US006344986B1

(12) United States Patent
Jain et al.

(10) **Patent No.: US 6,344,986 B1**
(45) **Date of Patent: Feb. 5, 2002**

(54) **TOPOLOGY AND CONTROL METHOD FOR POWER FACTOR CORRECTION**

(75) Inventors: **Praveen K. Jain**; **Yan-Fei Liu**, both of Kanata (CA)

(73) Assignee: **Astec International Limited** (HK)

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

(21) Appl. No.: **09/595,425**

(22) Filed: **Jun. 15, 2000**

(51) **Int. Cl.**[7] **H02M 5/42**; H02M 3/335
(52) **U.S. Cl.** **363/89**; 363/21.12
(58) **Field of Search** 363/16, 20, 21.01, 363/21.12, 21.14, 21.18, 84, 89, 95, 97, 131

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,434,767 A	*	7/1995	Bataeseh et al.		363/16
5,515,257 A	*	5/1996	Ishii		363/21
5,600,549 A		2/1997	Cross		
5,734,562 A		3/1998	Redl		
6,031,748 A	*	2/2000	Hong		363/89

OTHER PUBLICATIONS

Hewlett Packard 6th Annual Power Systems Symposium, Feb. 26–28, 1996, Palo Alto, California, "Novel Circuits for Implementing Power Factor Correction in Off–Line Power Converters", 10 pages.

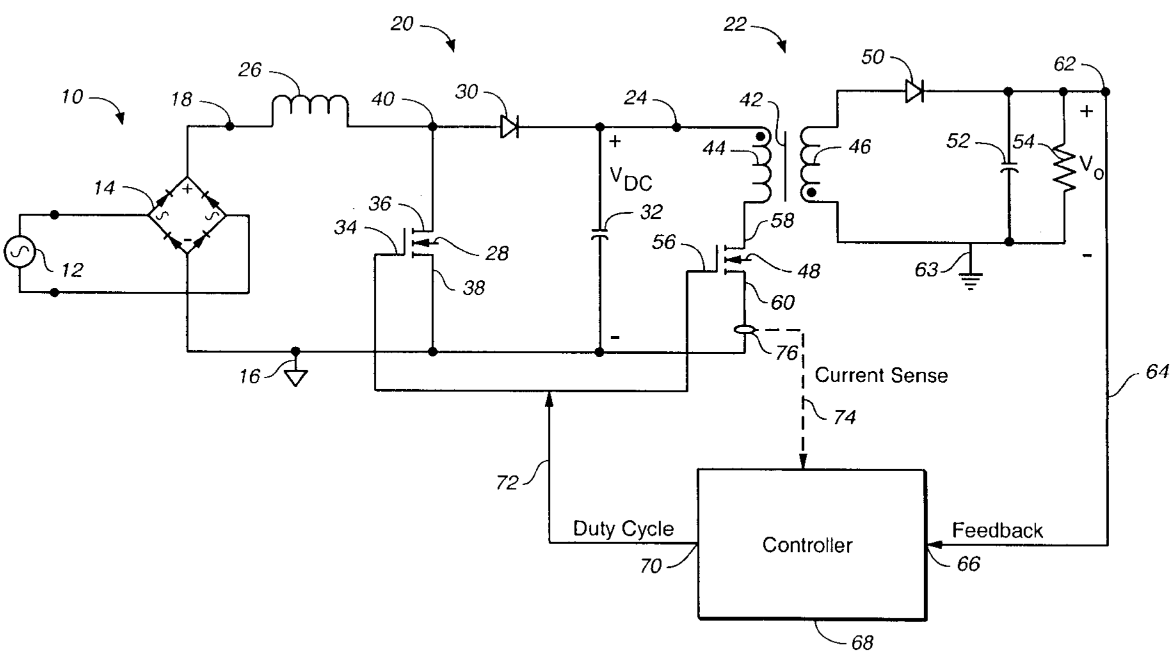
* cited by examiner

Primary Examiner—Matthew Nguyen
(74) *Attorney, Agent, or Firm*—Coudert Brothers LLP

(57) **ABSTRACT**

In a power factor corrected AC-to-DC power supply system, a DC-to-DC power converter is coupled to the output of an AC-to-DC power converter in order to produce a regulated DC output signal from a rectified AC input signal. The AC-to-DC power converter and the DC-to-DC power converter each includes a switch for controlling the operation of their respective power converter. The AC-to-DC converter includes an inductor. The system provides power factor correction for minimizing harmonic distortion by including a controller that receives the regulated DC output voltage as a feedback signal, and in response, produces a series of drive pulses having predetermined constant duty cycle. These pulses are simultaneously fed to each switch, to operate the respective converters alternately between ON and OFF states. When the AC-to-DC converter is driven by a fixed duty cycle of the series of pulses, power factor correction is improved since the current flowing through the inductor is substantially proportional to the waveform of the rectified AC input signal. By preselecting the value of the inductor, the AC-to-DC converter is operable in a discontinuous mode when the instantaneous rectified AC input signal is low and in a continuous mode when the instantaneous rectified AC input signal is high.

22 Claims, 2 Drawing Sheets



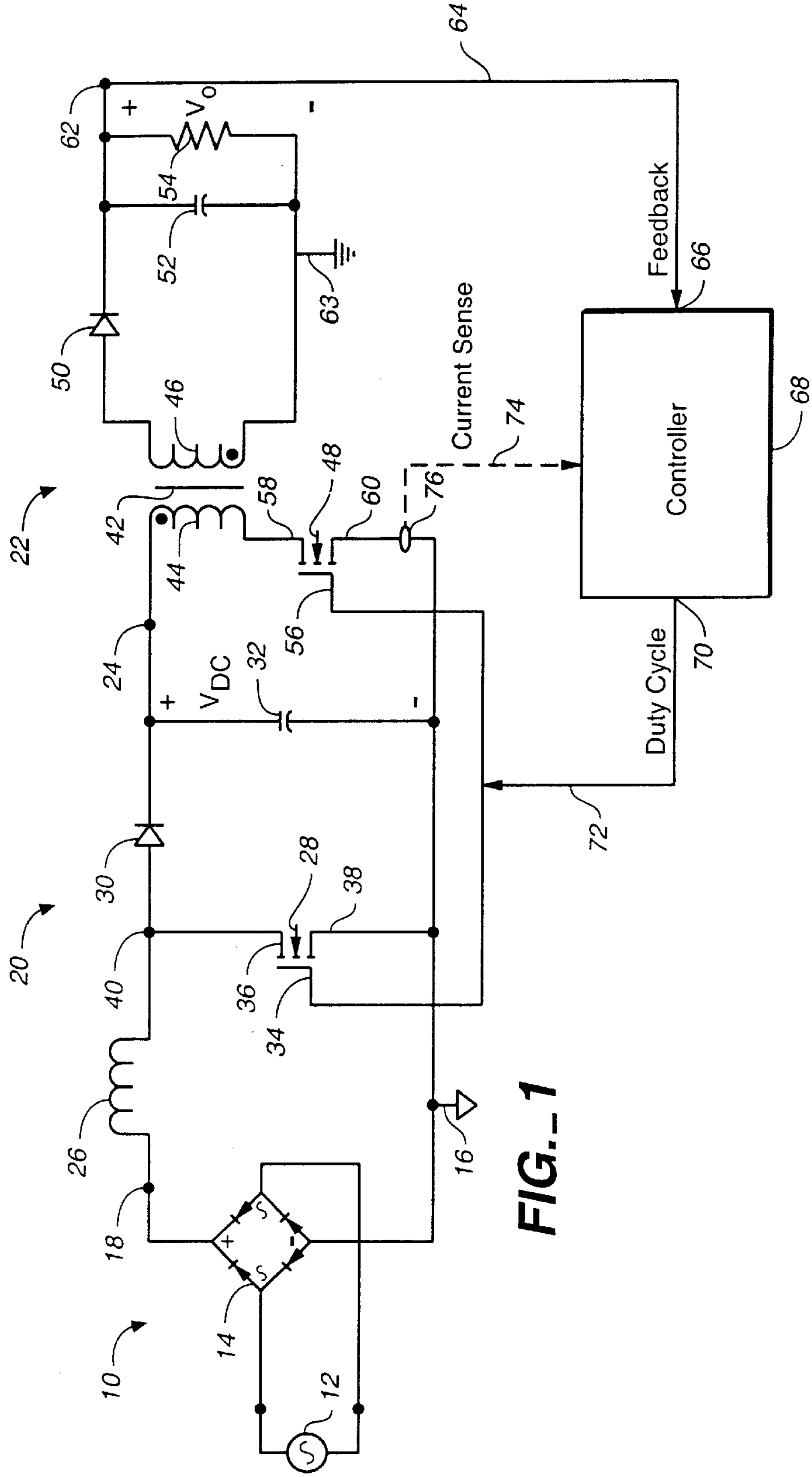

Feedback
Current Sense
Controller
Duty Cycle
V_O
V_{DC}
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
62
63
64
66
68
70
72
74
76

FIG._1

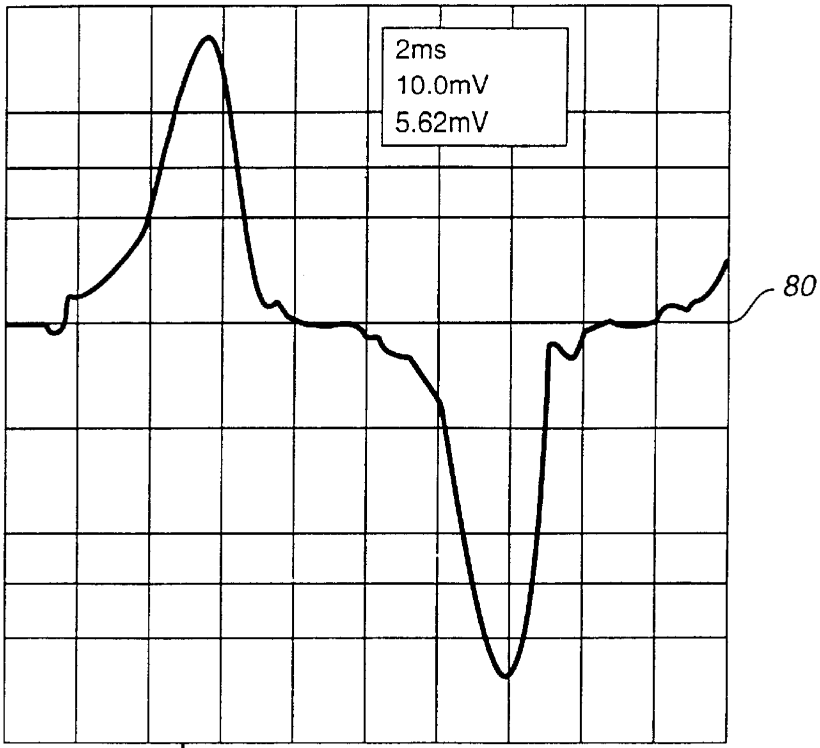


FIG._2

Harmonic Component	1st	3rd	5th	7th	9th	11th	13th
Input Current (amps)	0.9317	0.358	0.132	0.080	0.055	0.050	0.038
Current (amps) IEC-1000-3-2	No Limit	0.686	0.383	0.202	0.101	0.071	0.060

FIG._3

	New Circuit based on This Invention	Non PFC Circuit	Two Stage PFC Circuit
Power Factor	91.9%	70%	99%
EMI	-39.6dbm(max)	-48dbm(max)	-31.8dbm(max)
Efficiency	77.5%	78.5%	72.7%

FIG._4

TOPOLOGY AND CONTROL METHOD FOR POWER FACTOR CORRECTION

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to switching power supplies, and more particularly, to an AC-to-DC power factor correcting power converter comprising a boost power converter coupled to a DC-to-DC power converter where both converters are driven by the same signal derived from the output voltage of the power converter.

2. Description of the Prior Art

Many electronic devices, such as computers and many household appliances, require one or more regulated DC voltages. The power for such electronic devices is ordinarily supplied by power converters that convert an AC line voltage into the regulated DC voltages required by the devices.

Electrical power converters commonly include a rectifier circuit which converts the AC line voltage to an unregulated DC voltage, also known as a rectified line voltage, and a DC-to-DC converter for converting this unregulated DC voltage into one or more regulated DC output voltages. If a simple rectifier circuit is used, such power converters commonly draw high currents near the peak of the AC voltage cycle, and substantially zero current around the zero-crossing points of the voltage cycle. Thus, the input current drawn by the converter has a highly non-sinusoidal waveform with correspondingly high harmonic content.

As is known in the electrical power art, current harmonics above the fundamental frequency of the voltage do not contribute to the power drawn from a typical AC voltage source, with the result that the actual or true power drawn by the power supply is lower than the apparent power drawn.

The distinction between apparent power and true power is important because power supplies are rated according to the apparent power drawn rather than the true power drawn. As a basis of comparison, the true power and apparent power drawn by a device are divided to form a ratio called the "power factor." Power factors less than about 80 percent can pose barriers to the performance or improvement of many types of electronic devices that operate on direct current, including such devices as personal computers, minicomputers, and appliances using microprocessors. For example, the high current peaks associated with lower power factors can cause circuit breakers on the AC line to trip, which limits system design in terms of the functional load it places on the AC line. Additionally, the harmonics associated with the high, non-sinusoidal current peaks often result in power-line distortion, noise, and electromagnetic interference (EMI). In general, improving the power factor of the device reduces the harmonic content and electromagnetic noise.

To address these problems, many power supplies include power factor correction circuitry that is designed to raise power factors and eliminate harmonic distortion. Such circuits are often referred to as power factor correction circuits (abbreviated "PFC"). Power factor correction circuits generally rectify the AC line voltage and produce an unregulated DC voltage (referred to herein as the "PFC voltage") in a manner that has a relatively high power factor within a given range of AC line voltages. A switching power converter then converts the PFC voltage into the required regulated voltages.

The International Electrotechnical Commission (IEC) has set standards specifying certain requirements for AC-to-DC power converters. Specifically, the IEC-1000-3-2 standard requires that the harmonic components of the input current be below a certain level. Accordingly, it is desirable to provide power factor correction for AC-to-DC power converters in order to achieve a low input current harmonic content in the AC supply, and, equivalently, a higher power factor.

One known embodiment for providing power factor correction involves using an AC-to-DC converter followed by a DC-to-DC converter where the former is a boost converter and the latter is a flyback converter. In order to provide power factor correction with this topology, the drive signal of the boost converter must be controlled to force the current flowing through the inductor in the boost converter to follow the sinusoidal waveform of the rectified input AC signal. However, conventional control techniques used to achieve this result suffer from a number of drawbacks. The predominant drawback is that a complex control circuit is needed, as well as bulky and heavy filter components to filter ripple current and to meet the EMI specification of the power supply. The result is a high cost control circuitry and the need to use more printed circuit board (PCB) space, which in turn contributes to higher fabrication costs. The overall size of the AC-DC converter is also increased.

A conventional boost converter generally comprises an inductor which is coupled between a source of AC power (e.g., a rectifier producing an unregulated AC voltage) and a switch. The switch is preferably a MOSFET transistor, which is in turn coupled in parallel with a series combination of a rectifier and an output filter capacitor across which the load is connected. The output capacitor is selected to be large in order to ensure that the load receives a substantially constant DC voltage. This constant DC signal appears across the load and is greater than the peak sinusoidal value of the input AC voltage.

One well known control method for providing power factor correction in a boost converter is to set the duration of the ON state (e.g., a time T_{on} out of a period T) of the FET switch to a constant value. The constant duration of T_{on} is predetermined by certain operating conditions, such as the input voltage, output voltage and output current of the boost converter. Energy is stored in the boost converter's inductor during this time T_{on}. Additionally, certain circuit parameters, such as the value of the boost inductor, affects the duration of T_{on}. When the FET switch is switched to its OFF state for a certain time period (e.g., T_{off}), the polarity across the inductor reverses so that the energy that was stored in the inductor during T_{on} is transferred via the diode to the output capacitor. A constant DC voltage, V_{DC}, appears across the capacitor and has the following relationship with respect to the rectified input AC voltage:

$$V_{DC} = \frac{V_{in}}{1 - T_{on}/T} \tag{1}$$

While this control method ensures that the boost converter operates at the boundary of continuous and discontinuous modes of operation, it suffers from three drawbacks. First, because the duration of T_{on} is fixed, the ripple current passing through the inductor is large. Accordingly, a bulky and heavy Electromagnetic Interference (EMI) filter is required to filter out this ripple current in order to meet the EMI specification of the power supply. Second, the switching frequency of the transistor in the boost converter must be varied in order to regulate the constant DC voltage V_{DC}. Such variable switching frequency control is usually undesirable for applications involving telecommunications because of possible interference. Third, because the control chip and accompanying current sensing circuit are necessary in order to provide power factor correction, the inclusion of these components occupies a significant portion of the PCB area and results in increased size and cost of the power supply.

Another well known control method for providing power factor conversion in a boost converter and for producing a constant DC voltage that is substantially free from distortion is conventionally known as the average current mode control method. With this technique, the boost converter operates in a continuous conduction mode. In particular, to obtain a high power factor, the average value of the current passing through the inductor in the boost converter is sensed and forced to follow in phase the rectified sinusoidal waveform of the input AC voltage V_{in}. In this control method, a multiplier is needed to generate the reference current for the boost inductor current. The average value of the boost inductor current must be sensed to achieve average current control.

A key drawback of the average current control method is the high cost of the control circuit.

What is needed is improved power factor correction in a power converter whereby the boost and DC-DC converters are driven with a control method that overcomes the above described drawbacks.

SUMMARY OF THE INVENTION

The present invention is directed to a power supply system having power factor correction. The system includes an input rectifier for generating a rectified input AC voltage from an AC power source for two stages of power conversion. The first stage is a boost converter. It is coupled to the input rectifier and converts the rectified input AC voltage into a substantially constant first DC voltage. The boost converter includes a first switch. The second stage converter is a DC-to-DC converter and is coupled to the output of said boost converter. The second converter converts the first DC voltage to a second voltage, the output voltage of the power supply system. The second converter regulates the output voltage to a desired level. The second converter includes a second switch. The power supply system also includes a controller for providing feedback control as a function of the output voltage, said controller generating a drive signal for said first and second switches so as to cause said switches to be switched on and off simultaneously.

Accordingly, it is an object of the present invention to provide a power supply system for providing power factor correction in a cost efficient manner. Cost efficiency of power factor conversion is achieved because the present invention does not require current sensing circuitry to sense the boost converter's inductor current, nor the corresponding additional control circuitry for the boost converter as required in the prior art. PCB space is also reduced.

It is another object of the present invention to reduce EMI by fixing the switching frequency of the controller's drive signal at a constant value. By maintaining a constant frequency, the low frequency ripple component appearing at the output voltage is substantially reduced. This is essential for power supplies used with applications involving telecommunications where the level of C-message noise must be very low. Additionally, the current ripple of the boost inductor is small with the present invention. This is advantageous because less EMI filtering is required to meet the above-mentioned IEC standard.

Because only one feedback control loop is required in the present invention to operate the switches within the power converters of the power supply system, the circuitry is simplified. Moreover, the response of the power supply system output voltage is fast because the feedback loop can be selected to have a wide bandwidth.

Additionally, because a regulated output voltage may be obtained for a universal input voltage range (e.g., $86V_{RMS}$ to $265V_{RMS}$), an auto range circuit is not required.

These and other objects of the present invention will become apparent to those skilled in the art from the following detailed description of the invention and preferred embodiments, the accompanying drawings, and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a circuit diagram of a preferred embodiment of a power supply system according to the present invention that includes power factor correction.

FIG. **2** is a graphical representation of the input current waveform as a function of time for the DC-to-DC converter used in the present invention depicted in FIG. **1**.

FIG. **3** is a table listing measured harmonic components of the input current of the present invention as compared to the IEC standard values.

FIG. **4** is a table comparing the power factor and efficiency obtained by the system according to the present invention as compared to a converter that does not have power factor correction and a prior art two stage converter having power factor correction.

DESCRIPTION OF A PREFERRED EMBODIMENT

The present invention recognizes that prior art AC-to-DC power supplies having power factor correction require current sensing and signal comparison circuitry in order for the current in the boost converter to be substantially proportional to the input AC voltage. A separate control circuit is required for a second DC-DC converter such as a flyback converter, that provides DC regulation for the output voltage. This results in circuit complexity. By providing a means to obtain power factor correction, yet without such additional circuitry, the AC-to-DC power supply system according to the present invention provides power conversion with power factor correction that is accomplished more cost-effectively and efficiently. This is accomplished by providing a feedback control to simultaneously drive the power switches of the boost and flyback converters. In addition, the boost converter's inductor is selected to provide inductor current that is discontinuous when the instantaneous rectified AC input voltage is low and continuous when the instantaneous rectified AC input voltage is high.

The power supply system of the present invention produces a regulated DC output voltage. FIG. **1** depicts a preferred embodiment of an AC-to-DC power supply system **10**. An AC power source **12** is coupled to a rectifier **14** in power supply system **10**. Power source **12** comprises a sinusoidal voltage waveform. Rectifier **14** as shown is typically a diode bridge circuit; however, one of ordinary skill in the art will appreciate that other embodiments for providing rectification of sinusoidal waveforms originating from an AC power source may be substituted. Both the power source **12** and rectifier **14** are preferably connected to a common ground **16**. The rectifier **14** provides a rectified AC input voltage measured across from node **18** to ground

DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.

WHAT WILL YOU BUILD? | **sales@docketalarm.com** | **1-866-77-FASTCASE**

fastcase®
Smarter legal research.