United States Patent [19]

Vogt

[11] **3,859,563**

[45] **Jan. 7, 1975**

[54] VOLTAGE CONVERTER AND REGULATOR

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[22] Filed: **July 9, 1973**

[21] Appl. No.: **377,294**

[52] **U.S. Cl.** ..... **315/241 P,** 321/2, 331/11

[51] **Int. Cl.** **G05f 1/20,** H02p 13/22

[58] **Field of Search** ..... 323/22 Z; 321/2, 11, 12; 315/241 P; 331/111, 112

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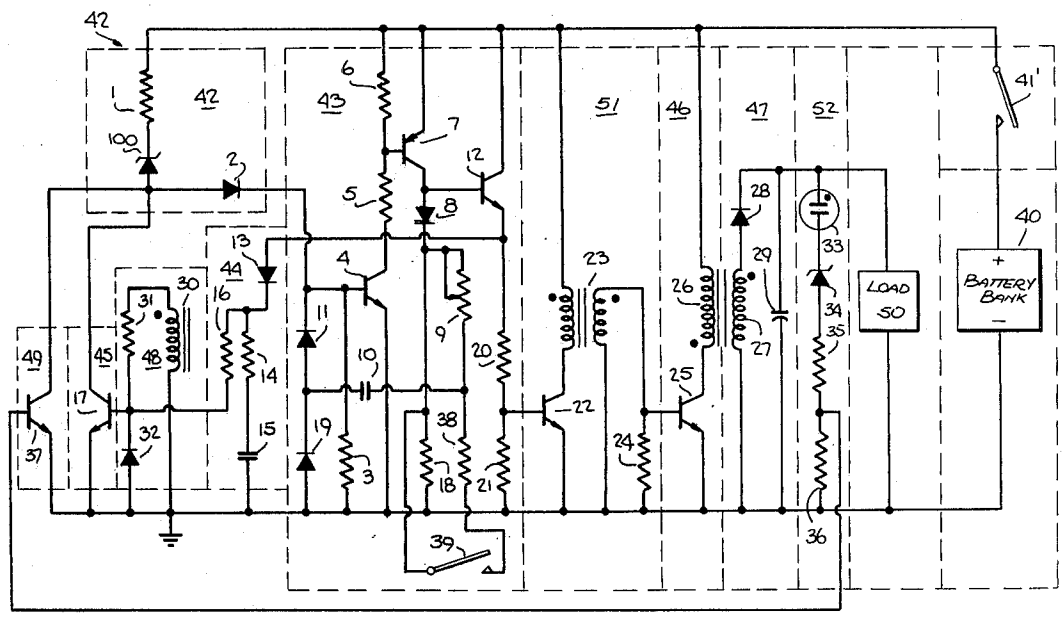
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[57] **ABSTRACT**

Voltage converter and regulator circuits are disclosed for converting a relatively low direct current input voltage to a higher output voltage for use in photographic flash equipment, power supplies and energy discharge applications. A battery supplies starting current for a transistor oscillator which provides current through a drive circuit to energize the primary winding of the transformer, during the "on" portion of the oscillator cycle. During the "off" portion of the oscillator cycle, no energy is supplied to the primary transformer winding, and the secondary winding provides charging current for a storage capacitor. While energy is being supplied to the storage capacitor, the circuit is maintained in the "off" condition by a second secondary winding through which current simultaneously flows and is used to energize a transistor to shunt battery current away from the oscillator. Voltage regulation is accomplished by a neon lamp and zener diode which are serially connected with a resistor, across the storage capacitor. While excess energy is being discharged from the storage capacitor the oscillator is maintained in the "off" condition by a feed-back connection responsive to current flowing through the neon lamp and zener diode to energize a switching transistor to shunt the starting current away from the oscillator. The duration of the "on" portion of the cycle can be controlled by a variable resistor, and the circuits are also provided with a mechanical switch for selection between different oscillator frequencies.

14 Claims, 4 Drawing Figures



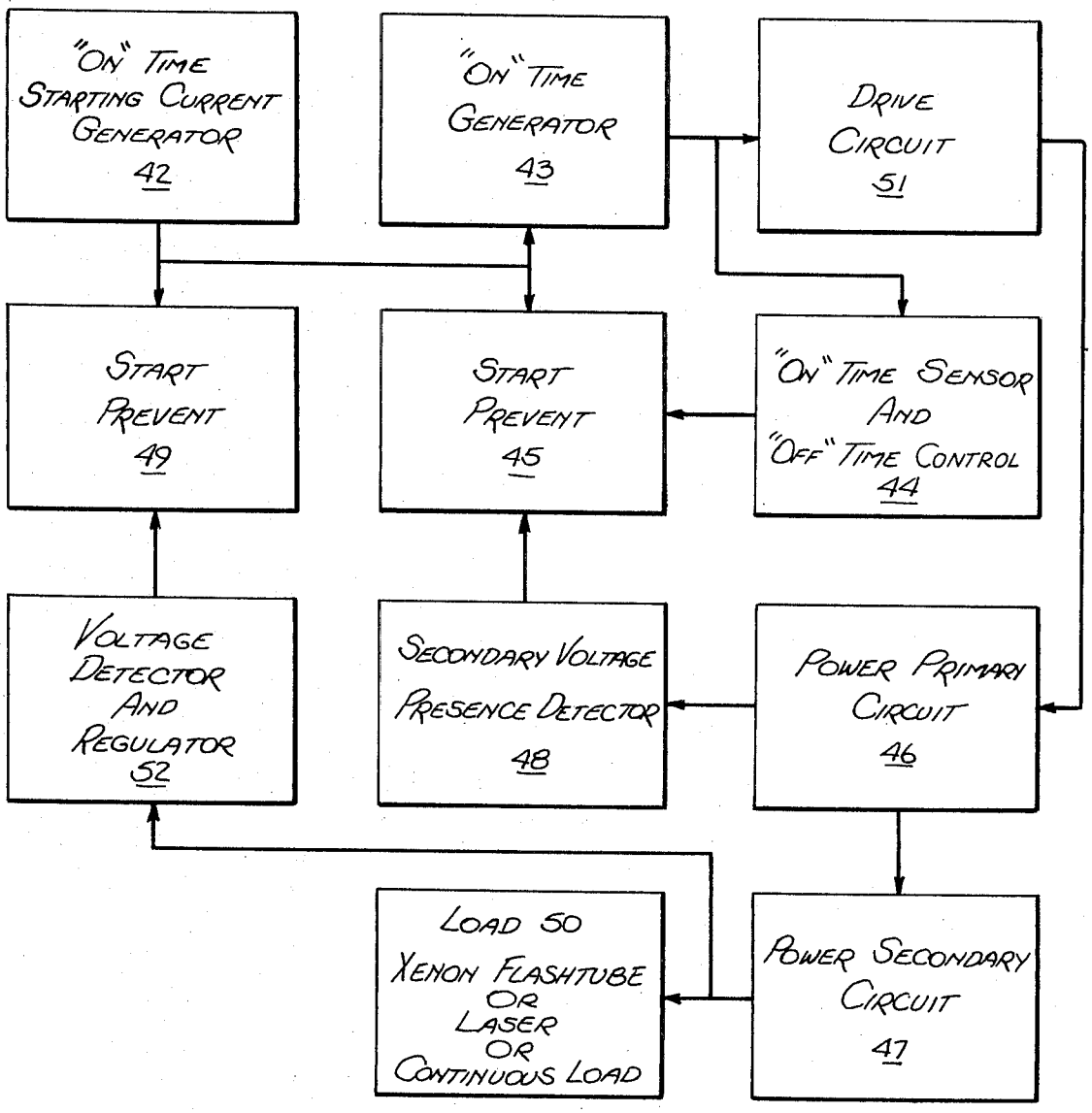

"ON" TIME STARTING CURRENT GENERATOR 42
"ON" TIME GENERATOR 43
DRIVE CIRCUIT 51
START PREVENT 49
START PREVENT 45
"ON" TIME SENSOR AND "OFF" TIME CONTROL 44
VOLTAGE DETECTOR AND REGULATOR 52
SECONDARY VOLTAGE PRESENCE DETECTOR 48
POWER PRIMARY CIRCUIT 46
LOAD 50 XENON FLASHTUBE OR LASER OR CONTINUOUS LOAD
POWER SECONDARY CIRCUIT 47

Fig. 1.

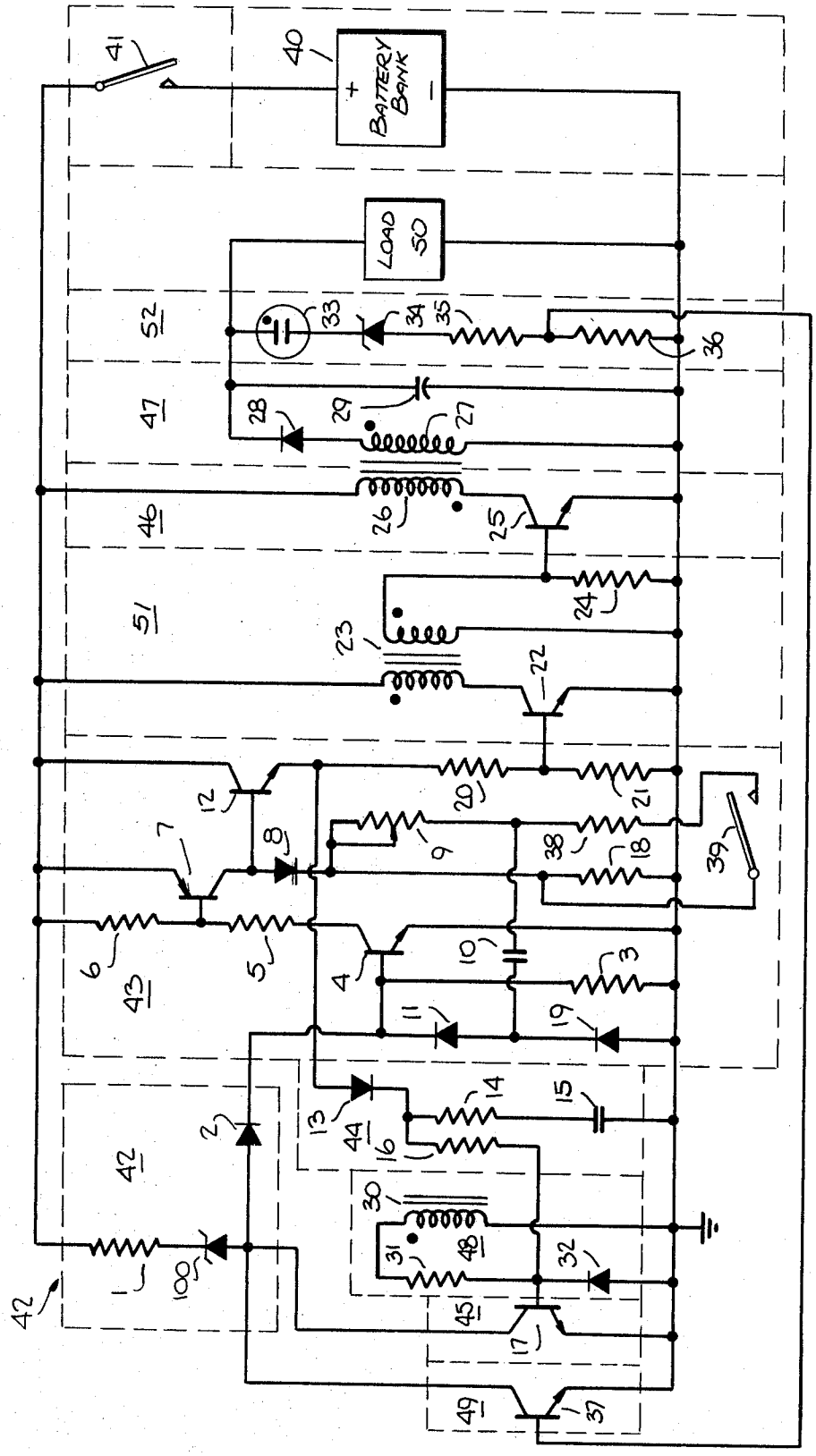

41
40
+
BATTERY
BANK
−
LOAD
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52
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34
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27
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16
30
31
48
32
45
17
49
37
100
1
42

Fig. 2.

Fig. 3.

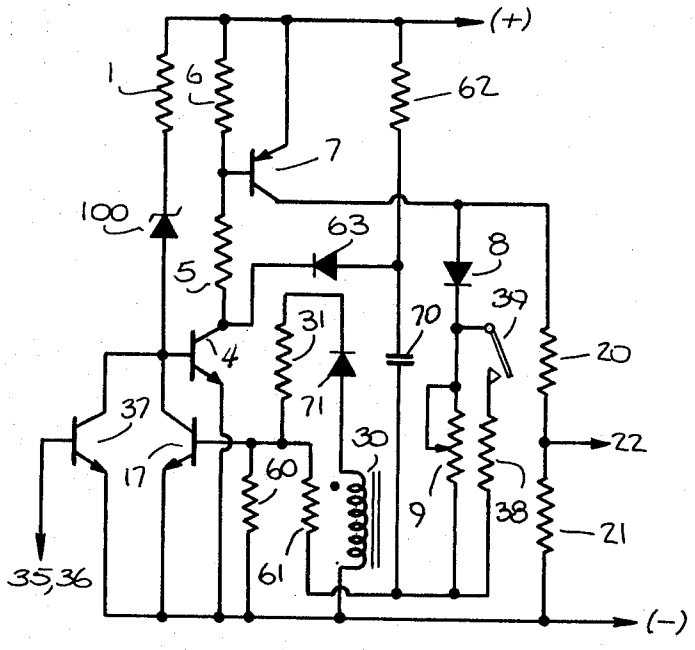
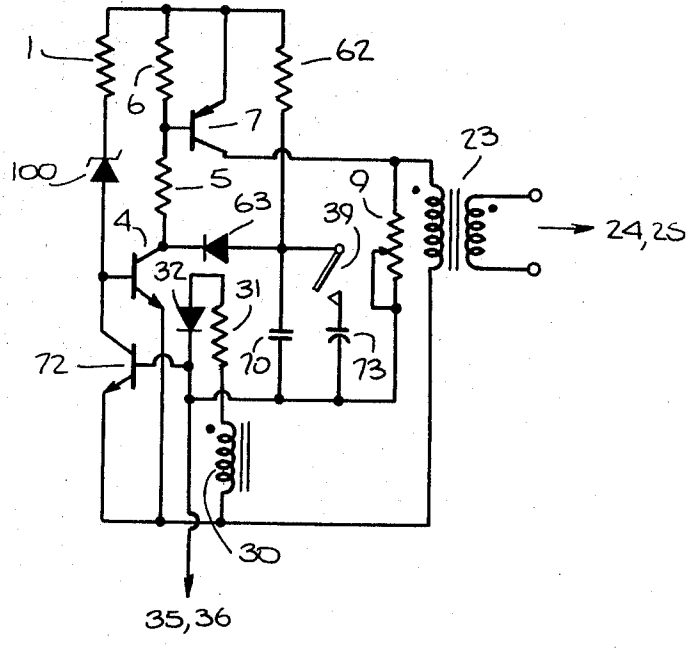

(+)
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71
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17
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9
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61
21
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Fig. 4.


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32
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72
70
73
30
35,36

VOLTAGE CONVERTER AND REGULATOR

BACKGROUND

This invention relates to DC voltage conversion and regulation, and particularly high power conversion for charging energy storage capacitors. Such a voltage converter and regulator can be used in photographic flash equipment, resistance welders, lasers, portable power supplies, signaling devices, and a variety of other battery powered equipment and energy discharge applications.

Many different types of electrical equipment of the general type to which the invention pertains are presently commercially available. However, existing voltage converters are unable to efficiently deliver the level of power required to quickly charge the energy storage capacitors necessary for use in, for example, high power, light weight, battery operated, portable equipment such as electronic flash power supplies.

It is impracticable to use circuits employing high voltage dry cell batteries because such batteries are extremely heavy, making them inconvenient for use in portable equipment. Also, the battery voltages drop as the batteries are used, resulting in non-uniform amounts of power being delivered from one electronic flash to the next, thereby interferring with picture quality.

Vibrator converters, which can be used with low voltage, rechargable batteries, are also known. However, such converters are not particularly reliable because vibrators are mechanical devices which make and break electrical contacts and are therefore susceptible to failure. Converters of this type generally have a low efficiency, and in addition, are not very light-weight.

Currently in more common use are transistor converter circuits which use electronic rather than mechanical switching. Many of these circuits use mechanical relays to shut off the circuit when the maximum desired charge voltage across the storage capacitor is reached, thereby reducing the reliability of the circuits as a unit. In addition, they often have no means to limit the current drain from the batteries or the magnitude of the charging current into the storage capacitors, except through the losses in the circuit components themselves, thus limiting the maximum efficiency of such circuits. Since the power losses are dissipated as heat in the components, heavier components must be used, thereby increasing the weight and volume of such converters. Moreover, the high peak currents which may be drawn from the batteries reduce the ampere-hour capacity of the batteries, further reducing efficiency.

Some converters, such as that shown in U.S. Pat. No. 3,541,420, issued to L.T. Rees, employ neon lamps or other types of glow lamps to control the voltage across the storage capacitors. Because neon lamps change their characteristics with age, ambient light variations, and ambient temperature changes, the regulated voltage will fluctuate depending upon these conditions. Moreover, neon lamps have a rather large voltage hysteresis (their turn-on voltage is significantly greater than their turn-off voltage) resulting in additional fluctuations in the regulated voltage. Thus, in an electronic flash unit where neon lamps are used as the sole voltage regulation control, flash power may undesirably differ from flash to flash,

Such converter circuits also contain no mechanism for adjusting either the frequency of the transistor oscillator in the circuit, or the "on" time portion of the oscillator cycle in a production unit. Since each different unit produced necessarily exhibits somewhat different characteristics because of variations in the performance of components within their inherent tolerances, production units will differ in efficiency and maximum power output unless the frequency or "on" time can be conveniently adjusted.

Another disadvantageous feature of converters such as that shown in Rees, in that the feed-back control which senses the current through the storage capacitors to affect the frequency of the oscillator prevents the isolation of the low (input) voltage from the high (output) voltage, as would be desirable in many power supply applications.

THE INVENTION

It is therefore an object of the present invention to overcome some of the disadvantages of the available portable voltage converter circuits. More specifically, an object of the present invention is to provide a more efficient, lighter, more reliable portable voltage converter and regulator having greater control over the operation of the circuit and allowing isolation between the input and output voltages.

These and other objects of this invention, which will become apparent from the detailed disclosure and claims to follow, are realized in several direct current voltage converter circuits, each of which is comprised of a direct current voltage source, a semi-conductor oscillator driven by the voltage source, a storage capacitor and voltage sensing and regulating means. The oscillator is in energizing relation with the storage capacitor to produce charging current to charge the capacitor, and the voltage sensing and regulating means is responsive to the voltage across the capacitor and regulates the voltage within a narrow range. The voltage sensing and regulating means comprises a glow lamp such as a neon bulb, a zener diode, and a resistor connected in series, which combination is connected across the storage capacitor. When the storage capacitor reaches its desired charge, the neon bulb and zener diode conduct energy away from the storage capacitor until its charge falls to a predetermined lower level, at which time the neon bulb and zener diode cease to conduct, and the charging current is once again supplied to the storage capacitor. The capacitor's charge is thus maintained within narrow limits.

Each circuit also comprises inductive coupling means coupled between the oscillator and the storage capacitor, and arranged so that during the "on" portion of each cycle of the oscillator, current is drawn from the voltage source and energizes the primary winding of the inductive coupling means, but no charging current is provided during that portion of the cycle to the storage capacitor. During the other, "off" portion of each cycle of the oscillator, current from the voltage source is no longer provided to the primary winding of the inductive element, but charging current to the storage capacitor is provided by the secondary winding of the inductive coupling means.

The oscillator is provided with a variable resistance circuit to control the duration of the "on" portion of the oscillation cycle, and also includes a switching circuit to control the frequency of oscillation. The switch-

ing circuit in one illustrative embodiment is operable by switching the resistance in a portion of the oscillator circuit, and in another illustrative embodiment, is operable by switching the capacitance in a portion of the oscillator circuit.

Each of the converter circuits also includes inductive feed-back from the inductive coupling means in the form of a further secondary winding. This winding is connected to a transistor circuit so that the commencement of the "on" portion of the oscillator cycle is prevented so long as current is being supplied from the inductive coupling means to the storage capacitor. The circuit also includes feedback from the voltage sensor and regulator to the oscillator so that, by transistor switching, the commencement of the "on" portion of the oscillator cycle is prevented whenever the glow lamp and zener diode in the voltage regulator circuit are conducting excess energy away from the storage capacitor.

So that the commencement of the "on" portion of a cycle is prevented after the completion of the "on" portion of the prior cycle of the oscillator, and before the transistor feedback circuit which is responsive to the supplying of current to the storage capacitor can operate to independently prevent the commencement of the "on" portion of the cycle again, a capacitor circuit is provided in conjunction with the oscillator, connected so that the capacitor charges during the "on" portion of the cycle, and uses that charge to prevent the commencement of the "on" portion of the next cycle until the inductive feedback prevention means can operate.

Each of the voltage converter circuits is provided with a second zener diode (in addition to the one in the voltage regulation circuit) whose cathode is connected in series to the positive terminal of the voltage source so that when the voltage of the source falls below a value determined by the parameters of the zener diode, current cannot be drawn from the voltage source to operate the circuit and damage the source.

A feature of the voltage converter circuit of the invention is thus the provision for a zener diode in series with a neon lamp for greater voltage regulation, so that output voltage variations are reduced to a level which is inconsequential for photographic electronic flash applications. Another feature of the circuit is the provision for an adjustable resistor for adjustment of the "on" time of the circuit oscillator, thereby permitting the output power delivered by the circuit to be controlled. In photographic electronic flash circuits, the recycle time for the storage capacitors to have sufficient charge after one flash to permit the next flash is controlled by controlling the output power level. Thus, when used in an electronic flash unit, the circuit of the present invention permits precise adjustment of the flash recycle time for each unit. In addition, a further feature of the circuit of the present invention is the provision for a recycle time switch which can be operated by the user of the flash unit so that the user may choose and switch between a more efficient but slower recycle time and a less efficient but faster recycle time. This capability permits the optimum utilization of the stored battery energy.

A further feature of the circuit of the present invention is the provision for maintaining the circuit oscillator in the "off" condition while charging current is flowing into the storage capacitor, by means of a transformer secondary winding coupled to the transformer providing power to the storage capacitor, thus allowing for isolation between the low input voltage and higher output voltage of the circuit when required. A still further feature of the invention is the provision for a zener diode in series with the rechargable battery which provides the input voltage for the circuit, to prevent damage to the battery which might be caused by drawing current from the battery after it has run down and needs recharging.

FIG. **1** illustrates one embodiment of the present invention in block diagram form.

FIG. **2** illustrates a circuit embodiment of the present invention in schematic form. The circuit units shown in the block diagram of FIG. **1** are indicated by dotted lines superimposed on the schematic diagram of FIG. **2.**

FIG. **3** illustrates another circuit embodiment of the present invention.

FIG. **4** illustrates still a further circuit embodiment of the present invention.

With reference to FIG. **1**, there is shown in block diagram form a voltage converter and regulator circuit such as can be used in a photographic flash unit. The "on" time starting current generator **42** produces a starting current for the circuit which is applied to the "on" time generator **43,** which generates a square wave signal which is applied to drive circuit **51** and also to the "on" time sensor and "off" time control **44.** Drive circuit **51** translates the square wave signal to a lower voltage, higher current form suitable for driving power primary circuit **46.** During the duration of the "on" time of the circuit, the drive circuit energizes the power primary circuit **46.** The "on" time sensor and "off" time control **44** applies a signal to start prevent circuit **45,** which is in turn connected to the "on" time starting current generator **42,** to end the "on" time of the circuit and begin the "off" time of the circuit, and to maintain the "off" condition until the secondary voltage presence detector **48** can take over as described below.

The power secondary circuit **47** is energized from the power primary circuit **46,** and delivers power to the load **50,** which may be, for photographic applications, a xenon flashtube, or for other applications, a laser, or continuous load, as may be required. The secondary voltage presence detector **48,** which is also coupled with the power primary circuit **46,** applies a signal to the start prevent circuit **45** so long as the power secondary circuit **47** is delivering power to the load. The start prevent **45** therefore prevents the "on" time of the circuit from starting again so long as the power secondary circuit **47** is delivering power to the load. When the power secondary circuit **47** ceases to deliver power to the load, the secondary voltage presence detector **48** senses the absence of secondary voltage and ceases to provide a signal to start prevent **45,** which in turn permits the "on" time starting current generator **42** to supply starting current to the "on" time generator **43.**

The "on" and "off" cycles are repeated until the power secondary circuit **47** output voltage reaches the point se by the voltage detector and regulator **52,** at which point the voltage detector and regulator **52** applies a signal to start prevent circuit **49,** which in turn prevents "on" time starting current generator **42** from providing a starting current to "on" time generator **43,** thereby commencing the "off" portion of the cycle of

the circuit. The circuit will remain in the "off" condition until the output voltage from power secondary circuit **47** reduces sufficiently for voltage detector and regulator **52** to remove the signal it is applying to start prevent **49**, thereby permitting the "on" time starting current generator **42** to provide starting current to begin the "on" time of the circuit once again.

The above described operation and "on" and "off" cyclical operation of the circuit is repeated until power is removed from the "on" time starting current generator **42**.

Referring now to the complete schematic diagram of the circuit contained in FIG. **2**, there is shown a direct current voltage source of battery **40**. The positive terminal of the battery **40** is connected to one pole of a switch **41**. The voltage source may be DC or rectified AC providing a voltage over a wide range, from about 6 volts to about 450 volts. For an electronic flash unit, the input voltage is preferably in about the 9 to 15 volt range for battery operation and in approximately the 130 to 190 volt range when the circuit is operated from rectified and filtered power line voltages. In certain power supply applications, higher input voltages may be desirable. The circuit decreases in efficiency as lower input voltage sources are used.

An "on" time starting current generator **42** is connected to the second pole of the switch **41**. The "on" time starting current generator **42** comprises a resistor **1**, one of whose terminals is connected to switch **41**, a zener diode **100**, whose cathode is connected to other terminal of resistor **1**, and a diode **2**, whose anode is connected to the anode of zener diode **100**.

Diode **2** provides starting current to the "on" time generator **43**. The cathode of diode **2** is connected through a resistor **3** to the negative terminal of the battery **40**, and is also connected to the base of a transistor **4** so that when current flows through diode **2** and resistor **3**, the voltage drop across resistor **3** will be sufficient to turn on (saturate) transistor **4**. The collector of transistor **4** is connected through divider resistors **6** and **5** to switch **41**, and the emitter of transistor **4** is connected to the negative terminal of battery **40**. Transistors **7** and **12** are also provided in the "on" time generator **43**. The base of transistor **7** is connected to a point between divider resistors **6** and **5**, its emitter is connected to switch **41**, and its collector is connected to the anode of a diode **8**, whose cathode is connected through a resistor **18** to the negative terminal of battery **40**. Connected between diode **8** and resistor **18** is a variable resistor **9**, which is connected in series with a capacitor **10** and the anode of a diode **11**, whose cathode is connected to the base of transistor **4**. The cathode of a diode **19** is connected to a point between capacitor **10** and diode **11**, and its anode is connected to the negative terminal of battery **40**. Between variable resistor **9** and capacitor **10** is connected one terminal of resistor **38**, which is serially connected with one terminal of switch **39**, the other terminal of switch **39** being connected to a point between diode **8** and variable resistor **9**. The base of transistor **12** is connected to the collector of transistor **7**; the collector of transistor **12** is connected to swtich **41**, and its emitter is connected through divider resistors **20** and **21** to the negative terminal of battery **40**.

Drive circuit **51** is comprised of a transistor **22**, a transformer **23**, and a resistor **24**. The base of transistor **22** is connected to a point between divider resistors **20** and **21** of the "on" time generator **43**. The emitter of transistor **22** is connected to the negative terminal of the battery **40**, and the collector is connected through the primary winding of transformer **23** to switch **41**. One end of the secondary winding of transformer **23** is connected to the negative terminal of the battery **40**, and the other end of the secondary winding is serially connected with resistor **24** which is in turn connected to the negative terminal of battery **40**.

The power primary circuit **46** is comprised of a transistor **25** and a primary inductive winding **26**, which are connected in a manner similar to transistor **22** and the primary winding of transformer **23** in drive circuit **51**. Hence, the base of transistor **25** is connected to a point between the secondary winding of transformer **23** and resistor **24**; the emitter of transistor **25** is connected to the negative terminal of the battery **40**, and its collector is connected through the winding **26** to swtich **41**.

Coupled with primary winding **26** is secondary inductive winding **27**, of opposite polarity, contained in the power secondary circuit **47**. One end of secondary winding **27** is connected to the negative terminal of the battery **40** and the other end is serially connected with the anode of a diode **28**. Connected between the cathode of diode **28** and the negative terminal of the battery **40** is storage capacitor **29**.

Connected across storage capacitor **29** is the voltage detector and regulator **52**, which consists of, connected in series, a neon bulb **33**, a zener diode **34**, and divider resistors **35** and **36**. One terminal of the neon bulb is connected to the terminal of the storage capacitor common to the cathode of diode **28**. The other terminal of the neon bulb is connected to the cathode of the zener diode **34**, whose anode is connected through resistors **35** and **36** respectively, to the negative terminal of the battery **40**.

Also connected across storage capacitor **29** is the load **50**, which in photographic applications would consist of a xenon flashtube and the associated camera sync shutter switch and firing circuit. The "on" time sensor and "off" time control **44** comprises a diode **13**, resistors **16** and **14** and a capacitor **15**. The anode of diode **13** is connected to the emitter of transistor **12** in the "on" time generator **43**. The cathode of diode **13** is connected to a point between resistors **16** and **14**, the opposite terminal of resistor **14** being connected through capacitor **15** to the negative terminal of the battery **40**, and the opposite terminal of resistor **16** leading to the start prevent **45**.

Start prevent **45** consists of a transistor **17**, the base of which is connected to resistor **16** in the "on" time sensor and "off" time control **44**. The emitter of transistor **17** is connected to the negative terminal of battery **40**, and its collector is connected to a point between the anode of zener diode **100** and the anode of diode **2** in the "on" time starting current generator **42**. Start prevent **49** consists of a transistor **37**, whose base is connected to a point between divider resistors **35** and **36** in the voltage detector and regulator **52**, to provide feed-back from that portion of the circuit to control the duration of the "on" and "off" times of the circuit as a function of the voltage across the storage capacitor **29**. The emitter of transistor **37** is connected to the negative terminal of the battery **40**, and its collector is connected to a point between the anode of zener diode **100** and the anode of diode **2** in the "on" time starting current generator **42**.

The secondary voltage presence detector **48** consists of a secondary inductive coil **30**, a resistor **31** and a diode **32**. Secondary coil **30** is inductively coupled with primary coil **26** of the power primary circuit **46**. One terminal of winding **30** is connected to the negative terminal of the battery **40**, and the other terminal is connected with one terminal of resistor **31** whose other terminal is connected to the cathode of diode **32**. The anode of diode **32** is connected to the negative terminal of battery **40**. Connected to a point between resistor **31** and the cathode of diode **32** is the base of transistor **17** in start prevent **45**.

OPERATION OF THE CIRCUIT IN FIG. 2

For explanatory purposes, assume initially that switch **41** of the circuit is open, that the circut is at rest, that all capacitors are discharged and all transistors are in an off, non-conducting condition. To start the operation of the circuit, switch **41** is closed. If the voltage on the positive terminal of battery **40** is below a certain level, zener diode **100** is chosen so that it will prevent the passage of current, and the circuit will not operate. This will prevent a "deep discharge" which may damage the battery if current is drawn from the battery when the battery voltage has fallen to too low a value. For an electronic flash unit, battery **40** may conveniently be a 12 volt nickel cadmium battery, and zener diode **100** may have a cut-off voltage at about 10 volts.

When the circuit is first turned on by the closing of switch **41**, the current flowing through resistor **1** and zener diode **100** will not flow through either of transistors **17** or **37**, which are initially in an off condition. Similarly, there will be no flow of current through transistors **7** or **12**, or through resistors **6** and **5** and transistor **4**, all three transistors **4**, **7**, and **12** being initially non-conductive.

Current will flow from the positive terminal of the battery **40**, through the closed switch **41**, through resistor **1**, zener diode **100** and diode **2** in the "on" time starting current generator **42**, and through resistor **3** back to the negative terminal of battery **40**. The current through resistor **3** in the "on" time generator **43** will cause a voltage drop across resistor **3** and hence between the base and emitter of transistor **4**, thereby turning on transistor **4** so that current can flow from the positive terminal of the battery **40** through resistors **6** and **5** and transistor **4**. The current flowing through resistor **5** to the base of transistor **7** will cause transistor **7** to conduct, with current flowing through transistor **7**, diode **8**, variable resistor **9**, capacitor **10** and diode **11**. Concurrently, the current flowing through transistor **7** to the base of transistor **12** causes transistor **12** to conduct, with current flowing through transistor **12** and into divider resistors **20** and **21**, which in turn turns on transistor **22** whose base is connected between divider resistors **20** and **21**. Transistor **22** drives transformer **23** in the drve circuit **51**, with transformer **23** stepping down the battery voltage and stepping up the current flow, to provide a suitable drive signal for transistor **25** in the power primary circuit **46**. The voltage drop across resistor **24** and hence between the base and emitter of transistor **25** causes transistor **25** to conduct, thereby applying a square wave voltage to the transformer primary winding **26**. The transformer contains a nonsaturable core, in which is established a magnetic field as current flows in the primary winding **26**. No current flows however, in transformer secondary winding **27** because of the reverse biasing of diode **28** in series with winding **27**. The voltage induced in transformer secondary winding **30** in the secondary voltage presence detector **48**, which is also coupled with primary winding **26**, has no effect at this stage, because its polarity is opposite to that which would be necessary to turn on transistor **17**. Diode **32** is provided to clamp the voltage level resulting from the current flowing through winding **30** and resistor **31** so that transistor **17** will not be damaged by excess reverse voltage being applied between its base and emitter.

The condition of the circuit at this point, with transistors **4**, **7**, **12**, **22** and **25** conducting, and current being drawn from the battery **40**, will be considered the "on" time of the circuit.

During the "on" time of the circuit, the current flowing through transistor **7**, diode **8**, variable resistor **9**, capacitor **10** and diode **11** is charging capacitor **10**. As the capacitor is charged, the current level through it decreases until the level is reduced below the value necessary to maintain a voltage drop between the base and emitter of transistor **4** sufficient to keep transistor **4** in a conducting condition.

During the "on" time of the circuit, the current flowing through transistor **12** flows through diode **13** and splits between resistors **16** and **14** in the "on" time sensor and "off" time control **44**. The current flowing through resistor **14** charges capacitor **15**, arming the "off" time control. The current in resistor **16** flows into the base of transistor **17**, causing it to conduct. With transistor **17** conducting, the starting current flowing through resistor **1** and zener diode **100** in the "on" time starting current generator **42** is shunted through transistor **17** to the negative terminal of the battery, and away from the "on" time generator **43**.

The "on" time of the circuit is determined by the time it takes until the current through variable resistor **9** and capacitor **10** has dropped sufficiently that transistor **4** is no longer conducting. This time is a function of the time constant of the combination of resistor **9** and capacitor **10**. The "on" time of the circuit can therefore be controlled by simply adjusting the variable resistor **9**.

When transistor **4** is no longer conducting, current no longer flows through resistor **5**, and transistor **7** no longer conducts, therefore shutting off also transistor **12**, and since current no longer flows through resistors **20** and **21**, transistor **22** becomes non-conducting and transistor **25** becomes non-conducting. This condition, in which transistors **4**, **7**, **12**, **22** and **25** are non-conducting will be considered the "off" time of the circuit.

Transistor **17** is initially turned on by current flowing through resistor **16** from diode **13** and transistor **12**. So long as current flows through transistor **17**, shunting away the starting current, the "on" time of the circuit will not begin again. When the "on" time of the circuit terminates as determined by the values of variable resistor **9** and capacitor **10**, the current flowing through transistor **12**, diode **13** and resistor **16** ceases. However, the charge that has been built up in capacitor **15** from current flowing through transistor **12**, diode **13** and resistor **14** provides drive current through resistors **14** and **16** for the base of transistor **17** to hold it in a conducting condition for the time period necessary for the other circuit elements to be able to control the "off" time of the circuit as described below.

When the circuit changes to the "off" condition, so that current ceases to flow through the primary winding of transformer **23** or the primary transformer winding **26**, the corresponding transformer secondary voltages reverse polarity. Thus, current flows through transformer secondary winding **27** in the power secondary circuit **47**, and through diode **28** and into storage capacitor **29**, thus providing energy to the storage capacitor and partially charging it during the "off" portion of the circuit's cycle.

Simultaneously with the current flowing through transformer secondary winding **27**, the voltage polarity of transformer secondary winding **30** (which is also inductively coupled to transformer primary winding **26**) is reversed, and current flows through winding **30** in the secondary voltage presence detector **48**, through resistor **31**, and (because diode **32** connected between resistor **31** and the negative terminal of the battery **40** is reverse biased) into the base of transistor **17**, causing transistor **17** to remain conducting and the starting current flowing through resistor **1** and zener diode **100** to remain shunted back to the negative terminal of the battery **40** so that the "on" time of the circuit cannot begin.

As the "off" time of the circuit continues, the transformer magnetic fields and secondary voltages gradually collapse, current ceases to flow through transformer secondary winding **27** and diode **28** into storage capacitor **29**, and current ceases to flow through transformer secondary winding **30**, resistor **31** and into the base of transistor **17**. Meanwhile, the charge on capacitor **15** has decreased below the voltage required to hold transistor **17** in a conducting condition. This time is determined by the time constant of the capacitor **15** and resistors **14** and **16**. Those elements are chosen so that the transistor **17** is held in a conducting condition between the beginning of the "off" time of the circuit, and until the voltage induced in secondary transformer winding **30** provides sufficient current to maintain transistor **17** in a conducting condition without the charge from capacitor **15**. With capacitor **15** discharged below the value required to maintain transistor **17** in a conducting condition, and the current ceasing to flow through winding **30** and resistor **31** into transistor **17**, transistor **17** shuts off, and the start prevent **45** no longer shunts starting current away from the "on" time generator **43**. Thus, current may again flow through resistor **1** and zener diode **100** into diode **2** and resistor **3**, turning on transistor **4** and in turn the other transistors, **7**, **12**, **22** and **25**, thereby once again beginning the " on" portion of the cycle.

The "on" and "off" portions of the cycle repeat until storage capacitor **29** has charged to a voltage level at which neon lamp **33** and zener diode **34** in the voltage detector and regulator **52** will conduct. That voltage level, and the parameters of neon lamp **33** and zener diode **34** are chosen depending on the output voltage that it is desired to provide for the load **50**. It is possible to regulate the voltage on storage capacitor **29** at virtually any voltage. For example, in a photgraphic flash unit, with the proper choice of components, for capacitor **29** to recycle to an energy level of about 100 watt seconds after a photogtaphic flash discharge will require between about 5 and 6 seconds of operation of the circuit, with the circuit completing a complete "on" and "off" cycle between 15,000 and 20,000 times per second. However, other desirable operating frequencies and recycle times may be obtained by varying the circuit components as is well understood by those skilled in the art. Longer recycle times after a discharge result is higer circuit efficiency, and shorter recycle times result in lower efficiency and also require larger and heavier transformer components. Lower frequencies require larger and heavier transformer components, while higher frequencies result in greater energy losses and hence lower efficiency of the circuit.

When the charge on storage capacitor **29** reaches the value necessary to cause neon lamp **33** and zener diode **34** to conduct, current flows through these two elements and also divider resistors **35** and **36**, and also into the base of transistor **37** in start prevent **49**, which is connected between the two divider resistors. This current will cause transistor **37** to conduct, and will shunt the starting current through resistor **1** and zener diode **100** through transistor **37** and back to the negative terminal of the battery **40**, thereby preventing the "on" time of the circuit from beginning again. The circuit will be held in the "off" mode until the voltage on storage capacitor **29** drops to a level at which zener diode **34** and neon lamp **33** no longer conduct, so that current will cease flowing through resistors **35** and **36** and into the base of transistor **37**, causing transistor **37** to become non-conductive and permitting the starting current to once again be applied to the "on" time generator **43** to being the "on" time of the circuit again.

When isolation between the low input voltage and the high output voltage of the circuit is required (as it may be in certain power supply applications), the connection between the voltage detector and regulator and the base of transistor **37** to provide the feedback signal to the start prevent circuit **49** can be replaced by an optical isolator, consisting of a light emitting diode connected across resistor **36** and a photo transistor responsive to light emitted from the diode in place of transistor **37**, as is known in the art. The negative terminal of the battery **40** must be disconnected from the negative voltage terminals of the power secondary circuit **47**, the storage capacitor **29**, the voltage detector and regulator **52** and the load **50** to complete the isolation. Such isolation is possible because the secondary voltage presence detector circuit **48** is already isolated from the power secondary circuit.

So long as power is applied to the circuit by switch **41** remaining closed, once the charge on storage capacitor **29** is built up to the desired value, the voltage regulation provided by the series combination of neon lamp **33** and zener diode **34** contained in the voltage detector and regulator **52** maintains the voltage across capacitor **29** within rather narrow limits so that uniform power can be obtained each time it is desired to operate the electronic flash. For example, if it is desired to regulate the voltage across capacitor **29** at about 365 volts, a zener diode may be chosen with a breakdown voltage of about 285 volts, and a neon lamp may be used having a turn-on voltage of about 80 volts and a turn-off voltage of about 65 volts. Thus, the zener diode and neon lamp would start to conduct when the voltage across capacitor **29** reached about 365 volts, and would cease conducting when the voltage dropped to below about 350 volts.

Without zener diode **34**, the charge on capacitor **29** would vary much more widely, and hence, at different times, widely varying amounts of power would be supplied to a flash unit. For example, if several neon lamps

were provided in series to provide a regulated voltage high enough for photographic flash applications, the resulting hysteresis would provide for poor voltage regulation, because the turn-on and turn-off voltages of the voltage detector and regulator would be the sum of the turn-on and turn off voltages respectively, of the several serially connected neon lamps, the total hysteres is consequently being the sum of the individual hystereses of the several neon lamps. If, instead, one or more neon lamps were provided in conjunction with voltage dividers to furnish regulation at a required voltage, the hysteresis of the neon lamp or lamps would likewise be multiplied. With zener diode **34** provided in series with neom bulb **33,** most of the voltage regulation is performed by the zener diode to prevent such wide fluctuations in power output, and also because the characteristics of neon bulbs vary with surrounding temperature and light conditions and with the age of the bulb. The one neon bulb is necessary because a zener diode has almost no hysteresis, so if a zener diode along were used to regulate the output voltage, the circuit would be on almost continuously, thus wasting a considerable amount of power.

When power is provided to the load **50,** such as by the electronic flash being fired, the effect on the circuit is simply to reduce the voltage across storage capacitor **29** below the desired value controlled by the voltage detector and regulator **52.** The circuit is thus in the same condition as it is during the initial charging of the storage capacitor and before the desired voltage is achieved. The neon lamp **33** and the zener diode **34** do not conduct, transistor **37** and start prevent **49** do not shunt the starting current away from the "on" time generator **43,** and the "on"–"off" cycles of the circuit repeat until storage capacitor **29** is again charged to the desired value.

The circuit is provided with a switch **39** which permits the user of the circuit to switch the circuit frequency. Closing switch **39** places resistor **38** in parallel with variable resistor **9** between the cathode of diode **8** and capacitor **10.** When the circuit is used to power an electronic flash unit, switch **39** permits the user to swtich the circuit between a lower level power operation with a slower recycle time and a higher frequency when the switch is closed, and a higher power level operation with a faster recycle time and lower frequency when the switch is open. The maximum power output of the circuit in either position of switch **39** is adjusted by varying the "on" time of the circuit, by means of variable resistor **9.** In power supply use for the circuit, the provision of variable resistor **9** permits a "power output limit" adjustment, and in electronic flash units, permits precise adjustment of the circuit recycle time, as opposed to switch **39** which merely provides for two different and preset recycle time modes.

Because of the manner of operation of the circuit, its efficiency is not limited as are many of the prior art circuits. Some loss of efficiency will occur at lower input voltages. Any output voltage is possible, and for example, if a lower output voltage is desired for a low voltage power supply, and/or if tighter output voltage control is desired, circuits which are well known in the art can be used to replace the voltage detector and regulator **52.**

OPERATION OF CIRCUIT SHOWN IN FIG. 3

With reference to FIG. **3,** there is shown a somewhat simplified version of the circuit shown in FIG. **2.** The components shown in the schematic circuit diagram of FIG. **3** corresponding to similar components in FIG. **2** have been identified with the same reference numerals.

For the modified circuit shown in FIG. **3,** resistor **1** and zener diode **100** are connected in series as in the circuit in FIG. **2.** However, diode **2** has been eliminated, so that the anode of zener diode **100** is connected directly to the base of transistor **4.** Transistors **17** and **37** are connected in a manner similar to FIG. **2,** with the emitter of each transistor being connected to the negative terminal of the battery **40,** and the collector of each transistor being connected to the base of transistor **4** and the anode of zener diode **100.** Divider resistors **6** and **5** are connected between switch **41** and the collector of transistor **4** as in FIG. **2.** Also as in FIG. **2,** the base of transistor **7** is connected to a point inbetween divider resistors **6** and **5,** its emitter is connected to switch **41** and its collector is connected through diode **8** to variable resistor **9.** As in FIG. **2,** in parallel with variable resistor **9** is the series connection of resistor **38** and switch **39,** for switching the circuit frequency if desired. Transistor **12** has been eliminated, and divider resistors **20** and **21** are now connected directly to the collector of transistor **7.**

Connected to the terminal of variable resistor **9** opposite to the terminal connected to the cathode of diode **8** is capacitor **70.** Connected to the opposite terminal of capacitor **70** are a resistor **62,** which is in turn connected to the switch **41,** and the anode of a diode **63,** whose cathode is connected to the collector of transistor **4.** Capacitor **70** replaces and performs the functions of capacitors **10** and **15** contained in the circuit shown in FIG. **2.** To a point between variable resistor **9** and capacitor **70** is connected one terminal of a resistor **61,** whose other terminal is connected to the base of transistor **17.** Also connected to the base of transistor **17** is a resistor **60,** whose other terminal is connected to the negative terminal of battery **40.** As in FIG. **2,** a resistor **31** and the secondary transformer winding **30** are respectively serially connected between the base of transistor **17** and the negative terminal of battery **40,** but in addition, a diode **71** is connected between those two elements with its anode connected to one end of the winding **30** and its cathode connected to one terminal of the resistor **31.**

Diodes **11, 13, 19** and **32,** and resistors **3, 14** and **16** are eliminated from the circuit shown in FIG. **2.** The rest of the circuit is the same as shown in FIG. **2.** Thus, the power primary circuit **46,** the power secondary circuit **47,** the voltage detector and regulator **52,** the drive circuit **51,** and the load **50** are unchanged from the circuit shown in FIG. **2.**

The circuit of FIG. **3** operates in basically the same manner as the operation heretofore described for the circuit shown in FIG. **2.** The primary difference is in the "on" time generator and the "on" time sensor and "off" time controls. When power is applied to the circuit by closing switch **41,** and if the voltage of battery **40** is sufficient for zener diode **100** to conduct, current flows through resistor **1** and zener diode **100** into the base of transistor **4** turning on transistor **4.** With transistor **4** conducting, current flowing through resistors **6** and **5** and transistor **4** causes transistor **7** to conduct. Current flowing through transistor **7** is provided to divider resistors **20** and **21,** and drives transistor **22** in the drive circuit **51,** which in turn provides drive to the

power primary circuit **46** during the "on" time of the circuit, and the power secondary circuit **47** provides energy to the storage capacitor **29** during the "off" time of the circuit.

Current flowing through conducting transistor **7**, diode **8**, variable resistor **9** and resistor **61** into the base of transistor **17** will turn on transistor **17**, causing it to shunt the starting current through resistor **1** and zener diode **100** away from the base of transistor **4**, and back to the negative terminal of the battery **40**, causing transistor **4** to become non-conducting and beginning the "off" time of the circuit. During the "off" time of the circuit, current stills flows through resistor **62**, into capacitor **70** and through resistor **61** into the base of transistor **17** maintaining transistor **17** in a conducting condition and the circuit in the "off" mode.

Unlike the circuit in FIG. **2**, in which the "on" time must precede the "off" time when switch **41** is closed, because there is no path for current to flow into the base of transistor **17** until transistors **4**, **7** and **12** are conducting, in this circuit the "off" time could precede the "on" time, because the current path through resistor **62**, capacitor **70** and resistor **61** into the base of transistor **17** is available even when transistors **4** and **7** are non-conducting. Which portion of the cycle begins first when power is applied to the circuit is of no consequence, and the "on"–"off" cyclical operation will occur in either event.

When, during the "off" time of the circuit, capacitor **70** becomes sufficiently charged that the current through it and through resistor **61** into the base of transistor **17** is reduced sufficiently so that transistor **17** is turned off, the circuit once again changes to the "on" condition with transistors **4** and **7** conducting. Thus, the "off" time of the circuit is determined by the time constant of the combination of capacitor **70** and resistors **61** and **62**.

During the "on" time of the circuit with transistor **4** conducting, current flows through resistor **62** and diode **63** into the collector of transistor **4**, causing capacitor **70** to apply a negative voltage across resistors **60** and **61**, maintaining transistor **17** non-conducting. The current flowing thorugh conducting transistor **7**, diode **8** and variable resistor **9** reduces the negative charge across capacitor **70**, until the positive voltage across resistors **60** and **61** is sufficient to turn on transistor **17**, ending the "on" time of the circuit and beginning its "off" time. Thus, the "on" time of the circuit is determined by the discharge time of the capacitor **70**, which depends on the current flowing through diode **8** and variable resistor **9**.

Switch **39** and resistor **38** perform the same function as in FIG. **2**, enabling the user to swtich the frequency of the circuit by closing switch **39**.

Secondary transformer winding **30** operates as in FIG. **2**. During the "on" time of the circuit, during which transformer primary winding **26**, to which winding **30** is inductively coupled, is being energized, the voltage induced in winding **30** is opposite to that necessary to turn on transistor **17**, and is blocked by diode **71**. Thus, diode **71** serves the same function as diode **32** performed in the circuit shown in FIG. **2**.

When the "on" time of the circuit ends and the "off" time of the circuit begins, and the voltage reverses in the primary transformer winding **26**, a voltage of opposite polarity is induced in secondary winding **30**, which provides current through diode **71**, resistor **31** and resistor **60** to maintain a sufficient voltage drop between the base and emitter of transistor **17** to keep it conducting and maintain the "off" condition of the circuit while power is being supplied to storage capacitor **29**.

It can be appreciated that the circuit shown in FIG. **3**, instead of having separate circuitry for the "on" time generator **43** and the "on" time sensor and "off" time control **44** as does the circuit shown in FIG. **2**, combines those functions using fewer components. An advantage of the circuit shown in FIG. **3** over that shown in FIG. **2** is thus that because there are fewer components it would be cheaper to manufacture, and would also be more reliable.

OPERATION OF THE CIRCUIT SHOWN IN FIG. 4

An even more simplified form of the circuit than that shown in FIG. **3** is shown in FIG. **4**. The functions of the start prevent circuits **45** and **49** have been combined, and instead of two separate transistors **17** and **37** as shown in the circuits in FIGS. **2** and **3**, there is provided a single transistor **72** whose collector is connected to the base of transistor **4** and whose emitter is connected to the negative terminal of the battery **40** as were each of the transistors **17** and **37** shown in FIG. **3**. The base of transistor **72** (rather than the base of transistor **37** as in FIGS. **2** and **3**) is connected to a point between divider resistors **35** and **36** to receive the feed-back signal from the voltage detector and regulator **52**.

Transistor **22** in the drive circuit **51** as shown in FIGS. **2** and **3** is eliminated, with one end of the primary winding of transformer **23** being connected directly to the collector of transistor **7**, and the other end of the winding being connected to the negative terminal of the battery **40**. The emitter of transistor **7** is connected to the switch **41**. Resistors **20** and **21** which provided current to drive now eliminated transistor **22** in FIGS. **2** and **3** are also eliminated. Resistors **60**, **61** and **38**, and diode **8** are also eliminated. Thus, one terminal of capacitor **70** is connected directly to the base of transistor **72**, and no resistor is provided between the base of transistor **72** and the negative terminal of the battery **40**. Thus, also, variable resistor **9** is connected directly between the emitter of transistor **7** and the base of transistor **72**, diode **8** and resistor **61** having been eliminated. Instead of resistor **38**, a capacitor **73** is provided in series with switch **39** which combination is in turn connected in parallel to capacitor **70**.

The operation of the circuit in FIG. **4** is basically the same as the circuit shown in FIG. **3**. The only differences are, first, that the frequency of the circuits oscillation, which may first, that the frequency of the circuits oscillation, which may be switched by closing switch **39**, is controlled by means of capacitor **73**, which is placed in parallel with capacitor **70** when switch **39** is closed, thus varying the "on" and "off" times of the circuit. In the circuit shown in FIGS. **2** and **3**, frequency was switched by means of switch **39** by providing a change in resistance, rather than capacitance. The second change in the circuit operation of FIG. **4** from that in FIG. **3** is that when the charge on storage capacitor **29** becomes large enough to cause neon lamp **33** and zener diode **34** to conduct, the circuit is maintained in the "off" condition by means of transistor **72**, which is the same transistor used to control the "off" time of the circuit while the charge on capacitor **29** is being built up in normal cyclical operation, Combining the functions of transistors **17** and **37**

into transistor 72 is less efficient, and although it results in a savings on components, will result in more power loss when the circuit is in the "off" condition.

It is to be understood that, while the specific embodiments of the invention described hereinabove have been shown and described in detail to illustrate the application of the principles of the invention, the invention may be embodied in other ways without departing from these principles in light of the teachings herein.

What is claimed is:

1. A direct current voltage converter, comprising:
a. a direct current voltage source;
b. storage capacitor means;
c. semi-conductor oscillator means driven by said direct current voltage source, and in energizing relation with said storage capacitor means to produce charging current for said storage capacitor means;
d. voltage sensing and regulating means comprising glow lamp means, first zener diode means and resistance means serially connected across said storage capacitor means, responsive to the voltage across said storage capacitor means to regulate said voltage within a narrow range; and
e. second zener diode means, the cathode of said second zener diode means being serially connected to the positive terminal of said direct current voltage source to prevent current from being drawn from said voltage source when its voltage falls below a value determined by said second zener diode means.

2. A direct current voltage converter, comprising:
a. a direct current voltage source;
b. storage capacitor means;
c. semi-conductor oscillator means driven by said direct current voltage source, and in energizing relation with said storage capacitor means to produce charging current for said storage capacitor means;
d. voltage sensing and regulating means comprising glow lamp means, zener diode means and resistance means serially connected across said storage capacitor means, responsive to the voltage across said storage capacitor means to regulate said voltage within a narrow range; and
e. inductive coupling means coupled between said semi-conductor oscillator means and said storage capacitor means; wherein during a first portion of a cycle of said semi-conductor oscillator means, current is drawn from said direct current voltage source and provided to energize said inductive coupling means, and no charging current is provided to said storage capacitor means, and during a second portion of a cycle of said semi-conductor oscillator means, no current from said direct current voltage source is provided to said inductive coupling means, and charging current is provided from said inductive coupling means to said storage capacitor means; wherein said semi-conductor oscillator means comprises inductive feed-back means inductively coupled to said inductive coupling means and comprising transistor means to prevent the commencement of said first portion of a cycle of said semi-conductor oscillator means while current is being supplied from said inductive coupling means to said storage capacitor means by shunting current from said voltage source away from said inductive coupling means; and wherein said semi-conductor oscillator means further comprises capacitive means connected to charge during said first portion of a cycle of said semi-conductor oscillator means, and connected to said transistor means in said semi-conductor oscillator means to prevent the commencement of said first portion of said cycle after the completion of the first portion of the prior cycle and before said inductive feedback means is operative to energize said transistor means when current is being supplied by said inductive coupling means to said storage capacitor means, to independently prevent the commencement of the first portion of

3. A direct current voltage converter, comprising:
a. a direct current voltage source;
b. storage capacitor means;
c. semi-conductor oscillator means driven by said direct current voltage source, and in energizing relation with said storage capacitor means to produce charging current for said storage capacitor means;
d. voltage sensing and regulating means comprising glow lamp means, zener diode means and resistance means serially connected across said storage capacitor means, responsive to the voltage across said storage capacitor means to regulate said voltage within a narrow range; and
e. inductive coupling means coupled between said semi-conductor oscillator means and said storage capacitor means; wherein during a first portion of a cycle of said semi-conductor oscillator means, current is drawn from said direct current voltage source and provided to energize said inductive coupling means, and no charging current is provided to said storage capacitor means, and during a second portion of a cycle of said semi-conductor oscillator means, no current from said direct current voltage source is provided to said inductive coupling means, and charging current is provided from said inductive coupling means to said storage capacitor means; wherein said semi-conductor oscillator means comprises switching means to control the frequency of oscillation of said semi-conductor oscillator means; and wherein said switching means is operable to switch the capacitance within said semi-conductor oscillator means.

4. A voltage converter, comprising:
a. storage capacitor means;
b. semi-conductor oscillator means responsive to a unidirectional power source, and in energizing relation with said storage capacitor means to produce charging current for said storage capacitor means;
c. voltage sensing and regulating means responsive to the voltage across said storage capacitor means to regulate said voltage within a narrow range; and
d. inductive coupling means coupled between said semi-conductor oscillator means and said storage capacitor means and comprising a first inductive winding and a second inductive winding, wherein during a first portion of a cycle of said semi-conductor oscillator means, current is provided to energize said first winding of said inductive coupling means and no charging current is provided to said storage capacitor means from said second winding of said inductive coupling means, and during a second portion of a cycle of said oscillator means, no current is provided to said first winding from said oscillator means, and charging current is provided from said second winding to said storage

capacitor means; and wherein said semi-conductor oscillator means comprises a transistor switching means and inductive feedback means inductively coupled to said first winding of said inductive coupling means and responsive to changes in the current flowing through said first winding, to prevent the commencement of said first portion of a cycle of said semi-conductor oscillator means while current is being supplied from said second winding of said inductive coupling means to said storage capacitor means, by energizing said transistor switching means when current ceases to be supplied to said first winding of said inductive coupling means from said semi-conductor oscillator means, to shunt current away from said first winding of said inductive coupling means; and wherein said semi-conductor oscillator means further comprises variable resistance means to control the duration of said first portion of a cycle of said semi-conductor oscillator means.

5. A voltage converter, comprising:

a. storage capacitor means;

b. semi-conductor oscillator means responsive to a unidirectional power source, and in energizing relation with said storage capacitor means to produce charging current for said storage capacitor means;

c. voltage sensing and regulating means responsive to the voltage across said storage capacitor means to regulate said voltage within a narrow range; and

d. inductive coupling means coupled between said semi-conductor oscillator means and said storage capacitor means and comprising a first inductive winding and a second inductive winding, wherein during a first portion of a cycle of said semi-conductor oscillator means, current is provided to energize said first winding of said inductive coupling means and no charging current is provided to said storage capacitor means from said second winding of said inductive coupling means, and during a second portion of a cycle of said oscillator means, no current is provided to said first winding from said oscillator means, and charging current is provided from said second winding to said storage capacitor means; wherein said semi-conductor oscillator means comprises a transistor switching means and inductive feed-back means inductively coupled to said first winding of said inductive coupling means and responsive to changes in the current flowing through said first winding, to prevent the commencement of said first portion of a cycle of said semi-conductor oscillator means while current is being supplied from said second winding of said inductive coupling means to said storage capacitor means, by energizing said transistor switching means when current ceases to be supplied to said first winding of said inductive coupling means from said semi-conductor oscillator means, to shunt current away from said first winding of said inductive coupling means, and wherein said semi-conductor oscillator means further comprises variable capacitance means to control the frequency of oscillation of said semi-conductor oscillator means.

6. A voltage converter, comprising:

a. storage capacitor means;

b. semi-conductor oscillator means responsive to a unidirectional power source, and in energizing relation with said storage capacitor means to produce charging current for said storage capacitor means;

c. voltage sensing and regulating means responsive to the voltage across said storage capacitor means to regulate said voltage within a narrow range; and

d. inductive coupling means coupled between said semi-conductor oscillator means and said storage capacitor means and comprising a first inductive winding and a second inductive winding, wherein during a first portion of a cycle of said semi-conductor oscillator means, current is provided to energize said first winding of said inductive coupling means and no charging current is provided to said storage capacitor means from said second winding of said inductive coupling means, and during a second portion of a cycle of said oscillator means, no current is provided to said first winding from said oscillator means, and charging current is provided from said second winding to said storage capacitor means; wherein said semi-conductor oscillator means comprises a transistor switching means and inductive feed-back means inductively coupled to said first winding of said inductive coupling means and responsive to changes in the current flowing through said first winding, to prevent the commencement of said first portion of a cycle of said semi-conductor oscillator means while current is being supplied from said second winding of said inductive coupling means to said storage capacitor means, by energizing said transistor switching means when current ceases to be supplied to said first winding of said inductive coupling means from said semi-conductor oscillator means, to shunt current away from said first winding of said inductive coupling means.

7. A voltage converter as in claim **6** wherein said semi-conductor oscillator means further comprises capacitive means connected to charge during said first portion of a cycle of said semi-conductor oscillator means, and also connected to said transistor switching means in said semi-conductor oscillator means to energize said transistor switching means to prevent the commencement of said first portion of said cycle after the completion of the first portion of a prior cycle and before said inductive feed-back means is operative.

8. A voltage converter, comprising:

a. storage capacitor means;

b. semi-conductor oscillator means responsive to a unidirectional power source, and in energizing relation with said storage capacitor means to produce charging current for said storage capacitor means;

c. voltage sensing and regulating means responsive to the voltage across said storage capacitor means to regulate said voltage within a narrow range; and

d. inductive coupling means coupled between said semi-conductor oscillator means and said storage capacitor means and comprising a first inductive winding and a second inductive winding, wherein during a first portion of a cycle of said semi-conductor oscillator means, current is provided to energize said first winding of said inductive coupling means and no charging current is provided to said storage capacitor means from said second winding of said inductive coupling means, and during a second portion of a cycle of said oscillator means, no current is provided to said first winding from said oscillator means, and charging current is provided from said second winding to said storage

capacitor means; wherein said voltage sensing and regulating means comprises transistor switching means and a circuit connected across said storage capacitor means, said circuit comprising serially connected glow lamp means and zener diode means, whereby energy is discharged from said storage capacitor means through said circuit when and so long as the voltage across said storage capacitor means is sufficient to cause said glow lamp means and said zener diode means to conduct current, and wherein said transistor switching means is responsive to current flowing through said circuit to shunt current away from said first winding of said inductive coupling means to prevent the commencement of said first portion of a cycle of said semi-conductor oscillator means when said glow lamp means and zener diode means are conducting.

9. An electronic photoflash apparatus, comprising:

a. a battery;

b. storage capacitor means;

c. semi-conductor oscillator means responsive to said battery and in energizing relation with said storage capacitor means to produce charging current fro said storage capacitor means;

d. voltage sensing and regulating means responsive to the voltage across said storage capacitor means to regulate said voltage within a narrow range;

e. inductive coupling means coupled between said semi-conductor oscillator means and said storage capacitor means and comprising a first inductive winding and a second inductive winding, wherein during a first portion of a cycle of said semi-conductor oscillator means, current is provided to energize said first winding of said inductive coupling means and no charging current is provided to said storage capacitor means, and during a second portion of a cycle of said semi-conductor oscillator means no current is provided to said first winding from said semi-conductor oscillator means, and charging current is provided from said second winding to said storage capacitor means; and

f. flashtube means, connected to said storage capacitor means; wherein said semi-conductor oscillator means comprises a transistor switching means and inductive feed-back means inductively coupled to said first winding of said inductive coupling means and responsive to changes in the current flowing through said first winding, to prevent the commencement of said first portion of a cycle of said semi-conductor oscillator means while current is being supplied from said second winding of said inductive coupling means to said storage capacitor means, by energizing said transistor switching means when current ceases to be supplied to said first winding of said inductive coupling means from said semi-conductor oscillator means, to shunt current away from said first winding of said inductive coupling means.

10. A photoflash apparatus as in claim **9,** wherein said semi-conductor oscillator means further comprises capacitive means connected to charge during said first portion of a cycle of said semi-conductor oscillator means, and also connected to said transistor switching means in said semi-conductor oscillator means to energize said transistor switching means to prevent the commencement of said first portion of said cycle after the completion of the first portion of a prior cycle and before said inductive feed-back means is operative.

11. An electronic photoflash apparatus, comprising:

a. a battery;

b. storage capacitor means;

c. semi-conductor oscillator means responsive to said battery and in energizing relation with said storage capacitor means to produce charging current for said storage capacitor means;

d. voltage sensing and regulating means responsive to the voltage across said storage capacitor means to regulate said voltage within a narrow range;

e. inductive coupling means coupled between said semi-conductor oscillator means and said storage capacitor means and comprising a first inductive winding and a second inductive winding, wherein during a first portion of a cycle of said semi-conductor oscillator means, current is provided to energize said first winding of said inductive coupling means and no charging current is provided to said storage capacitor means, and during a second portion of a cycle of said semi-conductor oscillator means no current is provided to said first winding from said semi-conductor oscillator means, and charging current is provided from said second winding to said storage capacitor means; and

f. flashtube means, connected to said storage capacitor means; wherein said voltage sensing and regulating means comprises transistor switching means and a circuit connected across said storage capacitor means, said circuit comprising serially connected glow lamp means and zener diode means, whereby energy is discharged from said storage capacitor means through said circuit when and so long as the voltage across said storage capacitor means is sufficient to cause said glow lamp means and said zener diode means to conduct current, and wherein said transistor switching means is responsive to current flowing through said circuit to shunt current away from said first winding of said inductive coupling means to prevent the commencement of said first portion of a cycle of said semi-conductor oscillator means when said glow lamp means and zener diode means are conducting.

12. A photoflash apparatus as in claim **11,** wherein said semi-conductor oscillator means comprises variable resistance means to control the duration of said first portion of a cycle of said semi-conductor oscillator means.

13. A photoflash apparatus as in claim **12,** wherein said flash tube means comprises a flash tube and switching means adapted to be attached to a camera so that energy is provided from said storage capacitor means to cause said flash tube to flash synchronously with operation of the camera shutter.

14. A photoflash apparatus as in claim **13,** further comprising second zener diode means, the cathode of said second zener diode means being serially connected to the positive terminal of said battery to prevent current from being drawn from said battery when the voltage of the battery falls below a certain value.

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