AC-DC Converter with Power Factor Correction (PFC).

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One-stage power factor correction (PFC) with output electrical isolation. Two types of PFC converters are proposed here: 1) Multi stage capacitive-switching network low voltage PFC converter and 2) two-switch soft switching PFC converters. This resulted in a near unity power factor AC-DC converter with low voltage output. The second converter uses the power switch in combination with a grounded auxiliary switch to produce soft-switching converter to operate in high switching frequencies. Due to its simplified power stage and control circuit, this converter presents a variety of benefits including better efficiency (87%), lower cost, higher reliability, increased operating frequencies into the hundreds of kilo-hertz range and low operating voltages of less than 5 volts. With PSPICE simulation and experimental results, a measured power factor of 0.99 was obtained by the single switch converter.
Fig. 13 (a)

Fig. 13 (b)
Fig. 14 (a)

![Graph showing power factor vs. line voltage with different load powers (Po=50W, Po=75W, Po=100W).]

Fig. 14 (b)

![Graph showing efficiency vs. line voltage with different load powers (Po=50W, Po=75W, Po=100W).]
Fig. 15

Full Bridge Rectifier

Line Voltage

Line Filter

$C_{sl} = C_{s2}$

$L_{k1} = L_{k2}$
Fig. 16

\[ V_{Sw} \uparrow \downarrow 2V_{cs} \]

\[ V_{Cra} = \frac{2V_{cs}/((Z1)(1+kc)^{0.5})}{2V_{cs}/kc} \]

\[ i_{Li} = \frac{(V_{cs}-(V_{o}/n))DTs/nLra}{\text{VinDTs/Li}} \]

\[ i_{Do} = \frac{(V_{cs}-(V_{o}/n))DTs/Lra}{t_0 \rightarrow t_0 + Ts} \]
AC/DC CONVERTER WITH POWER FACTOR CORRECTION (PFC)

This invention relates to AC to DC converters and claims the benefit of priority to U.S. Provisional Patent Application No. 60/176,608 titled “IMPROVED AC/DC CONVERTER WITH POWER FACTOR CORRECTION” filed Jan. 18, 2000 and is funded in part by NASA STTR Contract No.: NAS 10-98064.

BACKGROUND AND PRIOR ART

Conventional single-phase rectifier power electronic circuits suffer from high total harmonic distortion (THD) and poor power factor. A number of regulations have been enacted recently to control the harmonic content of line current drawn by the electronic equipment. As a result, researchers have been actively seeking development of power supplies, which can comply with those regulations. In recent years, many circuits and control methods were reported, in which high-frequency switching techniques were used to shape the input current waveform which becomes dominate in power factor correction (PFC). See for example: A. Prasada, P. D. Ziqog and S. Manias, “A Novel Passing Waveshaping Method for Single-Phase Diode Rectifiers.” PESC’89. pp. 99–105; L. Barbi and S. A. Oliveira da Silva, “Sinusoidal Line Current Rectification at Unity Power Factor with Boost Quasi-resonant Converters.” In Proceedings of IEEE-APEC’90, pp. 553–562; and, P. Kornetzky, H. Wei and L. Batarseh, “A Novel One-Stage Power Factor Correction Converter,” IEEE APEC’97 Proc., pp. 251–258.

The implementation of high frequency techniques can be classified into two categories, i.e. two-stage scheme and one-stage scheme. In a two-stage scheme, an ac/dc converter with power factor correction is connected to the line followed by a dc/dc converter. These two power stages can be controlled separately, and thus it makes both converters possible to be optimized. The drawbacks of this scheme is lower efficiency due to twice processing of the input power, larger control circuits, higher cost and low reliability.

A one-stage scheme combines the PFC circuit and power conversion circuit in one stage. Due to its simplified power stage and control circuit, this scheme is potentially more efficient. The underline strategy of this scheme is to design the circuit in a certain way that allows its PFC circuit and power conversion circuit to share the same power switch. Several PFC circuits have been reported. See for example: C. Camsem and L. Barbi, “A Unity of Power Factor Multiple Isolated Outputs Switching Mode Power Supply Using A Single Switch.” APEC’91. pp. 430–436. These circuits are especially attractive in low cost, low power applications. However, some drawbacks still exist: a) owing to improper sharing of the power switch, when the converter operates at high frequency, the unavoidable leakage inductance of their power transformers produces high voltage spike at the switching time resulting in decreased efficiency; b) because the power switch performs both PFC and regulation purposes, their regulation capabilities are limited; and, c) at high current and low duty ratio operation, a high voltage presents on the bulk capacitor, resulting in a high rating in design and hence raising the cost. Recently, several single switch converter topologies have been presented to overcome the above drawbacks. See for example: P. Kornetzky, H. Wei and L. Batarseh, “A Novel One-Stage Power Factor Correction Converter,” IEEE APEC ’97 Proc., pp. 251–258; and, Y. S. Lee, J. C. W. Sui and B. T. Lin, “Single-Stage Isolated Power-Factor-Corrected Power Supplies with Regenerative Clamping.” IEEE APEC ’97 Proc. pp. 250–265.

SUMMARY OF THE INVENTION

The first objective of the present invention is to provide a switching power supply that operates from AC line voltage having a high power factor and output isolation.

The second objective of this invention is to provide a mechanism for soft-switching to allow for a one-stage power factor correction in an AC to DC converter operating in the hundreds of kilo-hertz.

The third objective of this invention is to provide an AC to DC converter having an output transformer that allows the converter to be used for single output and multi-output applications in the low voltage range.

The fourth objective of this invention is to provide an AC to DC converter where the leakage inductance of the forward mode power transformer will not cause an additional voltage stress at the power switch so that a power switch having a lower voltage rating and less power dissipation can be used.

The preferred embodiment of the AC to DC converters with PFC according to this invention is a power supply that provides a DC power to a load from an AC source comprising: a rectifying stage for transferring electrical energy from an AC source into pulsating unipolar voltage pulses at output terminals; a boost stage having a controllable conducting means and a first unidirectional conduction means for controlling current flow from the output terminals of the rectifying stage and blocking the current flow into the opposite direction and a single controllable switching device connected across the output terminals and more than one inductive-capacitive stages preferably two connected between said boost stage and said forward stage providing an inductive energy storing circuit when said switching device is closed and a capacitive charging circuit when said switching device is open, whereby a conversion efficiency of over approximately 75% AC to DC is achieved and with output voltage of approximately five volts and lower on alternatively a power on and off switch and an on and off auxiliary switch for controlling both the PFC circuit means and the AC to DC power conversion circuit means, wherein the converter operates at a frequency of greater than about 500 kilo-hertz.

Further objects and advantages of this invention will be apparent from the following detailed description of a pres-
ently preferred embodiment, which is illustrated, schematically in the accompanying drawings.

**BRIEF DESCRIPTION OF THE FIGURES**

FIG. 1 is a schematic of the AC to DC converter disclosed and claimed in our U.S. Pat. No. 5,959,849 issued Sep. 28, 1999.

FIG. 2 is a simplified block diagram of the AC/DC low-voltage output converter.

FIG. 3 is the circuit of an AC/DC converter with four-stage switched-capacitor network.

FIG. 4 shows experimental line voltage (upper, 100V/div.) and line current (lower, 1A/div.) waveforms.

FIG. 5 shows experimental waveforms under 110VAC input and 8A output (from top, trace 1: gate signal for the power switch; trace 2: input inductor current, 2A/div.; trace 3: drain-source voltage of power switch, 400V/div.; trace 4: drain current of power switch, 4A/div.)

FIG. 6 shows measured power factor of the AC/DC converter of FIG. 3.

FIG. 7 shows measured efficiency of the AC/DC converter of FIG. 3.

FIG. 8 shows measured storage capacitor voltage comparing with calculation at \( L_s = 12 \mu F \).

FIG. 9 is a functional schematic of the soft-switching Dual Switch converter unit with PFC and soft switching.

FIG. 10 shows a soft-switching PFC converter with floating auxiliary switch.

FIG. 11 shows waveforms of the soft-switching PFC converter of FIG. 10.

FIG. 12 shows a FIG. 10 modified with voltage clamp circuitry.

FIG. 13a shows waveforms of the soft-switching PFC converter of FIG. 12 (recorded under 110VAC input and 110W output): (a) switch waveforms (top: gate signal; bottom: drain-source voltage, 100V/div.)

FIG. 13b shows waveforms of the soft-switching PFC converter of FIG. 12 (recorded under 110VAC input and 110W output): (b) line waveforms (top: line current, 1A/div.; bottom: line voltage, 100V/div.)

FIG. 14a shows measurements of the power factor for the converter of FIG. 12.

FIG. 14b shows measurements for the efficiency for the converter of FIG. 12.

FIG. 15 shows a soft-switching PFC AC/DC converter with grounded auxiliary switches.

FIG. 16 shows steady-state waveforms for the converter of FIG. 15.

**DESCRIPTION OF THE PREFERRED EMBODIMENT**

Before explaining the disclosed embodiment of the present invention in detail it is to be understood that the invention is not limited in its application to the details of the particular arrangement shown since the invention is capable of other embodiments. Also, the terminology used herein is for the purpose of description and not of limitation.

This invention relates to U.S. Pat. No. 5,959,849, issued: Sep. 28, 1999 to the same inventors and same assignee as the subject invention, which is incorporated by reference and which claims the benefit of priority to U.S. Provisional Patent Application No. 60/050,476 filed Jun. 23, 1997.

In our disclosure of the U.S. Provisional Application Serial No. 60/176,608, several novel converter topologies are set forth which are improvements over the converter topology that has been covered in our previously referenced U.S. Pat. No. 5,959,849 and set forth therein as FIG. 1. By this reference to U.S. Pat. No. 5,959,849, it is considered that its text is incorporated fully herein. FIG. 1 disclosed therein is a single-switch, 106, converter with Power Factor Correction utilizing a DCM boost circuit as the input stage to provide PFC and a forward circuit as an output staffs to provide electrical isolation. Two storage capacitors, 114 and 116, have been employed to enhance the PFC capability of the boost circuit and to relieve the voltage spike produced by the power transformer, 118. The voltages across the storage capacitors, 114 and 116, are kept at lower levels. The converter has enough line regulation capability to be applied to a universal input.

Referring to FIG. 1, converter 1 includes voltage supply VAC, 10, which can be altering voltage or current line, that provides sinusoidal voltage with rms value of approximately 120 Volts or another value with a line frequency of approximately 60 Hz. and the like. Output terminals of voltage supply 10, 10a and 10b are connected to input terminals 20a and 20b of any type of an electro magnetic interference (EMI) filter 20. EMI filter 20 includes storage devices that attenuates high transients of current passing terminals 2c and 20d on the way to the terminals 10a and 10b of the voltage supply VAC. Output terminals of EMI filter 20 and 20e are connected to the input terminals 50a and 50b of a line rectifier 50 of a conventional type such as KB106 or any other type consisting of a bridge arrangement of unidirectional conducting devices such as semiconductor diodes in a way that positive voltage of output line rectifier is delivered to terminal 50c connected to ground level 53 of boost/forward (primary) stage 53. Terminal 50c is connected to terminal 102a of an inductive device L1, 102, having a value of approximately 420 µH, and the like.

Terminal 102b is connected to terminal 104a of a unidirectional conducting device D1, 104 such as a fast acting semiconductor diode such as MUR580, and the like. Output terminal of D1, 104b is connected positive terminal 106a of a controllable switching device 106, such as a solid state switch such as power MOSFET Type IRF740 or another type of a switching device, and the like. Negative terminal of switching device 106b is connected to ground level 53. Switching device 106 switches on and off with a frequency higher than line frequency and with a ratio of an on and off time that is processed from output voltage at terminal VO, 132 with respect to output ground, 130 is kept constant within small limits. While switching device S, 106 is on, Inductive device I1, 102 receives energy from voltage supply VAC+m via EMI filter 20 and line filter 50. While switching device S 106 is off, energy stored in inductive device I1, 102 is mainly transferred to the capacitive devices CS2, 116 and CS1, 114 via the chain D1, 104, and CS2, 116 and D2, 112 and CS1 and CS2, 114 and terminal 50d and terminal 50c to terminal 102a of inductive device L1, 102. The capacitances of capacitive devices CS1, 114 and CS2, 116 have a value of approximately 820 µF that is great enough to keep the voltages VCS1 and VCS2 across capacitive devices CS1m 114 and CS2, 116 constant within small limits at a value that is always greater than peak value of voltage supply VAC.10 during normal operation. D2 is a unidirectional conducting device such as a fast acting semiconductor diode such as V336X and the like. This mode of operation is alike a boost converter and shapes the average current drawn from the power supply VAC. 10 to be of the same shape like the voltage VLine across the power supply VAC. 10. Referring to FIG. 1, forward mode transformer TR 100...
While switching device works, the value of approximately 900 µH is equal to the primary windings 110m and 118m with equal turn numbers and secondary winding 122. The turn ratio of windings 110:118:122 is approximately 1:1.04. Furthermore, leakage inductors L.1, 108 and L.2, 120, have a value of approximately 260 µH (each) and the like, in serial to primary windings 110m and 118m respectively.

Referring to FIG. 1, storage capacitors CS1, 114 and CS2, 116 are connected to the primary part of forward mode transformer TR, 100 as follows: Terminal 114a of capacitive device CS1, 114 and terminal 118c of leakage inductance L.2, 118 are connected ground 103. Terminal 114b of capacitive device CS1, 114 and terminal 112b of unidirectional conducting device are connected together with terminal 110a of primary winding 110m. Terminal 116b of capacitive device CS1, 116 and terminal 112a of unidirectional conducting device are connected together with terminal 118a of primary winding 118m. Terminal of 110c of leakage inductance L.1, is connected to terminal 116b of capacitive device CS2, 116 and to terminal 106a of switching device 106. The terminals 108b, 110g and 122a of forward mode transformer are marked with a dot. They are marked as the beginning of the windings; this means that they always have the same polarity with respect to the terminals 110b, 118b and 122b.

While switching device S, 106, is on, energy is transferred from the capacitive devices CS1, 114 and CS2, 116 to the secondary winding 122 of forward mode transformer TR, 100. While this happens part of the energy stored in the capacitive devices CS1, 114 and CS2, 116 is also stored in the leakage inductors L.2, 110 and L.2, 118 is fed back into the storage devices CS2, 116 and CS1, 114 as well as into the secondary winding, 122 of forward mode transformer TR, 100. The secondary winding 122 can be completely isolated from the primary side. R1 represents the resistive part of a possible load between the output terminal VO, 132 of converter and output ground 130. Secondary winding 122 and unidirecting device D3, 124 can be an unidirectional conducting device such as a fast acting semiconductor diode such as MUR850 and the like. Components D21, 112v, D22, 112w, D23, 112x, D24, 112z, and Diode D1, 112s, D32, 112u, and D33, 112z respectively.

Main switch S: IRFP460, identified as 106. Output rectifier switches S01, 110z, and S02, 110v identified as 102, Triangle 110s, IC chip: UC3525A, respectively.

The transformer, 112, turn-ratio n=5 was selected. In the construction of the prototype, the following components were used:

- Diodes D1, D2a, D3a and D4a: MUR840, identified as 112a, 112v, 112s, and 112u respectively.
- Diodes D2b, D2c, D3b, D3c, and D4b: EGP50GL, identified as 112w, 112x, 112z, and 112zz respectively.

Storage capacitor C1, 114, and C2, 114, and C3, 390 µF/180V identified as 114a, 114b, and 114c respectively. Storage capacitor C1, 114, 470 µF/10V identified as 126c. Output inductor L0: 100 µH, identified as 126d. Inductor L1, 4-stage switched-capacitor network (m=4), 110, 112, 114, and 116. The transformer, 112, turn-ratio n=5 was selected. In the construction of the prototype, the following components were used:

- Input choke L: 450 µH, identified as 102.
- Diodes D1, D2a, D3a, and D4a: MUR840, identified as 112a, 112v, 112s, and 112u respectively.
- Diodes D2b, D2c, D3b, D3c, and D4b: EGP50GL, identified as 112w, 112x, 112z, and 112zz respectively.

The transformer, 112, turn-ratio n=5 was selected. In the construction of the prototype, the following components were used:

- Input choke L: 450 µH, identified as 102.
- Diodes D1, D2a, D3a, and D4a: MUR840, identified as 112a, 112v, 112s, and 112u respectively.
- Diodes D2b, D2c, D3b, D3c, and D4b: EGP50GL, identified as 112w, 112x, 112z, and 112zz respectively.

Main switch S: IRFP460, identified as 106. Output rectifier switches S01, and S02, identified as 102. Forward transformer T: Philips 3CB5 ETDPST39. Storage capacitor C1, C2, and C3, 390 µF/180V identified as 114a, 114b, and 114c respectively. Output capacitor C1, 470 µF/10V identified as 126c. Output inductor L0: 100 µH, identified as 126d. IC chip: UC3525A, respectively.

The results of the operation with an input voltage of 110 volts @60 Hz were the following output values: Vout=3.3V ±0.5%; Nominal output power: Pnom=30W; Output power range: 10W-50W; and, Switching frequency: f=50 kHz.
Novel Soft-Switching Topologies with PFC

The novel soft-switching topologies can be used at much higher switching frequencies than the hard-switching topologies with results of being useful at frequencies in the giga-hertz range with much reduced energy loss.

2) Dual Switch Converter with Soft-switching and Power Factor Corrections

FIG. 9 shows the Dual Switch Converter Unit with Power Factor Correction and Soft Switching converter. The following discusses this operation of the dual switch converter unit with power factor correction (DSCL). The converter consists of a power transformer with four primary windings Lp 1_A, 3002, Lp 2_A, 3004, Lp 1_B, 3006, and Lp 2_B, 3008, and 2: isolated secondary windings Ls 1, 3010, and Ls 2, 3012, power switches S_a, 3014 and S_b, 2, 3016, choke inductors Lchoke_A, 3018, and Lchoke_B, 3020, 6 fast rectifiers diodes, 3021 and 3022, 4 primary storage capacitors Cs1_A, 3004, Cs2_A, 3026, Cs1_B, 3028, Cs2_B, 3030, and an output storage capacitor Cout, 3032. The power switches S_a, 3034 and S_b, 3036 are discharged by their parasitic drain source capacitances Cds_A, 3038, and Cds_B, 3034. The parasitic leakage inductances of power transformers are represented by Ll1_A, 3018, Ll1_B, 3020, 3014, and Lchoke_B, 3032. The converter provides power factor correction.

Assuming the converter operates in steady state mode. All capacitors are charged with their nominal voltages. It can be shown that here are 5 modes of operation described in their order of occurrences:

Mode 1
Lchoke_A, 3018, and Lchoke_B, 3020, are discharged and carry no current, S_A, 3034 is closed. Current of Lchoke_A, 3018, increases linearly as well as of leakage inductances Ll1_A, 3018, and Ll1_B, 3020, 3014, and Lchoke_A, 3018, is transformed to secondary winding Ls 1, 3010, and recharges Cout, 3032, via D3, 3022c. In that mode energy from power line Vline is stored in 35 giga-hertz range with much reduced energy loss.

Mode 2
S_A, 3034, opens and current of Lchoke_A, 3018, Ll1_A, 3018, Ll1_B, 3014, and Lchoke_A, 3018, is formed in a resonant tank, where Cds_A, 3038, and Cds_B, 3034, are discharged simultaneously until Cds_B, 3034, reaches Zero. Because of D2-A Voltage across S_A, 3034, is clamped to VCs2-A, 3026, +VCs1_A, 3018. During this process voltage across leakage inductances is voltage at storage capacitors reflected output voltage via Ls 1, 3010, Lp 1_A, 3002, and Ls 1, 3010, /Lp 2_A, 3004 respectively. As soon as the direction of current trough leakage inductances change their sign, converter enters mode 3.

Mode 3
Ll1_A, 3018, Ll1_B, 3014, and Lchoke_A, 3018, are connected and carry no current, S_A, 3034, is discharged and charged up to voltage at storage capacitor Cs1_A, 3004, and Lchoke_A, 3018, is open and D1-B, 3022b, D2-B, 3022b, and D4, 3006d, is closed. Current of Lchoke_A, 3018, is reversed biased, there is no current flow in Lp 1B, 3006, and Lp 2-B, 3008.

Mode 4
S_A, 3034, opens and current of Lchoke_A, 3018, Ll1_A, 3018, and Lchoke_A, 3018, is charged up to voltage at storage capacitor Cs1_A, 3004, and Lchoke_A, 3018, is open and D1-B, 3022b, is reversed biased, there is no current flow in Lp 1B, 3006, and Lp 2-B, 3008.

Mode 5
S_A, 3034, opens and current of Lchoke_A, 3018, Ll1_A, 3018, and Lchoke_A, 3018, is charged up to voltage at storage capacitor Cs1_A, 3004, and Lchoke_A, 3018, is open and D1-B, 3022b, is reversed biased, there is no current flow in Lp 1B, 3006, and Lp 2-B, 3008.

Mode 5 operates in the same way like Mode 3 where primary section A and B exchange their operation. After voltage across Cds_A, 3038, reaches Zero, converter enters Mode 6.
Before the auxiliary switch is turned on, the main switch, 1006, is open and its output capacitor holds a voltage of 2Vcsw. The resonant inductors carry zero current. Let’s start the cyclic operation when the auxiliary switch is turned on at to.

Switching Period 1:
At t=to, the auxiliary switch Sa, 1007 is turned on. A resonance takes place firstly among Csw, 1114d, C, 1114a, L, 1100 and L, 1100a. In order to create zero-voltage-switching condition for the main switch S, 1006, the resonant capacitance C, 1114a, must be larger than the output capacitance Csw, 1114d of the main MOSFET switch, i.e., C/Csw>Csw, 1114a, in order to create zero-voltage-switching condition for the main switch S, 1006, we must design the resonant capacitance C, 1114a, to be larger than the output capacitance Csw, of the main MOSFET switch, i.e., C/Csw>Csw, 1114a.

Switching Period 2:
With the switch voltage vsw decreasing to zero, diode D, 1124, conducts. The input inductor L, 1002, is magnetizing in this period. The resonance continues among C, 1114a, L, 1100 and L, 1100a.

Switching Period 3:
With the capacitor voltage vsw, 1114a, resonant to zero, diode D, 1112 turns on. Since S-L, 1100-D, 1124-S forms a freewheeling loop, the resonant inductor keeps a constant current. The auxiliary switch can be turned off with zero-current-switching (ZCS) anytime at the resonant inductor current iL becomes negative. The transformer primary windings N, 1100, and N, 1100a, transfer energy to its secondary N, 1110b, from energy storage capacitors C, 1114, and C, 1114b, respectively. The input inductor continues magnetizing, absorbing energy from the line.

Switching Period 4:
The main switch, 1006, is turned off. The switch output capacitor Csw, 1114d is quickly charged to 2Vcsw by input inductor current iL and resonant inductor current iL. Then diode D, 1112, starts conducting to clamp the main switch voltage. Assume the switch voltage reaches 2Vcsw with zero time. This switching period ends when both the resonant inductor current and the primary winding current reach zero. Because L, 1100, and L, 1100a, are very small, the duration of this period can be neglected.

Switching Period 5:
Input inductor, 1002, continues to demagnetize until all the magnetic energy is released to charge the storage capacitors, 1114 and 1114b.

Switching Period 6:
With the input inductor decreasing to zero, diode D, 1112, turns off. All the voltages and currents remain constant. The converter is waiting for the next driving signal Sa to start a new switching cycle.

Practical considerations are now noted to explain the values of the various components, which will be used in the construction of the referenced converter.

(a) To improve the input power factor and stabilize the output voltage, two higher value storage capacitors are used in the proposed converter. In steady-state operation, the storage capacitor voltages can be considered as constant. It can be shown that the higher the storage capacitor voltage the higher the input power factor can be obtained. Unfortunately, almost all the components voltage stresses are directly related to the storage capacitor voltage. In practical design, some trade off must be made.

(b) To ensure the converter operating in CCM, we must design the input inductance must be less than the critical inductance.
The measured power factor and efficiency are given in FIG. 14(a) and (b) respectively. Power factor higher than 93% can be ensured for output from 50W to 100W when line changes from 100V to 120V. At high load, the converter efficiency (including the line filter and the start resistor) is maintained about 80%. At light load, when the line becomes high, the efficiency decreases due to disappear of the ZVS condition.

The focus here is on eliminating some disadvantages of the previous soft-switching converter. Among the improvements to be made is make the auxiliary switch soft-switching, easy to drive switches, and to use less components.

The second Single-Stage PFC AC/DC Converter with ZVS/ZCS operation is shown in FIG. 15. The main advantages of this converter are:

1. Both switches are soft-switching; ZVS for the main switch and ZCS for the auxiliary switch.
2. Both switches are grounded which makes them easy to control.
3. Less components.

Principle of Operation:

The main switching waveforms and the equivalent circuits for the modes of operation are shown in FIG. 15 and FIG. 16 respectively. As can be noted, this converter has six modes of operation. Before the auxiliary switch, 1007, is turned on, the main switch, 1006, is open, and its output capacitor holds 2Vc. The resonant inductors carry zero current. The modes of operation start at t0 and are as follows:

Mode 1 (t0<t1): At t0, the auxiliary switch S0, 1007, is turned on. The equivalent circuit for this mode is shown in FIG. 16. Csw', 1502, Csw, 1504, and Lsw, 1506, form a resonant loop. The inductor is demagnetizing the current. The current through, 1007 S0, becomes zero. Because the current through, 1007 S0, is equal to zero now, 1007 S0, can be turned off at ZCS. As can be noted, this converter has six modes of operation. The main switching waveforms and the equivalent circuit for this mode is a freewheeling loop. The inductor current is zero. S0, 1007, is quickly turned on at ZVS.

Mode 2 (t1<t2): After turning S0, 1007, on at t1, waveform, Csw', 1504, and Lsw, 1506, resonate together until the current current through the voltage Vc across auxiliary switch, 1007, S0, become zero. Because the current through, 1007 S0, is equal to zero now, 1007 S0, can be removed. The auxiliary switch S0, 1007, can be turned off anytime before turning main switch, 1006, off.

Mode 3 (t2<t3): In this mode, Vc, 1506, and the equivalent circuit for this mode is a freewheeling loop. The inductor current is zero. S1, 1007, is turned off at t3.

Mode 4 (t3<t4): At t3, main switch, 1006, S is turned off. The switch output capacitor Csw, 1502, is quickly charged up to 2Vc by both currents i2 and i4. The conduction of the diode Dshg, 1508, clamps Vc across 2Vc. Also, i2 is zero at the end of this mode. Because Lsw, 1506, and L1, 1510, is very small, the duration of this mode can be neglected so that i2 is zero.

Mode 5 (t4<t5): This mode starts when Dshg, 1508, starts conduct. The input inductor L1, 1512 is demagnetizing during this mode until i2, hits zero at t5. The equivalent circuit for this mode is shown in FIG. 47e.

Mode 6 (t5<t0+T): Because i2 is zero at t5, 1514, turns off at the beginning of this mode. No changes occur for the voltages and currents during this mode until turning auxiliary switch 1007 S0, again initiating the next switching cycle.

While the invention has been described, disclosed, illustrated and shown in various terms of certain embodiments or modifications which it has presumed in practice, the scope of the invention is not intended to be, nor should it be deemed to be, limited thereby and such other modifications or embodiments as may be suggested by the teachings herein are particularly reserved especially as they fall within the breadth and scope of the claims here appended.

We claim:

1. A power supply that provides a DC (Direct Current) power to a load from an AC (Alternating Current) source comprising:
   - a rectifying stage for transferring electrical energy from an AC source into pulsating unipolar voltage pulses at output terminals;
   - a boost stage having a controllable conducting means and a first unidirectional conducting means for controlling current flow from the output terminal of the rectifying stage and blocking the current flow into the opposite direction and a single controllable switching device connected across the output terminals and more than one inductive-capacitive stages connected between said boost stage and a forward stage providing an inductive energy storing circuit when said switching device is closed and a capacitive charging circuit when said switching device opens whereby a conversion efficiency of over approximately 75% (seventy-five percent) AC to DC is achieved and an outlet voltage of approximately five (5) volts and lower.
   - a power supply of claim 1 wherein said more than one inductive-capacitative stages are from 2(two) to 5(five) in number.
   - A power supply of claim 1 wherein said more than one inductive-capacitative stages are from 2(two) to 5(five) in number.

2. A power supply of claim 1 wherein said more than one inductive-capacitative stages are from 2(two) to 5(five) in number.

3. A power supply of claim 1 wherein said more than one inductive-capacitative stages are from 2(two) to 5(five) in number.

4. An AC to DC converter with power factor correction, comprising in combination:
   - a power supply;
   - a power factor correction (PFC) circuit means;
   - an AC to DC power conversion circuit means connected to the PFC circuit means; a step-down switched capacitor network; and,
   - a power on and off switch and an on and off auxiliary switch for controlling both the PFC circuit means and the AC to DC power conversion circuit means, wherein the converter operates at an efficiency of greater than approximately 80% (eighty percent) and at a frequency of greater than about 500 (five hundred) kilo-hertz.

5. The power supply of claim 4 wherein the auxiliary switch is grounded.

6. The power supply of claim 4 wherein both of said switches each have a resonant capacitor and a blocking diode whereby the switch voltage is blocked.

7. The power supply of claim 4 wherein the controllable conducting means, which operates with a switching frequency, is greater than approximately 500 (five hundred) kilo-hertz.

8. The power supply of claim 4 wherein a ratio between on and off time of said controllable means is controlled by: means for sensing at least one of voltage and current of the power supply.

9. The power supply of claim 5 wherein the ratio between on and off time of said controllable conducting means is also controlled by: a sensed overload of the power supply.

10. The power supply of claim 5 wherein the ratio between on and off time of said controllable conducting means is further controlled by: an external source chosen from one of:
   - a voltage; and current.