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(54) **POWER SUPPLY FOR A LOAD CONTROL**

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3,742,337 A \* 6/1973 Digneffe ..... 323/300  
4,386,395 A \* 5/1983 Francis, Jr. .... 363/27  
4,560,909 A 12/1985 Peil  
4,563,592 A 1/1986 Yuhasz et al.

(Continued)

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FOREIGN PATENT DOCUMENTS

(\* ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(57) **ABSTRACT**

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A power supply adapted to be coupled in series electrical connection between an AC voltage source and an electrical load for generating a DC voltage, the power supply comprising an energy storage capacitor, the DC voltage produced across the capacitor; a charging circuit adapted to be coupled in series electrical connection between the source and the load and to conduct a load current from the source to the load, the charging circuit coupled to the energy storage capacitor for charging the energy storage capacitor; a controllably conductive device coupled in parallel electrical connection with the charging circuit and having a control input for rendering the controllably conductive device conductive, the controllably conductive device adapted to carry the load current from the source to the load when the controllably conductive device is conductive; and a triggering circuit coupled to the control input of the controllably conductive device for causing the controllably conductive device to become conductive when the energy storage capacitor has charged to a desired maximum value; wherein the charging circuit is adapted to conduct the load current from the source to the load when the controllably conductive device is non-conductive, the charging circuit imposing a low voltage drop relative to the peak value of an AC voltage of the AC voltage source, such that substantially all of the AC voltage is available to the load during the time when the controllably conductive device is non-conductive.

**Related U.S. Application Data**

(63) Continuation of application No. 11/447,489, filed on Jun. 6, 2006, now Pat. No. 7,423,413.

(60) Provisional application No. 60/738,083, filed on Nov. 18, 2005, provisional application No. 60/687,691, filed on Jun. 6, 2005.

(51) **Int. Cl.**

**G05F 1/455** (2006.01)  
**H02J 3/12** (2006.01)

(52) **U.S. Cl.** ..... **323/242; 323/239**

(58) **Field of Classification Search** ..... 323/235,  
323/237, 239, 241, 242, 243, 244, 246; 327/446,  
327/452, 455, 456, 469, 476

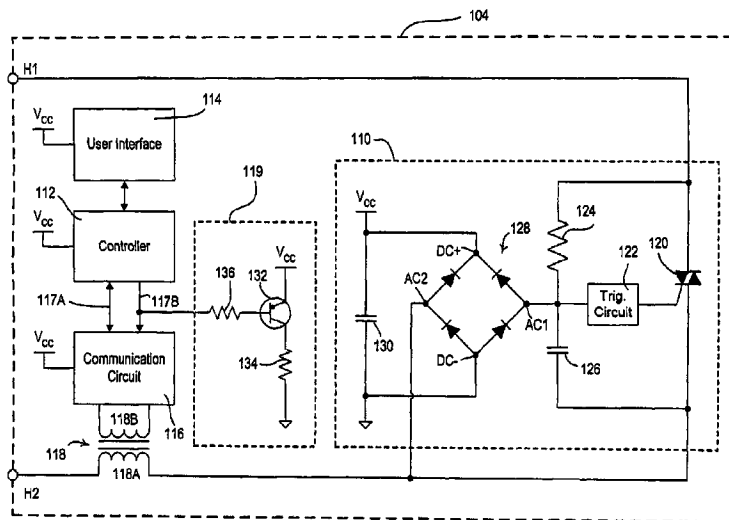
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,422,309 A 1/1969 Spria et al.

**18 Claims, 7 Drawing Sheets**



# US 7,564,227 B2

Page 2

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U.S. PATENT DOCUMENTS									
4,634,957	A *	1/1987	Hollaway .....	323/242	5,811,963	A	9/1998	Elwell	
4,689,547	A	8/1987	Rowen et al.		6,262,565	B1	7/2001	Williams et al.	
4,745,351	A	5/1988	Rowen et al.		6,396,672	B1	5/2002	Deam	
4,782,322	A	11/1988	Lechner et al.		6,992,904	B2 *	1/2006	Chen et al. ....	363/45
4,797,599	A	1/1989	Ference et al.		7,012,518	B2	3/2006	Novikov	
4,841,221	A	6/1989	Barney et al.		7,034,899	B2	4/2006	Symoen et al.	
4,876,498	A	10/1989	Luchaco et al.		7,193,404	B2	3/2007	Weightman	
4,954,768	A	9/1990	Luchaco et al.		7,423,413	B2 *	9/2008	Dobbins et al. ....	323/242
RE33,504	E	12/1990	Yuhasz et al.		2006/0255745	A1	11/2006	DeJonge et al.	
5,017,837	A	5/1991	Hanna et al.		2006/0255959	A1 *	11/2006	Salvestrini .....	340/664
5,189,412	A	2/1993	Mehta et al.		2007/0001654	A1	1/2007	Newman, Jr.	
5,365,154	A	11/1994	Schneider et al.		2007/0159153	A1	7/2007	Fricke	

\* cited by examiner

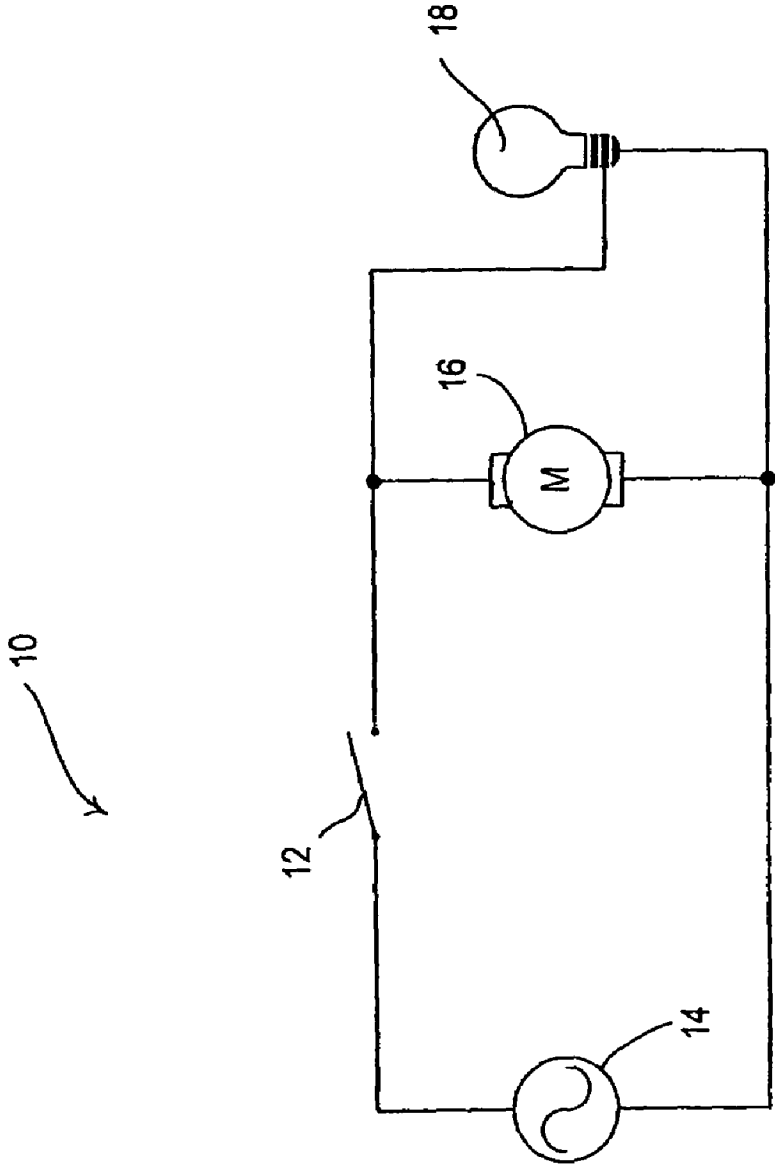


Fig. 1A  
Prior Art

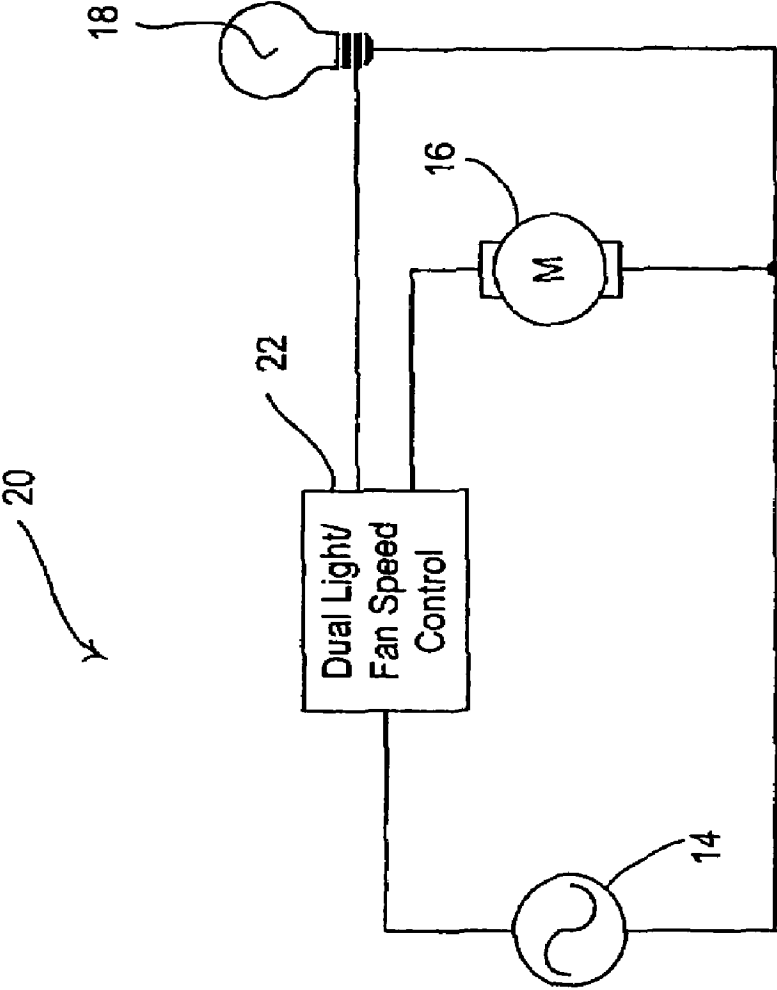


Fig. 1B  
Prior Art

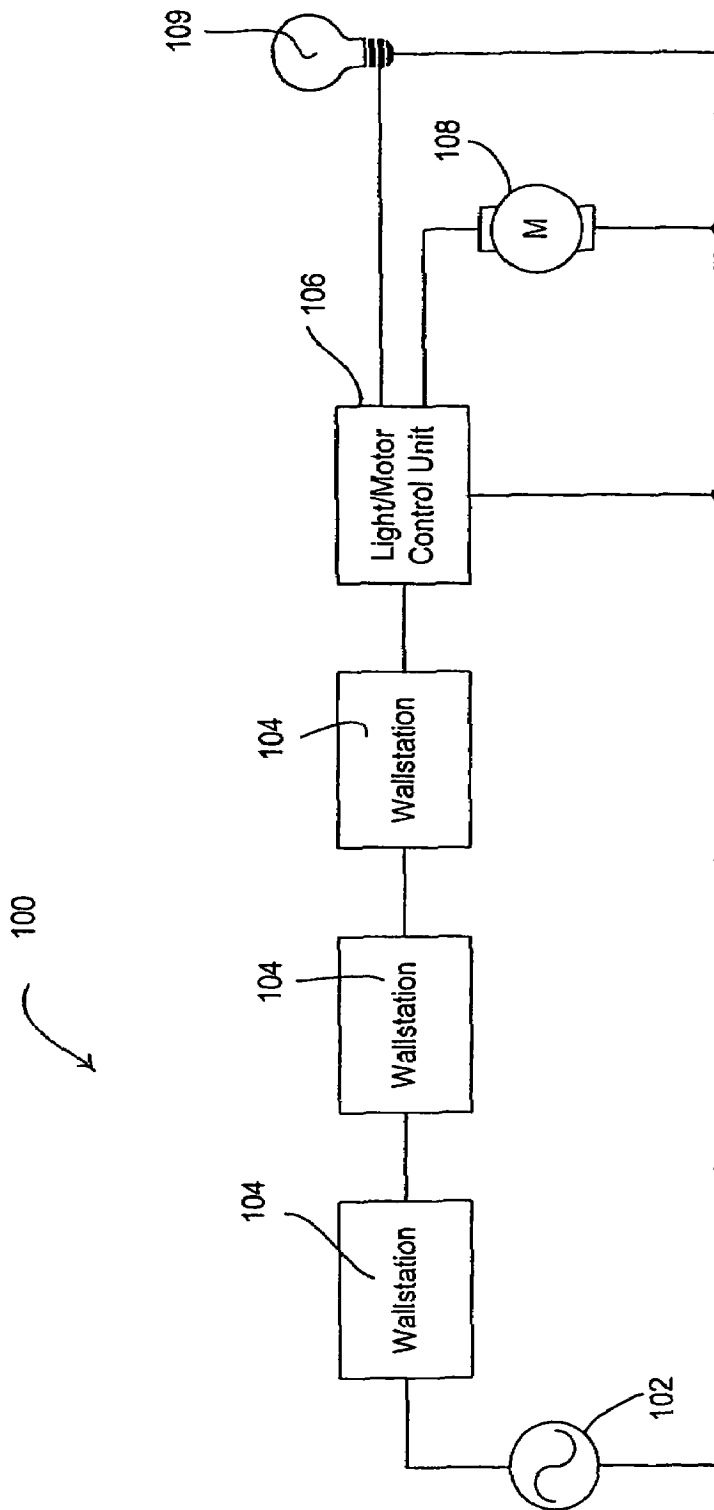


Fig. 2

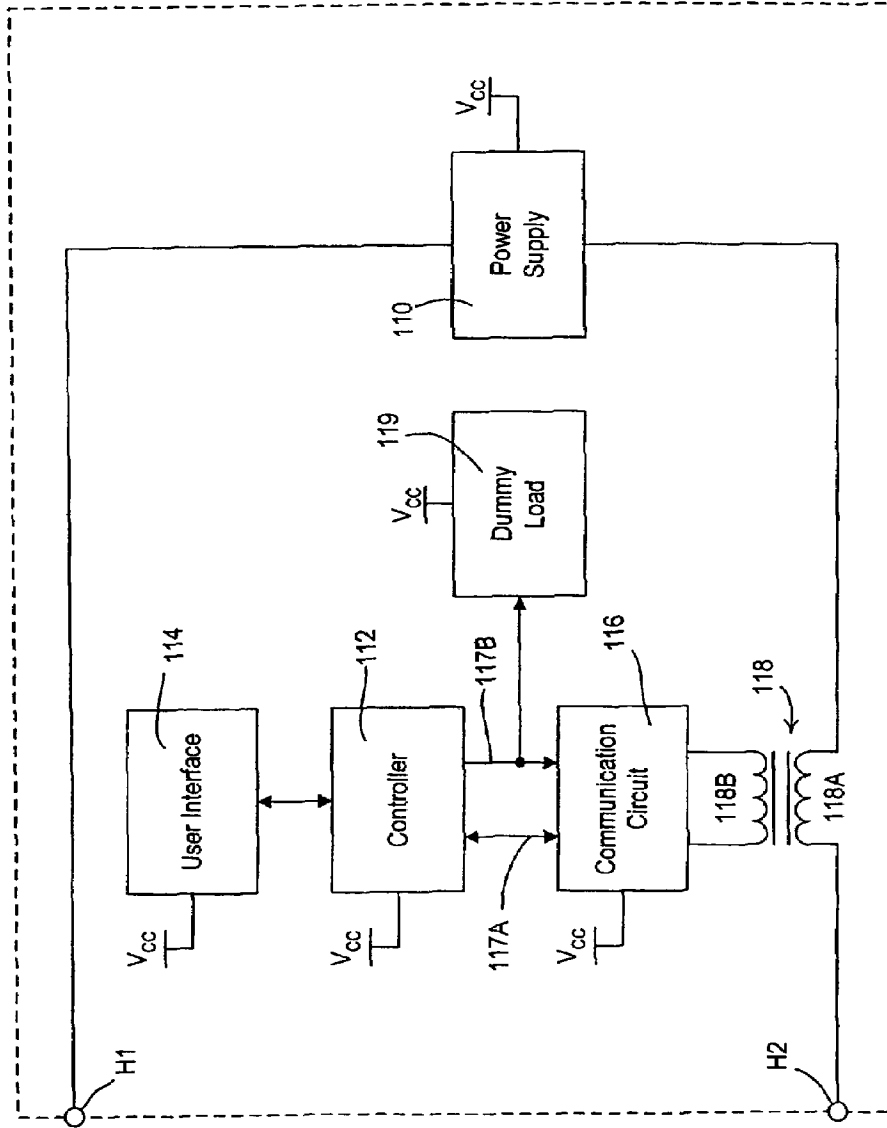


Fig. 3

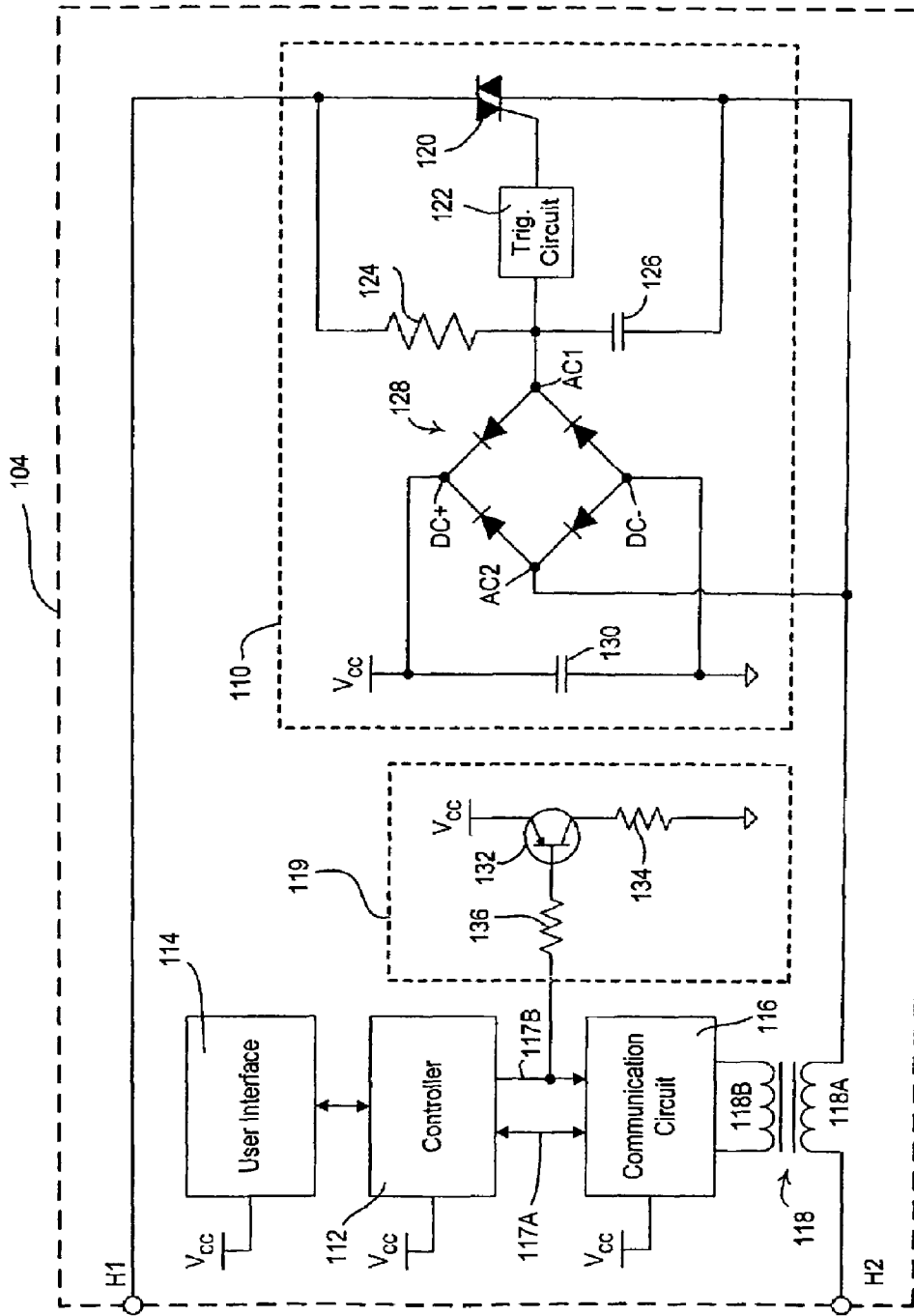


Fig. 4A

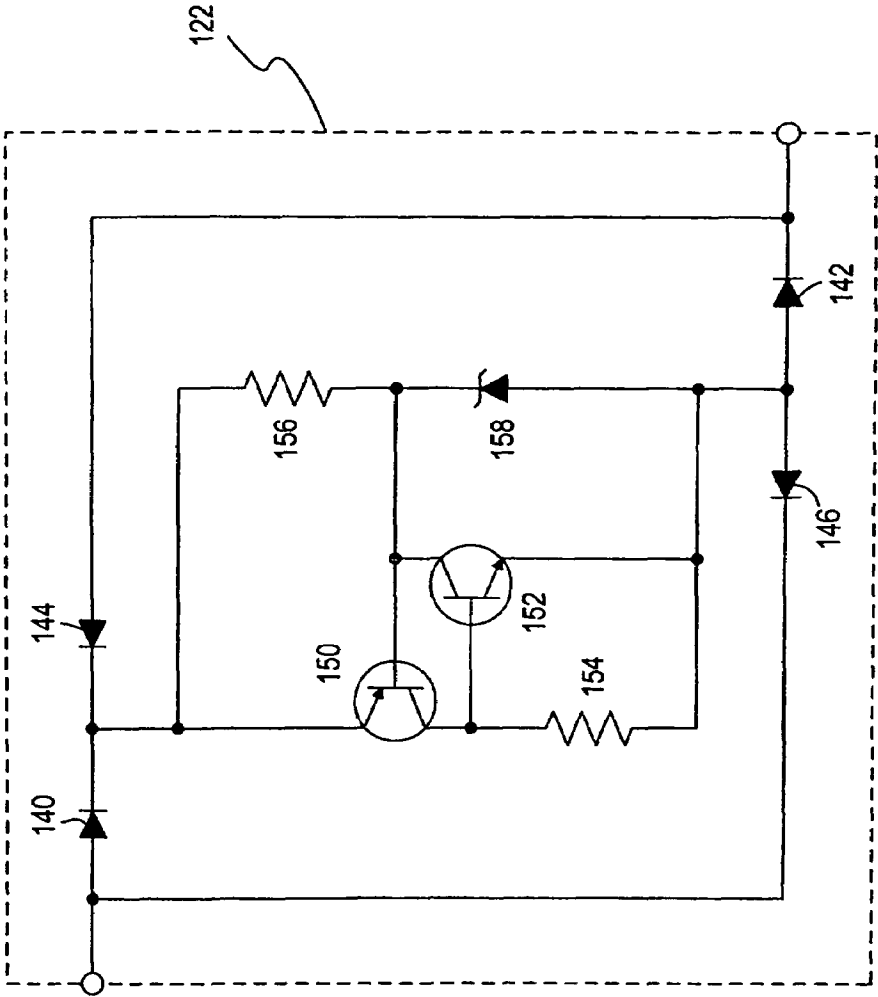


Fig. 4B



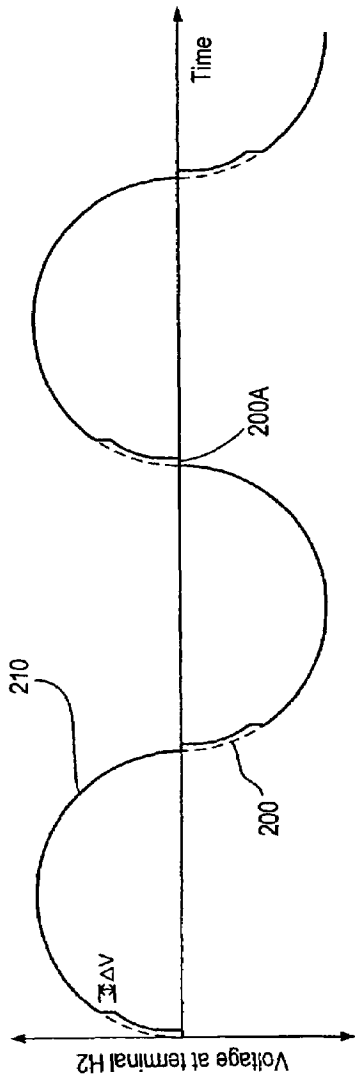


Fig. 5A

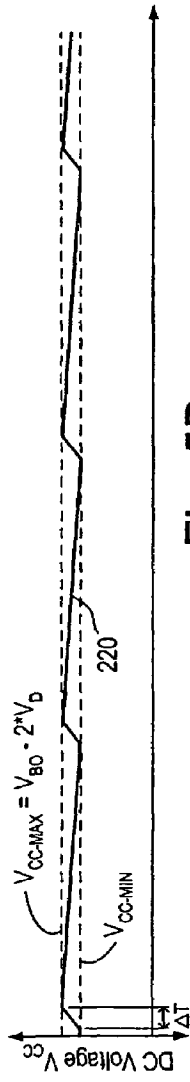


Fig. 5B

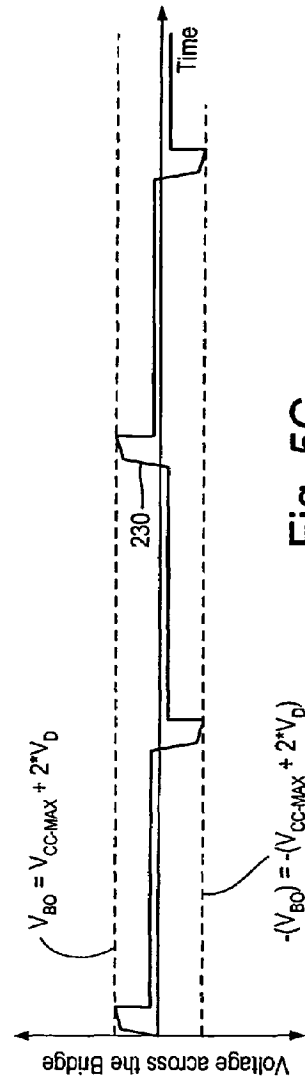


Fig. 5C

**POWER SUPPLY FOR A LOAD CONTROL****CROSS REFERENCE TO RELATED APPLICATIONS**

This is a continuation of U.S. patent application Ser. No. 11/447,489, filed Jun. 6, 2006, entitled POWER SUPPLY FOR A LOAD CONTROL DEVICE, which application claims priority from commonly-assigned U.S. Provisional Application Ser. No. 60/687,691, filed Jun. 6, 2005, and from commonly-assigned U.S. Provisional Application Ser. No. 60/738,083, filed Nov. 18, 2005, both having the same title as the present application. The entire disclosures of both provisional applications are hereby incorporated by reference.

**BACKGROUND OF THE INVENTION****1. Field of the Invention**

The present invention relates to an apparatus for independently controlling a motor, for example, a fan motor, together with a lighting source contained within the same enclosure as the fan motor or coupled to the fan motor. More specifically, the invention relates to a power supply for a remote control device for providing individual control of the lighting source and the fan motor.

**2. Description of the Related Art**

It is often desirable to include a lamp in the same enclosure as a fan motor. Since the lamp and the fan motor are often wired in parallel, the lamp and the fan motor are generally controlled together from a switch located remotely from the lamp and the fan motor. FIG. 1A shows a prior art light and fan motor control system **10**. The system **10** includes a maintained switch **12** coupled between an alternating-current (AC) voltage source **14** and two loads: a fan motor **16** and a lighting load **18**. The fan motor **16** and the lighting load **18** are connected in parallel such that when switch **12** is closed the fan motor **16** and the lighting load **18** will both be on, and when the switch **12** is open the fan motor **16** and the lighting load **18** will both be off.

There are also various schemes for independent control of a fan motor as well as a lighting load from a remote location such as a wallstation. FIG. 1B shows a prior art light and fan motor control system **20**, having a dual light and fan speed control **22** coupled to the AC voltage source **14**. The dual light and fan speed control **22** has two outputs: the first output coupled to the fan motor **16** and the second output coupled to the lighting load **18**, to allow for independent control of the loads. Further, the dual light and fan speed control **22** includes a fan speed circuit for adjusting the speed at which the fan motor **16** turns and a dimmer circuit for changing the intensity of the lighting load **18**. The dual light and fan speed control **22** is often mounted in a standard electrical wallbox and includes a user interface to allow a user to separately control the lighting load and the fan motor.

However, the dual light and fan speed control **22** requires two separate wires to be connected between the control and the loads, i.e., the lighting load **18** and the fan motor **16**. If these two connections are not provided between the wallbox and the enclosure containing the lamp and the fan motor, independent control of the lighting load and the fan motor will not be possible. Further, in the system **20** of FIG. 1B, it is only possible to have one dual light and fan speed control **22**, and thus, only one user interface to allow for adjustment of the light intensity and the fan speed. Control of the fan motor and lighting load from more than one location is not possible in this system.

Thus, it is desirable to provide a reliable means to independently control from a remote location a fan motor and a lighting load that are located in the same enclosure. Since a consumer may wish to locate the fan motor and the attached lamp in a position previously occupied by only a lamp controlled by a standard single-pole single-throw wall switch, it is desirable to be able to control the fan motor as well as the attached lamp independently, using a two-wire control device. A two-wire control device is a control device that has only two electrical connections (one connection to the AC voltage source and the other connection to the enclosure containing the lamp and the fan motor) and does not have a neutral connection. As shown in FIG. 1A, this kind of system typically only includes a switch in series electrical connection between the AC voltage source and the lamp/fan and no neutral connection is available in the electrical wallbox where the switch is housed. Since it is desirable to control the fan motor and the lamp independently, using the existing building wiring, it is necessary to develop a means to allow independent control over the existing building wiring consisting of a single pair of wires connecting the remote wallstation to the lamp/fan apparatus.

Such a remote wallstation preferably includes a microcontroller to receive inputs from a user interface and to communicate with a load control device in the enclosure of the lighting load and the fan motor. To power the microcontroller with a substantially direct-current (DC) voltage, the wallstation must also include a DC power supply.

Thus, there exists a need for a power supply for a two-wire load control device that passes as much of the voltage from the AC voltage source to the loads (or another load control device) as possible and derives a minimal amount of power from the AC voltage source to power a microcontroller and other low-voltage circuitry.

**SUMMARY OF THE INVENTION**

The invention provides a power supply disposed in series with an AC load for charging an energy storage device from an AC voltage of an AC supply. The power supply comprises a controllably conductive device, a triggering circuit, and a charging circuit. The controllably conductive device is adapted to carry a load current from the AC supply to the load when the controllably conductive device is conductive. The triggering circuit is operable to cause the controllably conductive device to become conductive. The charging circuit is operable to charge the energy storage device during a time period before the controllably conductive device becomes conductive. The charging circuit imposes a low voltage drop relative to the peak of the AC voltage such that substantially all of the AC voltage is available to the load during the time when the controllably conductive device is non-conductive. The triggering circuit is operable to cause the controllably conductive device to become conductive when the energy storage device has charged to a predetermined amount of energy.

The present invention further provides a power supply adapted to be disposed in series electrical connection between an electrical load and an AC voltage source and operable to generate a DC voltage. The power supply comprises a controllably conductive device having a control input, a triggering circuit, and a charging circuit. The controllably conductive device is adapted to carry a load current from the AC voltage source to the electrical load when the controllably conductive device is conductive. The triggering circuit is coupled to the control input of the controllably conductive device for causing the controllably conductive device to

3

become conductive. The charging circuit is operable to charge an energy storage capacitor when the controllably conductive device is non-conductive such that the DC voltage is produced across the energy storage capacitor. The charging circuit imposes a low voltage drop relative to the peak value of an AC voltage of the AC voltage source such that substantially all of the AC voltage is available to the load during the time when the controllably conductive device is non-conductive. The charging circuit is operable to stop charging the energy storage capacitor when the controllably conductive device is conductive. The triggering circuit is operable to cause the controllably conductive device to become conductive in response to the DC voltage so as to cause the energy storage capacitor from charging.

According to another aspect of the present invention, a remote control device for an electrical load is adapted to be coupled in series electrical connection between the electrical load and an AC voltage source. The remote control device comprises a communication circuit, a controller, and a power supply. The communication circuit is operable to transmit control information for controlling the electrical load. The controller is coupled to the communication circuit for providing the control information to the communication circuit. The power supply is adapted to be coupled in series electrical connection between the electrical load and the AC voltage source and is operable to generate a DC voltage to power the communication circuit and the controller. The power supply comprises a charging circuit for charging an energy storage device. The charging circuit imposes a low voltage drop relative to the peak value of an AC voltage of the AC voltage source such that substantially all of the AC voltage is available to the load during the time when the energy storage device is charging.

In addition, the present invention provides a method of generating a DC voltage in a remote control device adapted to be disposed in series electrical connection between an AC voltage source and an electrical load. The method comprises the steps of: (1) coupling a controllably conductive device in series electrical connection between the AC voltage source and the electrical load, the controllably conductive device having a control input; (2) charging an energy storage device through a charging circuit when the controllably conductive device is non-conductive; (3) rendering the controllably conductive device conductive in response to the step of charging the energy storage device; and (4) stopping the charging of the energy storage device in response to the step of rendering the controllably conductive device conductive. The charging circuit imposes a low voltage drop relative to the peak value of the AC voltage such that substantially all of the AC voltage is available to the load during the time when the controllably conductive device is non-conductive.

Other features and advantages of the present invention will become apparent from the following description of the invention, which refers to the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in greater detail in the following detailed description with reference to the drawings in which:

FIG. 1A is a simplified block diagram of a prior art light and fan motor control system;

FIG. 1B is a simplified block diagram of a prior art light and fan motor control system including a dual light and fan speed control;

FIG. 2 is a simplified block diagram of a system for control of lights and fan motors according to the present invention;

4

FIG. 3 is a simplified block diagram of a wallstation of the system of FIG. 2;

FIG. 4A is a simplified circuit diagram of a power supply of the wallstation of FIG. 3;

FIG. 4B is a simplified circuit diagram of a triggering circuit of the power supply of FIG. 4A; and

FIGS. 5A, 5B, and 5C show waveforms demonstrating the operation of the power supply of FIG. 4A.

#### DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

The foregoing summary, as well as the following detailed description of the preferred embodiments, is better understood when read in conjunction with the appended drawings. For the purposes of illustrating the invention, there is shown in the drawings an embodiment that is presently preferred, in which like numerals represent similar parts throughout the several views of the drawings, it being understood, however, that the invention is not limited to the specific methods and instrumentalities disclosed.

As is well known, a lamp and a fan motor are typically packaged in the same housing. It is desirable to be able to control the lamp and fan motor independently from the same remote location, for example, a wallstation. However, the two circuits to control the lamp and the fan motor are typically different. The lamp may be controlled by a series switch, typically a phase-angle dimmer. The fan motor may be controlled by a shunt switch in parallel with the fan motor, which is disclosed in commonly-assigned co-pending U.S. patent application, Attorney Docket No. 04-11701-P2, filed on the same day as the present application, entitled METHOD AND APPARATUS FOR QUIET VARIABLE MOTOR SPEED CONTROL, the entire disclosure of which is hereby incorporated by reference.

A block diagram of a system **100** for independent control of lights and fan motors is shown in FIG. 2. The system includes a plurality of wallstations **104**, i.e., remote controls, which are connected in series between an AC voltage source **102** and a light/motor control unit **106**. The light/motor control unit **106** is operable to control both the speed of a fan motor **108** and the intensity of a lighting load **109**. The system **100** for independent control of lights and fan motors is described in greater detail in commonly-assigned co-pending U.S. patent application, Attorney Docket No. 05-12143-P2, filed on the same day as the present application, entitled SYSTEM FOR CONTROL OF LIGHTS AND MOTORS, the entire disclosure of which is hereby incorporated by reference.

In the system **100** of FIG. 2, it is desirable to provide substantially the full AC voltage from the AC voltage source **102** to the light/motor control unit **106** for operation of the fan motor **108** and the lighting load **109**. Since the wallstations **104** are coupled in series electrical connection, it is desirable to minimize the voltage drop across each wallstation **104**. Thus, it is not desirable to develop a significant voltage across each of the wallstations **104** in order to charge an internal DC power supply to power the low-voltage circuitry of the wallstation.

FIG. 3 is a simplified block diagram of the wallstation **104**, which includes a power supply **110**, a controller **112**, a user interface **114**, and a communication circuit **116**. The power supply **110** is provided in series between a first electrical terminal H1 and a second electrical terminal H2. The power supply **110** provides a DC voltage,  $V_{CC}$ , to power the controller **112**, the user interface **114**, and the communication circuit **116**. The controller **112** is preferably implemented as a microcontroller, but may be any suitable processing device,

such as a programmable logic device (PLD), a microprocessor, or an application specific integrated circuit (ASIC).

The user interface **114** includes a plurality of buttons for receiving inputs from a user and a plurality of light emitting diodes (LEDs) for providing feedback to the user. The controller **112** accepts control inputs from the buttons of the user interface **114** and controls the operation of the LEDs. The user interface **114** may also include a wireless communications port for receiving inputs from a wireless transmitter, for example, an infrared (IR) or radio frequency (RF) remote control.

The controller **112** is also coupled to the communication circuit **116** for transmitting and receiving control information to and from the light/motor control unit **106** and the other wallstations **104** of system **100**. The control information is transmitted between the controller **112** and the communication circuit **116** via a data signal **117A**. The communication circuit **116** transmits and receives the control information via a communications transformer **118** over the hot line, which is coupled from the AC voltage source **102** via the wallstations **104** to the light/motor control unit **106**. The communications transformer **118** has a primary winding **118A** that is connected in series electrical connection with the terminals H1, H2 of the wallstation **104**, and a secondary winding **118B** that is coupled to the communication circuit **116**.

The controller **112** provides a communication-enable control signal **117B** to the communication circuit **116**. When the communication-enable control signal **117B** is high, i.e., substantially the same as the DC voltage  $V_{CC}$  of the power supply **110**, the communication circuit **116** is operable to transmit the control information to the light/motor control unit **106** and other wallstations **104**. The communication circuit **116** draws a substantially constant current, e.g., 12 mA, from the power supply **110** when transmitting the control information. When the communication-enable control signal **117B** is low, i.e., substantially the same as circuit common, the communication circuit is disabled and draws a substantially minimal current from the power supply **110**.

The wallstation **104** further comprises a dummy load **119** that is operable to draw a substantially constant current from the power supply **110** in response to the communication-enable control signal **117B**. The operation of the dummy load **119** will be described in greater detail below.

Turning to FIG. 4A, the power supply **110** of the wallstation **104** is shown in greater detail. The power supply **110** includes a controllably conductive device, such as a semiconductor switch, for example, a triac **120**. The controllably conductive device could also be implemented as a relay or another type of semiconductor switch, such as two field effect transistors (FETs) in anti-series connection, or insulated gate bipolar junction transistors (IGBTs). The triac **120** has two main load terminals that are coupled in series between the terminals H1, H2. The triac **120** is operable to be selectively rendered conductive dependent on the input at a gate (i.e., a control input). The triac **120** becomes non-conductive when the current through the triac becomes approximately zero (i.e., at a zero-crossing of the AC voltage source). However, if the semiconductor switch is implemented as two FETs in anti-series connection, for example, the FETs are operable to be selectively rendered non-conductive dependent on the input at the gate.

The gate of the triac **120** is coupled to a triggering circuit **122**. The triggering circuit **122** may be implemented as a diac, a sidac, a silicon bilateral switch (SBS), one or more zener diodes, a comparator circuit, or a transistor circuit. A resistor-capacitor (RC) circuit, comprising a limiting resistor **124** and a firing capacitor **126**, is coupled across the triac **120**. The

triggering circuit **122** is coupled in series with the gate of the triac **120** and the junction of the resistor **124** and the firing capacitor **126**. The triggering circuit **122** has a break-over voltage,  $V_{BO}$ , and conducts current to and from the gate of the triac **120** only when the voltage across the firing capacitor **126** exceeds the break-over voltage  $V_{BO}$ . The limiting resistor **124** preferably has a resistance of  $10\Omega$  and the firing capacitor **126** preferably has a capacitance of  $0.2\mu\text{F}$ .

FIG. 4B is a simplified schematic diagram of a possible implementation of the triggering circuit **122** of the power supply **110**. The triggering circuit **122** includes a rectifier bridge (comprising four diodes **140**, **142**, **144**, **146**), two transistors **150**, **152**, two resistors **154**, **156**, and a zener diode **158**. When the voltage across the triggering circuit **122** exceeds approximately the break-over voltage of the zener diode **158**, the zener diode begins conducting current. The break-over voltage of the zener diode **158** defines the break-over voltage  $V_{BO}$  of the triggering circuit **122**. The transistor **150** begins conducting as the voltage across the resistor **156** reaches the required base-emitter voltage of the transistor **150**. A voltage is then produced across the resistor **154**, which causes the transistor **152** to begin conducting. This essentially "shorts out" the zener diode **158** such that the zener diode stops conducting and the voltage across the triggering circuit **122** falls to a substantially small voltage, i.e., the sum of the forward voltage drops of two of the diodes **140**, **142**, **144**, **146** of the rectifier bridge, the base-emitter voltage of the transistor **150**, and the saturation voltage of the transistor **152**, which is typically in the range of 1.7 volts to 2.5 volts. This operation causes a pulse of current to flow through the triggering circuit **122** from the firing capacitor **126** through the gate of the triac **120**. The rectifier bridge comprising the diodes **140**, **142**, **144**, **146** allows current to flow through the triggering circuit **122** in both half-cycles.

The power supply **110** also includes a charging circuit comprising a rectifier bridge **128** having two terminals AC1, AC2 that are connected across the firing capacitor **126** and two terminals DC+, DC- that provide the DC voltage  $V_{CC}$  across an energy storage device, for example, a storage capacitor **130**. The voltage developed across the storage capacitor **130** provides power for the controller **112**. The storage capacitor **130** preferably has a capacitance of  $680\mu\text{F}$ . Herein, the term "charging circuit" means a circuit for causing energy to be stored in an energy storage device and is not intended to be limited to a circuit for causing electrical charge to be stored in a capacitor.

The limiting resistor **124** limits the charging current through the rectifier bridge **128** and the storage capacitor **130**. The limiting resistor **124** may be replaced with a short circuit if the impedance in series with the power supply **110** in the system **100** is enough to limit the peak charging current of the storage capacitor **130** to an appropriate level.

When the voltage across the terminals AC1, AC2 of the rectifier bridge **128**, which is also the voltage across the firing capacitor **126**, exceeds the break-over voltage  $V_{BO}$  of the triggering circuit **122**, a gate current flows through the gate of the triac **120** and the triac begins conducting current through the main load terminals. The firing capacitor **126** consistently provides enough charge to produce the gate current through the gate of the triac **120** when the triggering circuit **122** begins conducting. However, the firing capacitor **126** is not necessary for proper operation of the power supply **110**, since the gate current can be drawn through the resistor **124**, and may be omitted.

The generated DC voltage  $V_{CC}$  has a ripple, and thus, a maximum value ( $V_{CC-MAX}$ ) that is set by the break-over voltage of the triggering circuit **122** and a minimum value ( $V_{CC}$ ).

*MIN*) that is dependent on the current drawn by the controller **112** between the times that the triggering circuit **122** breaks over. The break-over voltage  $V_{BO}$  of the triggering circuit **122** is preferably the same as the desired maximum value of the DC voltage  $V_{CC-MAX}$  plus the forward voltage drop  $V_D$  of two of the diodes in the rectifier bridge **128**, i.e.,

$$V_{BO} = V_{CC-MAX} + 2 * V_D \quad (\text{Equation 1})$$

Thus, assuming  $V_D$  is 0.6 volts, and that the desired  $V_{CC-MAX}$  is 5.1 volts, then  $V_{BO}$  is preferably approximately 6.3 volts.

Since the break-over voltage  $V_{BO}$  is related to the desired maximum value of the DC voltage  $V_{CC-MAX}$  (as shown in Equation 1), the triggering circuit **122** begins conducting current, and thus the triac **120** begins conducting current, in response to the DC voltage  $V_{CC}$  across the storage capacitor **130** reaching  $V_{CC-MAX}$ . As a result, the voltage across the triac **120** drops to a substantially low voltage (e.g., 1.5 volts), which causes the storage capacitor **130** to stop charging. Accordingly, the power supply **110** exhibits a closed loop control scheme since the time that the storage capacitor **130** stops charging is dependent upon the DC voltage  $V_{CC}$  across the storage capacitor.

As the storage capacitor **130** charges, a wallstation voltage,  $V_{WS}$ , which is equal to the present value of the DC voltage  $V_{CC}$  of the power supply **110**, plus two diode voltage drops  $V_D$ , i.e.,

$$V_{WS} = V_{CC} + 2 * V_D \quad (\text{Equation 2})$$

develops across the terminals H1 and H2 for a time period during each half-cycle until the voltage developed across the firing capacitor **126** reaches the break-over voltage  $V_{BO}$  of the triggering circuit **122** and the triac **120** begins conducting. During the time that the triac **120** is non-conducting and the wallstation voltage  $V_{WS}$  develops across the firing capacitor **126** and thus the wallstation **104**, the load current flows through the limiting resistor **124**, the rectifier bridge **128**, and the storage capacitor **130**, which charges to the voltage  $V_{CC-MAX}$ . During this time, the charging circuit imposes a low voltage drop relative to the peak of the AC voltage when current is flowing through the power supply **110** to the load. The resistor **124** preferably has a small resistance so that only an insignificant voltage is developed across the resistor when the load current is flowing through the storage capacitor **130**. Thus, the maximum voltage drop across the wallstation **104** when the triac **120** is non-conducting is approximately the same as the break-over voltage  $V_{BO}$  of the triggering circuit **122** (assuming the voltage drop across the resistor **124** is small).

FIGS. 5A, 5B, and 5C show waveforms demonstrating the operation of the power supply **110**. FIG. 5A shows a line voltage waveform **200** and an output voltage waveform **210** (i.e., the voltage measured from the load-side terminal of the wallstation **104** to neutral of the system **100**). The power supply **110** induces only a minimal amount of distortion in the output voltage waveform **210** as a result of a voltage drop,  $\Delta V$ , which is developed across the wallstation **104**, and which is substantially equal to the break-over voltage  $V_{BO}$ . Note that no voltage is provided to the load during a short interval **200A** at the beginning of each half-cycle, until the voltage across the wallstation exceeds the present value of the DC voltage  $V_{CC}$  plus two diode voltage drops  $V_D$ , i.e.,  $V_{CC} + 2 * V_D$ .

FIG. 5B show a DC voltage waveform **220** of the DC voltage  $V_{CC}$  that is generated by the power supply **110**. Until the voltage across the firing capacitor **126** (i.e., the voltage across the rectifier bridge **128**) exceeds the break-over voltage  $V_{BO}$ , the storage capacitor **130** charges to the voltage

$V_{CC-MAX}$  for a time interval,  $\Delta T$ . The time interval  $\Delta T$  is dependent upon the break-over voltage of the triggering circuit **122**, and the minimum value  $V_{CC-MIN}$  which is determined by the current drawn by the low-voltage circuitry connected to the storage capacitor **130** (i.e., the controller **112**).

FIG. 5C show a bridge voltage waveform **230** of the voltage measured across the input terminals AC1, AC2 of the rectifier bridge **128**. The bridge voltage waveform **230** is slightly less than the break-over voltage  $V_{BO}$  of the trigger circuit **122** and increasing when the storage capacitor **130** is charging. After reaching the break-over voltage  $V_{BO}$  (approximately 6.3V in the power supply **110** of the present invention), the bridge voltage waveform **230** drops to approximately 1V (i.e., the voltage drop across the triac **120**). The bridge voltage waveform **230** is substantially the same as the voltage waveform measured across the wallstation **104** since the voltage drop across the resistor **124** is negligibly small.

The waveforms of FIGS. 5A, 5B, and 5C are shown solely to demonstrate the operation of the power supply **110**. The waveforms as shown would result from a resistive load connected between the load-side terminal of the wallstation **104** closest to the loads and neutral of the AC supply **102**, i.e., with a resistive load in place of the light/motor control unit **106** (see FIG. 2). However, a reactive load (such as the combination of the light/motor control unit **106**, the fan motor **108**, and the lighting load **109**) causes a phase shift between the voltage and the current through the wallstation **104**. Accordingly, this shifts the position of the charging time interval  $\Delta T$  relative to the zero-crossing of the line voltage waveform **200**, i.e., to some other time later in the half-cycle.

The light/motor control unit **106** utilized the zero-crossings of the line voltage waveform to control the motor load **108** and the lighting load **109**. If the charging time interval  $\Delta T$  of the power supply **110** of the wallstation **104** occurs near the zero-crossings, the light/motor control unit may encounter "zero-crossing noise", which may cause the lighting load **109** to flicker and motor load **108** to be controlled incorrectly. Zero-crossing noise occurs when the zero-crossings of the line voltage waveform is inconsistent from one line-cycle to the next.

Preferably, the charging time interval  $\Delta T$  does not occur near the zero-crossings to reduce the possibility of noise in the detection of the zero-crossings. Further, the charging time interval  $\Delta T$  should be a constant length of time from one half-cycle to the next. To ensure that the charging time interval  $\Delta T$  each half-cycle, the wallstation **104** employs the dummy load **119** to draw current when the communication circuit **116** is not transmitting.

Referring to FIG. 4A, the dummy load **119** comprises a PNP bipolar-junction transistor (BJT) **132** coupled between the DC voltage  $V_{CC}$  and a dummy load resistor **134**. The base of the transistor **132** is coupled to the communication-enable signal **117B** through a base resistor **136**, e.g., having a resistance of 4.7 k $\Omega$ . When the communication-enable signal **117B** is high (i.e., the communication circuit **116** is transmitting), the base of the transistor **132** is also pulled high and no current flows through the dummy load resistor **134**. However, when the communication-enable signal **117B** is low (i.e., the communication circuit **116** is disabled), the transistor **132** is conductive and the dummy load resistor **134** draws a predetermined current from the storage capacitor **130**. The dummy load resistor **134** is preferably sized such that the predetermined current is substantially the same as the current draw of the communication circuit **116**. For example, the dummy load resistor **134** may have a resistance of 375 $\Omega$  if the current drawn by the communication circuit **116** is 12 mA (assuming

a saturation voltage of the transistor **132** of 0.3 V and an average DC voltage of 4.8 V across the storage capacitor **130**).

Although the words “device” and “unit” have been used to describe the elements of the systems for control of lights and fan motors of the present invention, it should be noted that each “device” and “unit” described herein need not be fully contained in a single enclosure or structure. For example, the light/motor control unit **106** may comprise a controller in a wall-mounted device and fan motor control circuit in a separate location, e.g., in the canopy of the fan motor and the lamp. Also, one “device” may be contained in another “device”.

Although the present invention has been described in relation to particular embodiments thereof, many other variations and modifications and other uses will become apparent to those skilled in the art. Therefore, the present invention should be limited not by the specific disclosure herein, but only by the appended claims.

What is claimed is:

**1.** A power supply adapted to be coupled in series electrical connection between an AC voltage source and an electrical load for generating a DC voltage, the power supply comprising:

an energy storage capacitor, the DC voltage produced across the capacitor;

a charging circuit adapted to be coupled in series electrical connection between the source and the load and to conduct a load current from the source to the load, the charging circuit coupled to the energy storage capacitor for charging the energy storage capacitor;

a controllably conductive device coupled in parallel electrical connection with the charging circuit and having a control input for rendering the controllably conductive device conductive, the controllably conductive device adapted to carry the load current from the source to the load when the controllably conductive device is conductive; and

a triggering circuit coupled to the control input of the controllably conductive device for causing the controllably conductive device to become conductive when the energy storage capacitor has charged to a desired maximum value;

wherein the charging circuit is adapted to conduct the load current from the source to the load when the controllably conductive device is non-conductive, the charging circuit imposing a low voltage drop relative to the peak value of an AC voltage of the AC voltage source, such that substantially all of the AC voltage is available to the load during the time when the controllably conductive device is non-conductive.

**2.** The power supply of claim **1**, wherein the controllably conductive device comprises a bidirectional semiconductor switch.

**3.** The power supply of claim **2**, wherein the bidirectional semiconductor switch comprises a triac.

**4.** The power supply of claim **1**, wherein the desired maximum value of the DC voltage is approximately 5.1 volts.

**5.** The power supply of claim **4**, wherein a break-over voltage of the triggering circuit is approximately 6.3 V.

**6.** The power supply of claim **1**, wherein the low voltage drop of the charging circuit is approximately 6.3 volts or less.

**7.** The power supply of claim **1**, wherein the charging circuit comprises a rectifier bridge coupled in parallel electrical connection with the controllably conductive device, the rectifier having DC terminals coupled to the energy storage capacitor such that the DC voltage is produced across the capacitor, the rectifier bridge and the energy storage capacitor

adapted to conduct the load current when the controllably conductive device is non-conductive.

**8.** A power supply disposed in series with an AC load for charging an energy storage device from an AC voltage of an AC supply, the power supply comprising:

a controllably conductive device adapted to carry a load current from the AC supply to the load when the controllably conductive device is conductive;

a triggering circuit for causing the controllably conductive device to become conductive; and

a charging circuit for charging the energy storage device when the controllably conductive device is non-conductive, a voltage of approximately 6.3 V or less generated across the charging circuit when the controllably conductive device is non-conductive;

wherein the triggering circuit is operable to cause the controllably conductive device to become conductive when the energy storage device has charged to a predetermined amount of energy.

**9.** The power supply of claim **8**, wherein the energy storage device comprises a storage capacitor and a DC voltage is generated across the energy storage capacitor.

**10.** The power supply of claim **9**, wherein the DC voltage has a maximum value of approximately 5.1 volts.

**11.** The power supply of claim **8**, wherein a break-over voltage of the triggering circuit is approximately 6.3V.

**12.** A power supply adapted to be disposed in series electrical connection between an AC voltage source and an electrical load for generating a DC voltage, the power supply comprising:

a triac adapted to be coupled in series electrical connection between the source and the load and having a gate for rendering the triac conductive, the triac adapted to carry a load current from the source to the load when the triac is conductive;

a triggering circuit coupled to the gate of the triac for causing the triac to become conductive;

a rectifier bridge coupled in parallel electrical connection with the triac and having DC terminals, the rectifier bridge adapted to conduct the load current when the triac is non-conductive; and

an energy storage capacitor coupled to the DC terminals of the rectifier bridge, such that the DC voltage is generated across the energy storage capacitor, the energy storage capacitor adapted to conduct the load current through the rectifier bridge when the controllably conductive device is non-conductive;

wherein the triggering circuit causes the triac to become conductive when the energy storage capacitor has charged to a desired maximum voltage.

**13.** The power supply of claim **12**, further comprising:

a limiting resistor coupled in series with the rectifier bridge, the series-combination of the rectifier bridge and the limiting resistor adapted to be coupled in series between the source and the load, the limiting resistor adapted to limit the magnitude of the load current through the rectifier bridge.

**14.** A power supply adapted to be disposed in series electrical connection between an AC voltage source and an electrical load for generating a DC voltage, the power supply comprising:

a triac adapted to be coupled in series electrical connection between the source and the load and having a gate for rendering the triac conductive, the triac adapted to carry a load current from the source to the load when the triac is conductive;

## 11

a triggering circuit coupled to the gate of the triac for causing the triac to become conductive;

a rectifier bridge coupled in parallel electrical connection with the triac and having DC terminals, the rectifier bridge adapted to conduct the load current when the triac is non-conductive; and

an energy storage capacitor coupled to the DC terminals of the rectifier bridge, such that the DC voltage is generated across the energy storage capacitor, the energy storage capacitor adapted to conduct the load current through the rectifier bridge when the controllably conductive device is non-conductive;

wherein the triggering circuit causes the triac to become conductive when the energy storage capacitor has charged to a desired maximum voltage

further comprising:

a limiting resistor coupled in series with the rectifier bridge, the series-combination of the rectifier bridge and the limiting resistor adapted to be coupled in series between the source and the load, the limiting resistor adapted to limit the magnitude of the load current through the rectifier bridge,

further comprising:

a firing capacitor coupled to the junction of the limiting resistor and the rectifier bridge, such that the series-

## 12

combination of the limiting resistor and the firing capacitor are coupled in parallel with the triac;

wherein the triggering circuit is coupled between the control input of the triac and the junction of the limiting resistor and the firing capacitor, the triggering circuit operable to conduct current to and from the gate of the triac when a voltage across the firing capacitor exceeds a break-over voltage of the triggering circuit.

**15.** The power supply of claim **14**, wherein the rectifier bridge is coupled in parallel with the firing capacitor, such that the limiting capacitor, the rectifier bridge, and the energy storage capacitor conduct the load current when the triac is non-conductive.

**16.** The power supply of claim **12**, wherein the triggering circuit comprises a semiconductor triggering device.

**17.** The power supply of claim **16**, wherein the semiconductor triggering device comprises a diac coupled in series with the gate of the triac.

**18.** The power supply of claim **16**, wherein the triggering circuit comprises a zener diode and two semiconductor switches coupled such that a pulse of current is conducted through the gate of the triac when the voltage across the zener diode exceeds a break-over voltage of the zener diode.

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