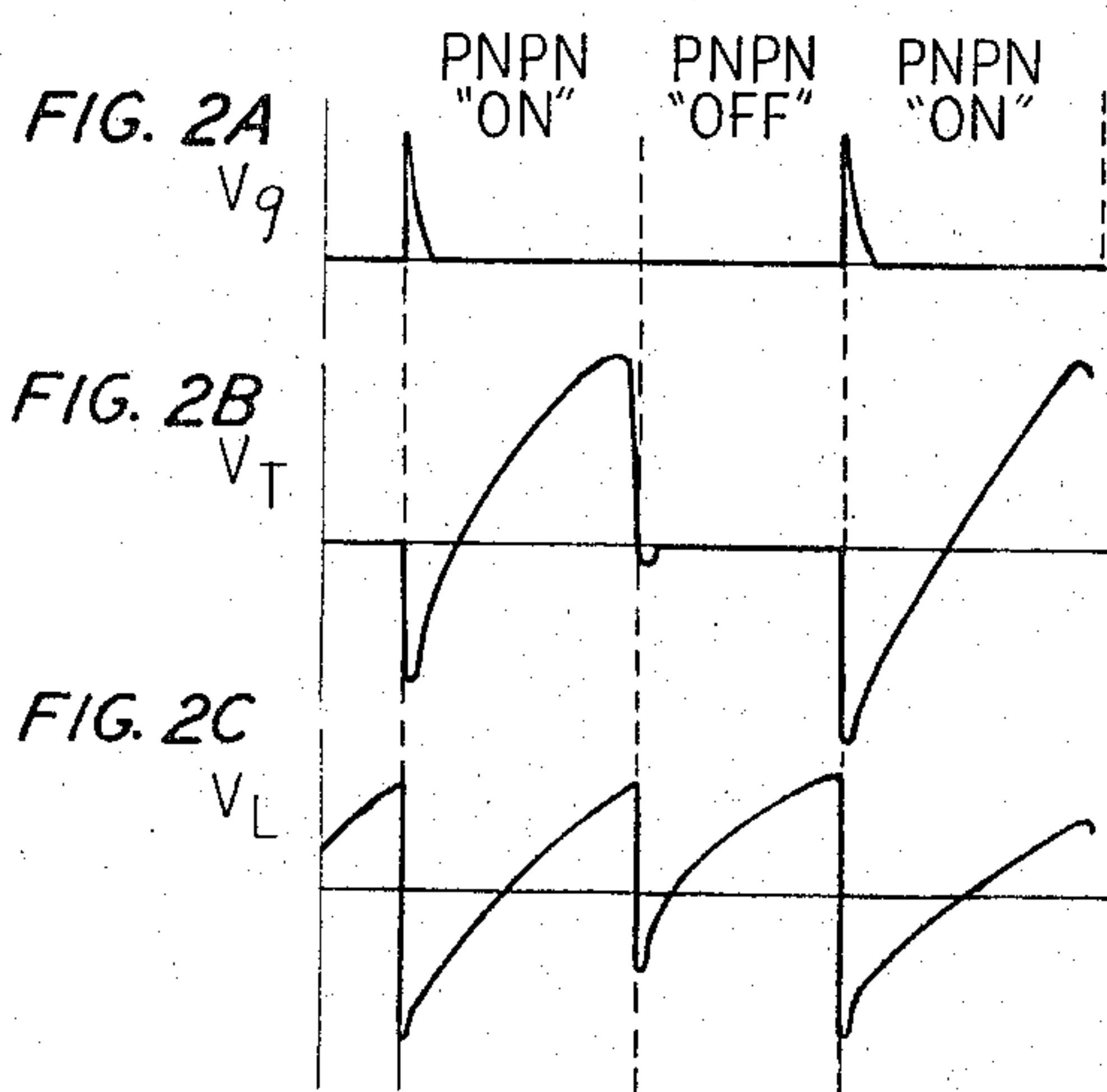
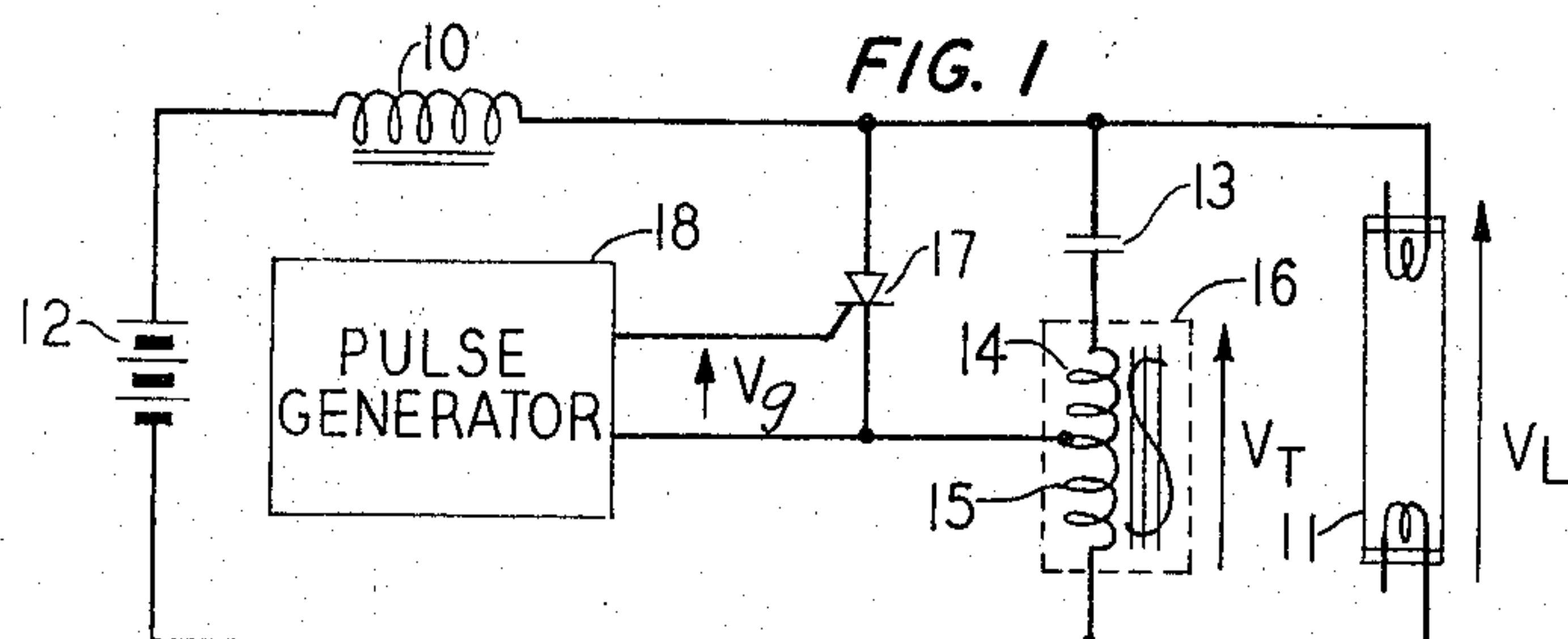
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POWER SUPPLY FOR NEGATIVE-RESISTANCE ARC-DISCHARGE LAMPS

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POWER SUPPLY FOR NEGATIVE-RESISTANCE ARC-DISCHARGE LAMPS

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This invention relates to electrical power conversion apparatus and more particularly, although in its broader aspects not exclusively, to an arrangement for supplying electrical energy to a fluorescent, gaseous discharge lamp from a source of a direct-current potential.

In recent years, fluorescent lamps have established themselves as the principal source of artificial light (from the standpoint of lumen-hours produced) in the United States. Their popularity is due in large part to the pleasant, diffused quality of fluorescent lighting. The glare often experienced from "point source" incandescent bulbs is minimized by the large-area fluorescent tubes.

Unfortunately, fluorescent lighting elements must be used in conjunction with rather complicated auxiliary equipment. In addition to the lamp and its holder, it is necessary to provide a ballast impedance and a starting circuit. This added equipment is needed because of the unusual characteristics of a fluorescent lamp. Being a discharge-type device, it exhibits a negative resistance volt-ampere characteristic; that is, as the arc current increases, the voltage drop across the lamp goes down. Accordingly, a current limiting impedance must be connected in series with the current supply conductors. Otherwise, an increase in the line voltage would increase the arc current and this, in turn, would lower the voltage across the lamp causing a still further increase in arc current. This process would continue and very quickly destroy the lamp. For alternating-current operation, the ballast impedance normally comprises an inductor. When a direct-current supply is used, however, the current must be limited by a resistive ballast. The ballast resistor uses about as much power as the fluorescent lamp itself—thus detracting greatly from the efficiency of the overall lighting system.

The starting circuit must also be included to provide initial cathode heating for the lamp and to deliver the high voltage surge needed to initiate arc conduction after the cathodes are heated. For D.C. operation, the starting circuit usually includes a switch for connecting the cathodes in series across the source voltage for a short period of time (one or two seconds) and an inductance in series with the ballast resistance for providing an inductive voltage "kick" when the switch is opened once more. There are some lamps designed for rapid starting without cathode preheating. These so-called "instant-start" lamps require a higher than usual starting voltage, typically as much as four times that needed to maintain the arc, and consequently they still require the inductance for limiting the current through the lamp.

It is a general object of the present invention to supply electrical energy from a D.C. source to a fluorescent discharge lamp or other negative-resistance load in a new and improved manner.

It is a further object of the present invention to improve the efficiency of D.C. operated fluorescent lighting systems.

More particularly, it is an object of the present inven-

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tion to supply a fluorescent lamp with a stable operating current from a low impedance D.C. source without the use of a power-consuming ballast resistance.

It is a still further object of the present invention to supply a fluorescent lamp with the high initial voltage required to start the discharge arc.

In a principal aspect, the present invention takes the form of a power conversion system for operating a fluorescent lamp from a low-impedance direct-current source without the use of either a large inductive ballast or a power-consuming resistive ballast. As contemplated by the invention, the lamp load is connected in series with a small inductor across the source and a high-frequency switching network is connected in parallel with the lamp load. This switching network comprises a capacitor serially connected with a saturable transformer across the load and a PNP semiconductor switch connected between one side of the load and a tap connection on the transformer. According to a principal feature of the present invention, the constant switching frequency allows the supply to deliver substantially constant power to the lamp, thus providing the high starting voltage required before the lamp load can conduct and providing the high effective output impedance necessary for stable operation without an additional ballast impedance. In accordance with still another feature of the invention, the capacitor-saturable transformer combination supplies the required turn-OFF voltage for the PNP device and, in addition, provides an essential energy storage function during various portions of the operating cycle.

A more complete understanding of the present invention, as well as a fuller appreciation of its objects, features, and advantages, may be obtained by considering the following detailed description of a specific embodiment thereof. In the description below, reference will be made to the accompanying drawings in which:

FIG. 1 shows one embodiment of the invention in simplified form;

FIGS. 2A, 2B and 2C show several waveforms, a consideration which will aid in understanding the operation of the circuit shown in FIG. 1;

FIG. 3 depicts the relationship between the output characteristic of the current supply apparatus and the negative resistance lamp characteristic; and

FIG. 4 is a more detailed schematic drawing of the embodiment of the invention shown in FIG. 1.

In FIG. 1 of the drawings, an inductance 10 and a fluorescent lamp 11 are shown connected in series across a low-impedance direct-current source 12. A capacitor 13 is serially connected with both primary winding 14 and secondary winding 15 of a saturable transformer 16 across the lamp 11. A tap connection between winding 14 and winding 15 is connected to the cathode of a PNP semiconductor switch 17, its anode being connected to the junction of inductor 10 and lamp 11. Pulses which initiate conduction through the PNP switch 17 are generated by pulse generator 18 and are applied between the cathode and the gating electrode of the switch 17.

To better understand the operation of the circuit shown in FIG. 1, note should be taken of the waveforms shown in FIG. 2 of the drawings. FIG. 2A shows the pulse voltage waveform V_g which is produced by pulse generator 18 and applied between the cathode and gating electrode of PNP device 17. FIG. 2B shows the voltage waveform V_T which appears across both windings 14

and 15 of the saturable autotransformer 16 and FIG. 2C illustrates the voltage waveform V_L appearing across the fluorescent lamp 11.

When voltage from the source 12 is applied to the circuit shown in FIG. 1, the capacitor 13 is charged through a current path which includes the two windings 14 and 15. During this time the PNP switch 17 is turned OFF; that is, switch 17 is nonconducting. The core upon which windings 14 and 15 are wound is saturated during this period and, as shown in FIG. 2B, little or no voltage appears across the autotransformer 16. Hence, while switch 17 is turned OFF, the voltage across capacitor 13 is essentially equal to the voltage across the lamp 11 as shown in FIG. 2C. Eventually, a pulse from the generator 18 is applied to the PNP switch 17, turning it ON. The entire voltage previously established across capacitor 13 is now applied across the winding 14 of the saturable autotransformer 16, bringing the core out of saturation. Since the PNP device is conducting, the lamp voltage is closely equivalent to the voltage established across winding 15. (The voltage across winding 15 is merely a portion of the voltage V_T .) Due to the capacitor discharge current flowing through the winding 14, the voltage induced across winding 15 rapidly reverses the voltage across the lamp at the moment PNP device 17 becomes conductive.

It will be noted that the voltage across winding 15 immediately after switch 17 is turned ON is added to the voltage across source 12 and applied across the inductance 10. Accordingly, the current flowing through inductor 10 and the winding 15 increases while the capacitor discharge current decreases. Eventually, the voltage across the two windings 14 and 15 turns positive, as shown in FIG. 2B, and the capacitor 13 begins to charge in the opposite direction by autotransformer action. Finally, the core of the saturable autotransformer saturates, applying the capacitor voltage across the PNP switch in a reverse direction, turning it OFF. Afterwards, the current flowing through inductor 10 and windings 14 and 15 of the saturated autotransformer returns the capacitor voltage to its original voltage.

As will be appreciated from the brief description of FIG. 1 given above, the total "ON-time" per cycle for the PNP switch 17 is determined by the length of time it takes to saturate the core of the saturable autotransformer. The total "OFF-time" per cycle is determined by the time placement of the pulses produced by the generator 13. In accordance with a feature of the present invention, the switching is accomplished at substantially constant frequency such that the lamp current supply delivers substantially constant power to the lamp load.

FIG. 3 of the drawings illustrates this substantially constant power characteristic of the supply. Since the product of lamp voltage and load current as supplied by the circuit is substantially constant, the volt-ampere output characteristic (shown by the solid line) has an approximately hyperbolic shape. Accordingly, the lamp voltage on an R.M.S. basis rises rapidly as the lamp current decreases. It is this feature of the invention which allows the lamp to be started without resorting to auxiliary apparatus for producing an initial voltage surge. Since current through the lamp is negligible until it "fires," the lamp voltage rises rapidly to initiate conduction.

It will also be noted that for low values of lamp current, the voltage delivered by the source drops quite rapidly for each small increase in lamp current. Consequently, when the load voltage is substantially greater than the voltage delivered by the low-impedance source 12, the effective internal impedance of the source may be quite high. This high effective impedance allows the lamp to be operated stably, yet does not require the use of any additional resistive or inductive bias. Since both inductance 10 and capacitor 13 are energy storage elements, they operate quite efficiently. Furthermore, at the

high switching frequencies contemplated by the invention, both may be quite small in value.

The combination of the lamp current supply and the fluorescent lamp operates at a stable R.M.S. lamp current, I_O , located at the intersection of the supply output characteristic and the lamp's negative resistance characteristic. To insure stable operation, a lamp should be selected (or the supply should be designed) such that the operating voltage of the lamp is substantially greater than the voltage delivered by the primary, low-impedance source. This allows the supply system to be operated in a range where its effective impedance is considerably greater than the negative resistance of the lamp load. Considerable variation in the operating current for a given lamp is possible but it should be borne in mind that as lamp current increases the illumination from the lamp increases but the overall efficiency of the lamp goes down. The value of lamp current delivered by the supply may be conveniently adjusted by varying the value of capacitor 13 or by varying the switching frequency.

DETAILED DESCRIPTION

FIG. 4 of the drawings schematically illustrates an embodiment of the present invention in more detail. The operating potential for the circuit is obtained from a low impedance direct-current source 20. A filter capacitor 21, which reduces the noise appearing at the input terminals, is connected in series with a fuse 22 across source 20. A pair of fluorescent lamps 23 and 24 are connected in series with an inductor 25 across capacitor 21.

The switching function for the circuit shown in FIG. 4 is performed by a blocking oscillator 29 which drives a PNP semiconductor switch 30. The cathode of PNP device 30 is connected to the tapped connection on a saturable autotransformer 31 while its anode is connected to the positive terminal of source 20, one end of autotransformer 31 is connected to the junction of inductor 25 and lamp 24 while the other end is connected to the positive terminal of source 20 by means of a capacitor 32. The series combination of a resistance 35 and a capacitor 36 is connected in parallel with the two windings of autotransformer 31. The position and function of elements 30, 31 and 32 of FIG. 4 are similar to the corresponding elements 17, 16 and 13 discussed in regard to FIG. 1.

The pulse generator 29, which is of the blocking oscillator type, includes a low level voltage source comprising Zener diode 40, capacitor 41 and resistance 42, the parallel combination of diode 40 and capacitor 41 being connected in series with resistance 42 across the capacitor 21. The emitter-collector path of a transistor 50 is connected in series with winding 51 of a pulse transformer across the capacitor 41. A second winding 52 of the pulse transformer is connected in series with a capacitor 54 between the base of transistor 50 and the positive terminal of source 20. The third winding 53 of the pulse transformer is connected between the cathode and gating electrode of the PNP switch 30 by means of a current limiting resistance 57. The junction of winding 52 and the capacitor 54 is connected through a variable resistance 58 and a diode 59 to the junction of capacitor 32 and reactor 31.

Each of the fluorescent lamps 23 and 24 is provided with a starting circuit connected across the lamp in series with its filaments. For lamp 23, the starting circuit comprises a resistance 60 and a starting switch 61. Starting switch 61 may be of the "glow-switch" variety which is adapted to close for a short time upon the application of a sufficient voltage across the lamp. The fluorescent lamp 24 is provided with a similar starting circuit comprising resistance 62 and starting switch 63.

In order to more completely describe the embodiment

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of the invention shown in FIG. 4, a table of element values is given below. It is to be understood that these values are merely illustrative of one operative embodiment and are by no means critical. Substantial departures from the listed values may be made without significantly altering the basic operation of the apparatus.

Source 20	48 volts.
Capacitor 21	2 μ fd.
Fuse 22	2 amp. dual element.
Lamps 23 and 24	20 watt fluorescent.
Inductor 25	.012 henry.
PNPN switch 30	C15D.
Reactor 31	76 turns on Ferroxcube core, tap at center.
Capacitor 32	.22 μ fd.
Resistance 35	100 ohms.
Capacitor 36	2700 μ fd.
Zener diode 40	IN1770.
Capacitor 41	1 μ fd.
Resistance 42	3900 ohms.
Transistor 50	2N461.
Capacitor 54	.02 μ fd.
Diode 55	IN645.
Resistance 57	330 ohms.
Resistance 58	10K to 60K ohms.
Diode 59	4JA10E.
Resistances 60 and 62	14.7 ohms.
Start switches 61 and 63	Type FS-2.

When the operating voltage from source 20 is applied to the circuit shown in FIG. 4, a small operating potential for the pulse generator 29 is established across the Zener reference diode 40. The capacitor 32 begins to charge through the two windings of autotransformer 31 toward the voltage across source 20 causing the capacitor 54 to charge toward a fraction of the source voltage. The voltage across capacitor 54 soon becomes large enough to apply a forward voltage across the emitter-base junction of transistor 50 thus allowing current flow through winding 51 which is connected in the collector circuit of transistor 50. Winding polarities of the pulse transformer are arranged such that the voltage thus applied across winding 51 induces a voltage across winding 52 which is series-aiding with the voltage across capacitor 54. In consequence, the transistor 50 is turned on still further. The resulting regenerative increase in collector current through transistor 50 creates a pulse of current in winding 53 which is applied to the gate of PNP device 30, turning it on. The operation of switch 30, autotransformer 31 and capacitor 32 is substantially identical to the operation of the corresponding elements shown in FIG. 1 and discussed previously.

In the pulse generator 29 the variable resistance 58 controls the charge time for capacitor 54, thereby controlling the frequency of operation of the pulse generator. The connection of resistance 58 through diode 59 to the junction of capacitor 32 and reactor 31 insures that the pulse generator 29 will not produce a pulse unless the voltage across capacitor 32 has reached a sufficient magnitude of correct polarity. The series R-C network comprising resistor 35 and capacitor 36 limits the output voltage delivered to the load to a safe value during starting and damps out "ringing" in the windings of autotransformer 31.

During starting the switches 61 and 63 are closed for a short period to preheat the filaments. The starter contacts then separate, open-circuiting the load and the output voltage rises rapidly to fire the lamps. The lamp supply may also be used to operate the so-called "instant start" lamps, as shown in FIG. 1, since it is capable of providing the high initial voltage required. The arrange-

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ment is also particularly well adapted for starting two starter-type lamps which are connected in series as shown in FIG. 3. Usually the contacts of switch 61 and switch 63 will not open simultaneously. The lamp associated with the starter which opens first, lights first and the preheat current for the cathode of the unlighted lamp is then supplied through a path which includes the lamp which has lighted and the still closed resistor and starter of the unlit lamp. When the starter contacts of this unlit lamp open, the lighted lamp is extinguished. Due to its having already been lighted, less voltage is required to relight the extinguished lamp and this voltage is once again supplied since the load current is once again near zero until it starts. With both lamps lighted, insufficient voltage for operation of the starters appears across the lamps and the starter contacts remain open. If it is desired to operate the lamps at a direct-current potential, a diode rectifier may be serially connected with the lamp load such that an essentially constant charge is trapped on a filter capacitor connected in parallel with the lamp.

It is to be understood that the above-described embodiment is merely illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. An inverter for supplying at least one fluorescent lamp from a low impedance source of direct current potential comprising an inductor, a first direct current circuit path connecting said inductor and said lamp in series across said sources, a saturable autotransformer having primary and secondary windings, a semiconductor switch having a transconductive path and a control electrode, a second direct current circuit path connecting said transconductive path and said secondary winding in series across said lamp, a capacitor, a circuit path connecting said capacitor and said primary winding in series across said transconductive path, and a pulse generator for supplying a periodic control signal to said control electrode to control the conductivity state of said transconductive path.

2. Apparatus as set forth in claim 1 wherein the magnitude of said direct-current potential is substantially less than the specified root-mean-squared operating potential of said lamp.

3. Apparatus as set forth in claim 2 wherein said fluorescent lamp load comprises a pair of lamps connected in series and a starting switch connected between the cathodes of each of said lamps.

4. An inverter for supplying at least one fluorescent lamp from a low impedance source of direct current potential comprising an inductor, a first direct current circuit path connecting said inductor and said lamp in series across said source, a saturable autotransformer having primary and secondary windings, a semiconductor switch having a transconductive path and a control electrode, a second direct current circuit path connecting said transconductive path and said secondary winding in series across said lamp, a capacitor, a circuit path connecting said capacitor and said primary winding in series across said transconductive path, a pulse generator for supplying a periodic control signal to said control electrode to control the conductivity of said transconductive path, and unidirectional conducting means interconnecting said pulse generator and the junction of said primary winding and said capacitor for allowing the generation of turn-on pulses only when said capacitor is charged to a predetermined voltage of a given polarity.

5. In combination a low impedance source of direct current potential, an inductor, a load having a negative resistance volt-ampere characteristic, a first direct current circuit path connecting said inductor and said load in series across said source, a saturable autotransformer having a primary and secondary windings, a PNP semiconductor device having a transconductive path and a

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gating electrode, a second direct current circuit path connecting said transconductive path and said secondary winding in series across said load, a circuit path including a series capacitor connecting said primary winding in parallel with said transconductive path, a source of pulses connected to said gating electrode for periodically initiating conduction through said transconductive path, said pulses appearing at substantially constant frequencies such that said negative resistance load receives substantially constant power at a voltage across said load that is substantially greater than said direct current potential from said source.

6. Apparatus as set forth in claim 5 wherein said load comprises at least one fluorescent lamp.

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