Title: SWITCH-MODE POWER SUPPLY WITH AUTONOMOUS PRIMARY INVERTER

Abstract: A switching power supply is provided in two stages with the primary of the power transformer (18) being in the first stage and the secondary in the second stage. The first stage (Stage 1) includes an EMI filter (12) connected to the input of a rectifier (14). The output of the rectifier is connected to a self-oscillating, half-bridge, resonant inverter (16) operating in open loop with the primary of the transformer (18) to provide isolation from the power source (10). Feed-forward control is used to compensate for line variations, providing very small output voltage variation compared with input voltage variation. In the second stage (Stage 2), the secondary of the transformer (18) provides an input to post regulator circuitry (20) including a PWM control circuit (34) to regulate the output current using the error signal representing the differences between the current sensed and the desired value.
Switch-mode power supply with autonomous primary inverter

**Technical Field**

This invention relates generally to switching power supplies and, more particularly, to two-stage switching converters with transformer separation. One area in which the invention finds particular utility is in connection with high end battery chargers.

**Background Technology**

The increasing demand for size reduction of virtually all electronic appliances is difficult to meet with presently available switching power supplies. Several features inherent in devices of relevant technology militate against achievement of the desired goal. For example, the whole converter must typically be designed to handle a relatively wide range of input voltage, resulting in low efficiency. Moreover, reducing the size of magnetic and filtering elements requires high switching frequencies, with concomitant high converter losses. High losses are inherent for high frequency operation due to the necessity of dissipating the energy stored in the leakage inductance of the transformer to avoid large voltage spikes across the main transistor. Also, implementation of isolation of the feedback signal is costly and bulky, and the whole converter has to be redesigned if there are changes in the load voltage requirements.

Switching power supplies presently employed in high end battery chargers typically use a single stage off-line converter 1, most commonly a flyback converter.

Rectified and filtered line voltage $V_M$ is applied to the converter which provides isolation from the mains and regulates the output voltage $V_R$. To regulate the charging current $I_{CH}$ the converter needs a feedback signal from the output. The feedback is normally provided by an optocoupler 2 which passes the signal to the control 3 and which provides isolation. A typical circuit is depicted in FIG. 1. The present invention is directed to overcoming one or more of the problems or disadvantages associated with the present state of the art.

**Summary of the Invention**

It is inter alia an object of the invention to provide a power supply with the following features and advantages:

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1. Compensation for variations in input voltage is effected in two different stages of the circuit, permitting design of each part for a smaller regulation range, resulting in more efficient circuits. In this way the output is stabilized against variations in the input voltage.

2. The reduced regulation range in each stage also results in reduced voltage and current stress in the components, permitting the use of lower cost components to provide the same performance.

3. Changes in load voltage requirements can be accommodated with redesign of only the second stage.

4. Output regulation is performed in the second stage, which is isolated from the mains, whereby no isolation of the feedback signal is required.

To this end the invention provides a two-stage switching power supply as claimed in claim 1. Advantageous embodiments are defined in the dependent claims.

In an embodiment in accordance with the invention efficiency is further enhanced by utilizing the secondary converters as a synchronous rectifier with less losses of the diode used in conventional relevant technology.

The first stage, in a preferred embodiment, is a half-bridge, resonant, self-oscillating circuit, operating with zero voltage switching (ZVS) with much lower switching losses, recovery of the leakage energy, and clamping of the voltage of the switches to the voltage after the line rectifier.

**Brief Description of the Drawings**

FIG. 1, as previously mentioned, is a schematic of a typical switching power supply presently used in high end battery chargers;

FIG. 2 is a block diagram of the present invention;

FIG. 3 is an electrical schematic of a preferred embodiment of a portion of the first stage of block diagram of FIG. 2;

FIG. 4 is a graphical representation of voltage and current waveforms associated with operation of the invention;

FIG. 5 is an electrical schematic of a preferred embodiment of another portion of the first stage of the circuit; and

FIG. 6 is an electrical schematic of a preferred embodiment of the second stage of the circuit of the invention.
Best Mode for Carrying Out the Invention

The switching power supply of the invention comprises a first stage and a second stage, denoted in the block diagram of FIG. 2 as S1 and S2. In the first stage S1, power supplied from a conventional AC power source 10 is delivered through a common EMI (electromagnetic interference) filter represented by box 12. Filter 12 is connected to rectifier 14, the output of which is connected to a self oscillating, half-bridge, resonant inverter 16 operating in open loop with transformer 18 in the output to provide isolation from power source 10. Feed-forward control is used, as disclosed later in more detail, to compensate for line variations. The feed-forward control will provide very small output voltage variation compared with input voltage variation. In the second stage S2, the secondary of transformer 18 provides an input to post regulator circuitry 20, a preferred embodiment of which is discussed hereinafter, the output of which is connected across load 22, depicted as a battery receiving a charge from the switching power supply of the invention. Regulator 20 is connected to the positive side of load 22 through an additional winding of the transformer, indicated by box 24, and capacitor C1 is connected in parallel with load 22.

A preferred embodiment of portions of Stage 1 is depicted in the schematic diagram of FIG. 3. Half bridge 16 includes a pair of solid state switching devices, shown in FIG. 3 in the form of MOSFETs Q1 and Q2, operating in a complementary manner. The circuit self-oscillation is effected by generating gate signals for MOSFETs Q1 and Q2 utilizing a square wave current source 26. The gates of the MOSFETs are the control inputs of the MOSFETs. The sinusoidal inductor current is sensed with a current transformer with three secondaries S1, S2 and S3. Secondaries S1 and S2 drive the gates of power MOSFETs Q1 and Q2, respectively, and the third secondary S3 supplies the control signal to current source 26.

Operating without regulation, the change of polarity of the gate voltage for MOSFETs Q1 and Q2 occurs when the magnetizing current, indicated in FIG. 4 by triangular wave 28, is equal to the resonant inductor current, indicated by sinusoidal wave 30. Thus, the voltage supplied by the half bridge is the square wave denoted by reference numeral 32. The conditions for oscillation are described in "Self-Oscillating Electronic Ballast Analysis via Relay Systems Approach," C. Chang and G. Bruning, APEC 1999 and "Analysis of the Self-Oscillating Series Resonant Inverter for Electronic Ballasts," C. Chang and G. Bruning, IEEE Transactions On Power Electronics, vol. 14, no. 3, May 1999, pp. 533-540.
Figure 5 is an electrical schematic of a preferred embodiment of the current source to generate the current applied to the control winding of the current transformer. The generated current is a triangular waveform synchronous with the resonant current and has an amplitude proportional to the input voltage. A simple RC filter converts the square waveform of the voltage at the mid-point of the half bridge to a triangular waveform without DC component. The amplitude of the waveform is proportional to the input voltage. The generated triangular waveform is used to drive the base of a bipolar transistor to generate a proportional current. Since the bipolar transistor is a unidirectional device, one transistor is required for the positive part of the waveform and another for the negative part. Some distortion is expected around the crossover point, but it has no significant effect on circuit operation because the phase shift between current and voltage at the input of the resonant tank is controlled by the value of the peak current. The waveforms look the same as in Fig. 4, but in this case the triangular waveform is generated from the bridge voltage and its amplitude is proportional to the input voltage.

The preferred embodiment of Stage 2, a converter which uses the voltage at the secondary of the power transformer of the inverter stage, is shown in Fig. 6. A conventional full wave rectifier, or a version with synchronous rectifiers, cannot provide control of the current delivered to the load. The two MOSFETs Q5 and Q6 act as synchronous rectifiers, but their orientation ensures that the internal body diodes will not conduct when the channel is turned off. The conduction time can be controlled to regulate the average output current. PWM control circuit 34 provides control of the gate voltages to regulate the output current using the error signal representing the difference between the current sensed via a Resistor R_{sense} and the desired value, determined by a reference voltage V_{ref}.

Functional Description

From the foregoing, it will be appreciated that the invention provides a novel and improved switching power supply operating in two stages. The first stage comprises a self oscillating, half-bridge, resonant inverter operating in open loop with a transformer in the output to provide isolation from the utility line. Feed-forward control is used to compensate for line variations. The feed-forward control will provide very small output voltage variations relative to input voltage variation. The second stage comprises a converter for load regulation which can be optimized for a very small input voltage variation because the input voltage variation is already eliminated, or at least greatly reduced by the operation of
the inverter. This is very advantageous in terms of size reduction and efficiency, particularly for universal input line chargers.

It is important to note that each of the two stages can be used independently for different applications. For example, the disclosed embodiment of the inverter of Stage 1 could be used to drive a lamp in a ballast application as well as for driving the post-regulator disclosed for battery charging. In the disclosed system the limited input range permits the magnetics and filtering elements of the post-regulators to be optimized for cost and size improvements. Isolation of the feedback signal is no longer needed because the converter providing the output regulation does not need to be isolated. Moreover, the proposed system allows modularity of design. That is, different load regulation converters in the secondary can be used with the same self-oscillating half bridge and transformer, eliminating the need to redesign the entire converter. Also, more than one module could be used if several output are required. It should also be noted that power source 10 need not necessarily be an AC source, but may be a solar or other DC source.

Other aspects and features of the present invention can be obtained from a study of the drawings, the disclosure, and the appended claims.
CLAIMS:

1. A two-stage switching power supply for connecting a power source (10) to a load (22), said power supply comprising:
   a) a first stage (S1) including:
      i) an input circuit (11) receiving power from said power source (10) and having an output;
      ii) a self oscillating, half-bridge, resonant inverter (16) connected to said output; and
      iii) a primary side of a transformer (18), said inverter operating in open loop with said primary side, the transformer providing isolation from said power source (10); and
   b) a second stage (S2) including:
      i) the secondary side of said transformer (18); and
      ii) post regulator circuitry (20) connected to said secondary side and having an output connected across said load (22).

2. The switching power supply of claim 1 wherein said power source (10) is an AC power source and the input circuit (11) comprises a rectifier (14).

3. The switching power supply of claim 1 wherein said power source (10) is an AC power source and the input circuit (11) is a rectifier (14).

4. The switching power supply of claim 2 wherein said load (22) is a battery receiving a charge from said AC source (10) through said power supply.

5. The switching power supply of claim 2 wherein said input circuit (11) further comprises an EMI filter having an input connected to said AC source (10) and an output connected to said rectifier (14).
6. The switching power supply of claim 2 wherein said resonant inverter (16) comprises a first pair of solid state devices (Q1,Q2), each having a control input, and said first stage (S1) further comprises a square wave current source (26) providing control input signals to said first pair of devices (Q1,Q2) to effect self oscillation of said inverter (16).

7. The switching power supply of claim 6 wherein said first pair of solid state devices (Q1,Q2) are MOSFETs operating in a complementary manner.

8. The switching power supply of claim 6 wherein said inverter (16) further comprises a current transformer having first (51), second (52), and third (53) secondaries, said first and second secondaries being respectively connected to drive said control inputs of said first pair of devices (Q1,Q2), and said third secondary (53) being connected to said square wave current source (26) to provide a control signal thereto.

9. The switching power supply of claim 8 wherein said current transformer further includes a control winding and a current generating source (Fig. 5) which generates a current having a triangular waveform connected to said control winding.

10. The switching power supply of claim 9 wherein said waveform is synchronous with the resonant current and has an amplitude proportional to input voltage.

11. The switching power supply of claim 9 and further comprising an RC filter converting the square waveform of the voltage at the mid-point of said half bridge to a triangular waveform without DC component.

12. The switching power supply of claim 2 wherein said post regulator circuitry (20) comprises a converter connected to said transformer (18) secondary.

13. The switching power supply of claim 12 wherein said converter comprises a second pair of solid state devices (Q5,Q6), each having a control input, acting as a synchronous rectifier oriented for non-conduction when the respective channel is turned off.

14. The switching power supply of claim 13 wherein said second stage (S2) further comprises a PWM control circuit (34) providing control of the control input voltages
of said second pair of solid state devices (Q5, Q6) to regulate the output current using the error signal representing the differences between the current sensed and the desired value.

15. The switching power supply of claim 13 or 14 wherein said second pair of devices (Q5, Q6) are MOSFETs.

16. The switching power supply of claim 14 wherein said load (22) is a battery receiving a charge from said AC source (10) through said power supply.

17. The switching power supply of claim 1 wherein the power source (10) is a source of electrical power, and wherein the input circuit (11) connects the said power source (10) to said inverter (16).

18. The switching power supply of claim 2 or 17 wherein feed-forward control is used in said first stage (S1) to compensate for input line variations.

19. The switching power supply of claim 17 wherein said inverter (16) comprises the first pair of solid state devices (Q1, Q2), each having a control input, and said first stage (S1) further comprises a square wave current source (26) providing control input signals to said devices to effect self oscillation of said inverter.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IP C 7 HO2M3/338 HO2J7/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
IP C 7 HO2M HO2J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
WPI Data, PAJ, EPO-Internal, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<td>X</td>
<td>US 5 923 544 A (URANO TAKASHI) 13 July 1999 (1999-07-13) column 1, paragraph 1</td>
<td>1-4,7,17</td>
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<td>column 6, line 8 - column 7, line 14 column 8, line 4 - line 7 figure 3</td>
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Patent family members are listed in annex.

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Date of the actual completion of the international search: 11 July 2002
Date of mailing of the international search report: 31/07/2002

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Form PCT/ISA/210 (second sheet) July 1992

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