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(54) **MODULAR APPARATUS FOR REGULATING THE HARMONICS OF CURRENT DRAWN FROM POWER LINES**

MODULARES GERÄT ZUR KONTROLLE DER HARMONISCHEN EINES STROMES, DIE VON EINEM STROMNETZ GELIEFERT WERDEN

APPAREIL MODULAIRE SERVANT A REGULER LES HARMONIQUES D'UN COURANT SOUTIRE DE LIGNES D'ENERGIE ELECTRIQUE

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(73) Proprietor: **Green Power Technologies Limited**
Rehovot 76703 (IL)

(72) Inventor: **BEN-YAAKOV, Shmuel**
84236 Beer-Sheva (IL)

(74) Representative: **Rees, Alexander Ellison et al**
Urquhart-Dykes & Lord,
30 Welbeck Street
London W1G 8ER (GB)

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Description

Field of the Invention

[0001] The present invention relates to the field of power electronics. More particularly, the invention relates to a method for regulating the harmonics of current drawn from power lines, by electric equipment, using modular design and construction techniques.

Background of the Invention

[0002] The art has devoted a considerable effort to the problem of shaping the current amplitude and phase drawn from the power line, loaded by electric equipment. Switch Mode and Resonant Converters are widely used for DC-DC (Direct Current - Direct Current), DC-AC (Direct Current - Alternate Current), AC-DC and AC-AC conversion. In some applications, the purpose of power conversion is to shape the current at the input of the converter. For example, an input power stage known in the art as an Active Power Factor Correction (APFC) circuit, the function of the converter is to insure that the AC current supplied from the source (power line) will appear in almost the same shape and phase as the source voltage. Thus, a Power Factor (PF) of unity is obtained.

[0003] The need for APFC stages is driven by the worldwide concern about the quality of power supplies. Generally, poor power factors results is several problems, comprising low efficiency of power transmission, interference to normal operation of other units connected to the same power line, as well as distortion of the voltage shape. Voluntary and mandatory standards that restrict the acceptable level of the current harmonics generated by the loading equipment, have been adopted by many countries, so as to maintain high power quality.

[0004] Another advantage of APFC is increased power levels that may be drawn from the power line. Looking at the spectral components of the current without APFC, only the fundamental (first) harmonic component contributes to the real load power. The root mean square (rms) magnitude of the current is increased beyond the level of the fundamental magnitude, as a result of higher order harmonics. Since the operation of protection elements, such as fuses and circuit breakers, is affected by the rms current, increased tins level limits the maximum power level that may be drawn from the line. Using electric equipment with APFC enables the rms current level to be equal to the level of the fundamental harmonic. Hence, the power that may be drawn from the line may reach its maximum theoretical level.

[0005] From the above description, it is clear that the need for APFC is wide spread, and economic implementation of APFC circuitry is of prime importance. Moreover, the cost of APFC circuits is of great concern considering the fact that APFC cost is an add-on expense to the functionality of the original equipment. As a result, APFC units should be constructed using methods that are economic during production, and are easy to integrate in any existing equipment.

[0006] Some known methods for physical implementation of APFC stages, sub-circuits, which are part of the electrical circuit of the (loading) equipment are used. In this case, the designer of this equipment engages passive and active components, as well as Integrated Circuits (ICs) to construct the desired APFC stage. Normally, designs that involve many components suffer from several drawbacks, like relatively high cost and low reliability. Moreover, these designs require many wiring connections, resulting in relatively high susceptibility to Electro-Magnetic Interference (EMI), "ground noise" and other engineering disadvantages.

[0007] Other construction methods comprise one "block" (APFC block) that includes all the components and circuitry of an APFC stage. This implementation provides functional solution to the design problem from the electrical aspect, but still requires satisfactory heat dissipation design. Still, a separate APFC unit should be normally purchased from another manufacturer (which is more skilled in this kind of products), leading to higher cost. Another disadvantage is the fact that this realization is not compatible with IC technology, which normally has the benefit of low cost in mass production. Further problem using APFC block is the fact that in this implementation, all heat dissipating components, such as the main switch, diodes and the inductor are close to each other. This proximity leads to a severe heat dissipation problem, which may limit the power handling capability of such module. Additionally, because of this component proximity, EMI restrictions require heavy snubbing, shielding and filtering, all leading to complexity, higher cost and lower efficiency.

[0008] U.S. Patent 5,530,635 to Yashiro describes a power supply divided into a noise filtering module, one or more power factor and harmonic correction modules, one or more DC-DC converter modules and a backup power supply for the power converter modules. Each module may optionally be combined so as to construct a desirable power supply according to various required specifications. However, this construction lacks simplicity, since it is not realizable using IC technology and in addition is not advantageous with respect to optimal heat dissipation.

[0009] U.S. Patent 5,047,912 to Pelly describes a modular four terminal realization of APFC stages. The control circuit comprises a signal differentiator, for generation of a reference signal to the feedback loop of the circuit. Differentiators are known in their extreme noise sensitivity, which may corrupt the output signal. Switching circuits such as Pulse Width Modulation (PWM) Boost converters, which are characterized by high frequency noise injection, are also problematic to use. Another problem arises from this patent is the reference feedback signal is driven from the line voltage, which contains additive noise that distorts the shape of the desired controlled line current.

[0010] A different problem, which is not solved by U. S. Patent 5,047,912 is the generation of a local power supply (from the line voltage) for the control circuitry. High power APFC stages requires local power supplies of several watts. Using an external power supply for this purpose requires additional circuitry and pin connection, which increase cost. Another approach is to drive the power supply from a voltage divider from of the output voltage, or from the voltage across the main switch. This approach is extremely inefficient, especially in case of high power applications.

[0011] Another disadvantage of U.S. Patent 5,047,912 is the need for fast diodes for its input rectifier, due to the fact that the line rectifier in this patent is locate after the input inductor. At this point, the signals are switching frequency signals that requires fast rectifier diodes, so as to eliminate high power loss. Using fast diodes introduces higher switching noise, as well as higher cost (since such diodes are more expensive).

[0012] The prior art reference "PWM converters with resistive input" by S. Ben-Yaakov in IEEE Transactions on Industrial Electronics, vol. 45, no. 3, June 1998 describes a PWM control method that can be used in the design of active power factor correctors that do not need input voltage sensing.

[0013] All the methods described above have not yet provided satisfactory solutions to the task of constructing simple, low-cost, modular APFC stages.

[0014] It is an object of the invention to provide an APFC unit, for regulating the harmonics of power line current, that comprise low number of components.

[0015] It is another object of the invention to provide a compact, low cost APFC unit.

[0016] It is another object of the invention to provide a compact APFC unit, with a minimal amount of interconnections.

[0017] It is still another object of the invention to provide an APFC unit with efficient local power supply feeding switching and control circuit.

[0018] It is yet another object of the invention to provide an APFC unit which is compatible with IC technology.

[0019] It is yet another object of the invention to provide an APFC unit which do not comprise signal differentiation, while overcome the drawbacks of the prior art.

[0020] Other purposes and advantages of the invention will appear as the description proceeds.

Summary of the Invention

[0021] The invention is directed to modular apparatus for regulating the harmonics of current drawn from power lines by an electric load, comprising:

a) a first rectifier circuit module consisting of an array of rectifying diodes, the inlet of which is connected to the power lines;

characterized in that is further comprises:

b) a second Switch and Controller Assembly (SCA) module for controlling said current to follow the voltage across said power lines by only sampling the current drawn from said power lines and the output voltage of said second SCA, said second SCA module consisting of a power switch and controller and their interconnections, the inlet of which is connected to the outlet of said first rectifier circuit module through at least one serially connected input inductor, for filtering the current drawn from the rectifier module; and

c) at least one output capacitor connected in parallel with the output of said SCA and said load, for filtering the output voltage ripple at said load.

[0022] Preferably, the main power factor correction operation is carried out by the SCA module. Correction is obtained by a high frequency controlled switching of the input rectified voltage. Further rectification is carried out by a high frequency rectifier diode connected in series with the SCA outlet. The control circuit samples both the input current and the output voltage of the SCA and controls the switching transistor accordingly by an inherent pulse width modulator responsive to the control signal. The control circuit is fed by a power supply via an inlet in the SCA module.

Preferably, optional soft switching is obtained using an integrated turn-on snubber, consists from an inductor, a capacitor and two rectifier diodes, connected between the input and output of the SCA. These two diodes are integrated into the SCA module.

[0023] Preferably, the SCA module contains only semiconductor components, so as to be fabricated as a monolithic integrated circuit for low power applications, or as a hybrid circuit for medium and high power applications, in both cases packaged in a three terminal or two port heat dissipating package. Using this construction, increased power handling capability is obtained. This construction also reduces the number of interconnections required for integration, as well as reducing the unit cost of mass production. Passive components required for SCA operation, like inductors and some of the capacitors, which can not be fabricated as semiconductor products are connected via suitable inlets in the SCA package in case of monolithic design, or within the module in case of hybrid design.

[0024] Preferably, the proposed construction enables separate mounting of modules and components in a manner that is optimal to heat dissipation. Interconnections between different terminals of models or components of this construction are provided using wires and/or conductive traces on a printed circuit board or on an alumina substrate, reducing the labor associated with low cost construction. The apparatus further comprises an internal power supply driven from the output voltage or from the switched voltage of the SCA module.

Brief Description of the Drawings

[0025] The above and other characteristics and advantages of the invention will be better understood through the following illustrative and none-imitative detailed description of preferred embodiments thereof, with reference to the appended drawings, wherein:

- Fig. 1 is a schematic diagram of a conventional (prior art) PWM boost converter;
- Fig. 2 is a schematic diagram of a conventional (prior art) APFC stage;
- Fig. 3 is a schematic diagram of a conventional (prior art) APFC stage in one block;
- Fig. 4 is a schematic diagram (prior art) of a control circuit of an APFC stage;
- Fig. 5 is a schematic diagram (prior art) of another control circuit of an APFC stage;
- Fig. 6 is a schematic diagram of a modular construction of an APFC stage, according to the present invention;
- Fig. 7 is a schematic diagram of a modular construction of an APFC stage, as a two-port network;
- Fig. 8 is a schematic diagram of the construction illustrated in Fig. 6 , with improved heat dissipation;
- Fig. 9 is a schematic diagram of a Switch and Control Assembly (S C A) , according to the present invention;
- Fig. 10 is a schematic diagram of an SCA with a lossless snubbing circuitry, according to the present invention;
- Fig. 11 illustrates the APFC stage of Fig. 6, constructed according to the present invention, where the SCA is fabricated as a four pin IC;
- Fig. 12 illustrates the APFC stage of Fig. 7, constructed according to the present invention, where the SCA is fabricated as a five pin IC;
- Fig. 13 illustrates an APFC stage, constructed according to the present invention, where the SCA is fabricated using hybrid technology;
- Fig. 14 illustrates an APFC stage, constructed according to the present invention, where the SCA is constructed in a manner suitable for hybrid IC technology;
- Fig. 15 illustrates a full APFC stage construction according to the present invention.

Detailed Description of Preferred Embodiments

[0026] For a better understanding of the present invention, the structures of prior art are examined, according to the illustrations presented by Fig. 1 to 5. A typical prior art implementation of APFC stage, known as PWM boost converter, is shown in Fig. 1. The input AC voltage is rectified by an array **1,** of four rectifying diodes, and fed into a boost stage that comprises an input inductor **2** (L_{in}), a switch **3** (S_1), a high frequency rectifier **4** (D_2), an output filtering capacitor **5** (C_0) and a load, represented by a resistor **6** (R_L). Switch **3** is driven by a high frequency control signal with duty cycle D, such that the shape of the input current i_{in} follows the shape of the rectified input voltage V_{ivR}. Consequently, the input terminal (before the inductor **2**) will have resistive characteristics, i.e., the Power Factor (PF) equals unity.

[0027] Another prior art implementation, shown in Fig. 2, comprises both passive and active components. The input AC voltage is rectified by an array **7,** of four rectifying diodes, and fed into a boost stage that comprises an input inductor **8** (L_{in}), a power Metal Oxide Semiconductor Field Effect Transistor (MOSFET) switch **9** (Q_1), a high frequency rectifier **10** (D_2), an output filtering capacitor **11** (C_0), a load, represented by a resistor **16** (R_L), an IC Active Power Factor (APF) controller **12** with its auxiliary passive components circuit **17,** a current sensing resistor **13** (R_s), a voltage sensing resistor 18 (R_{ac}), and an output voltage divider, constructed from resistors **14** (R_1) and **15** (R_2). MOSFET switch **9** is driven by a high frequency control signal from the APF controller **12.** Here, some components (such as inductor **8** and capacitor **11**) are of relatively large size, which is not compatible with microelectronics technology. Other silicon semiconductors, such as APF controller **12** and rectifier **10** may be fabricated on a monolithic IC chip. However, the stage of Fig. 2 still comprises many discrete components with their associated wiring, that preclude the streamlining of the APFC stage. For example, the rectified input voltage V_{ivR} should be sensed, and hence a wire should be connected between the feed point "**c**" and the controller **12.** In order to regulate the output voltage, the voltage at point "**b**" (the output of the voltage divider R_1, R_2) is also sensed by the controller **12.**

[0028] Another prior art, comprising a complete stage, similar to the stage of Fig. **2,** (excluding the output filtering capacitor **20**) packaged into one APFC block **19** is shown in Fig. **3.** Here, all heat dissipating elements are in close proximity, complicating heat removal.

[0029] In an improved prior art APFC stage, illustrated in Fig. 4, comprises a modified control operation, in which sensing of the input voltage V_{ivR} is not required. The voltage V_a at point **"a"** is a pulsating voltage of maximum amplitude V_0 and duration of T_{OFF} when switch **21** (S_1) is not conducting. Consequently, the average voltage at point **"a"** ν_{av} is given by:

$$\nu_{av} = \frac{V_0 \cdot T_{OFF}}{T_s} \quad \text{[Eq. 1]}$$

where T_s is the PWM switching period, or:

$$\nu_{av} =$$

$$V_0 \cdot D_{OFF} \quad \text{[Eq. 2]}$$

where

$$D_{OFF} = \frac{T_{OFF}}{T_S} \quad \text{[Eq. 3]}$$

[0030] Similarly, the "on" duty cycle D_{ON} while S_1 is conducting (a period of T_{ON}) is given by:

$$D_{ON} = \frac{T_{ON}}{T_S} \quad \text{[Eq. 4]}$$

[0031] The input voltage V_{ivR} fed into the boost converter is assumed to be of low frequency, compared to the switching frequency f_s (f_s=1/T_s), and hence may be considered constant during one or several switching periods. If the power stage is properly controlled, the average low frequency voltage across inductor **22** (L_{in}) is almost zero (otherwise the current would risen to large values). Thus:

$$v_{ivR} = v_{av} \quad \text{[Eq. 5]}$$

where v_{ivR} is the instantaneous low frequency component of V_{ivR}.
From Eq. 1 and Eq. 5, the following equality is obtained:

$$v_{ivR} =$$

$$V_0 \cdot D_{OFF} \quad \text{[Eq. 6]}$$

[0032] In case when D_{OFF} is programmed according to the following rule:

$$D_{OFF} = K \cdot i_{ina} \quad \text{[Eq. 7]}$$

where K is a constant, and i_{ina} is the low frequency component of the input current i_{in}, then:

$$v_{ivR} =$$

$$V_0 \cdot K \cdot i_{in} \quad \text{[Eq. 8]}$$

or:

$$i_{ina} = \frac{v_{ivR}}{V_0 \cdot K} \quad \text{[Eq. 9]}$$

[0033] If the filtering capacitor **23** (C_0) is sufficiently large so that the ripple of the output voltage V_0 may be neglected, then according to Eq. 9 the input current follows the input voltage. Hence, the converter stage looks resistive with the following input resistance:

$$\text{Re} = K \cdot V_0 \quad \text{[Eq.10]}$$

[0034] From Eq. 10, the value if the input resistance R_e as well as the input current may be controlled by adjusting the value of K. Practically, the output voltage should remain constant even for variations in the load **24** (R_L). This may be obtained by establishing a closed control loop on K. The voltage v_{iin}, which is proportional to the input current (i_{ina}) sensed by the sensing resistor **25** (R_s), is fed into a multiplier **26** (M). An error amplifier **27,** compares the output voltage V_0 with a reference voltage V_{ref}, generating an error voltage V_e, which is also fed into the multiplier **26.** The product v_{iin}\$$V_e$, which is proportional to i_{ina} by the factor K, is fed into a PWM modulator **28,** which generates the duty cycle pulse (D_{OFF}) according to Eq. 7.

[0035] Another improved prior art APFC stage, illustrated in Fig. 5, exploits the current flowing in the MOSFET switch **29** to generate the duty cycle pulse (D_{OFF}). The sensing resistor **30** (R_s) is placed in series with the MOSFET switch **29,** whereas the voltage across it is being used to measure the input current i_{ina}. This implementation, as well as the implementation described in Fig. 4 above, do not require input voltage sensing, lowering the number of the required interconnections.

[0036] According to one preferred embodiment of the present invention, the APFC stage comprises four basic sub-circuits, two modules and two structural elements, being connected to each other as illustrated in Fig. 6. The first module consists from a widely used input rectifier array **31** (D_1). This module has one inlet connected to the power line and one DC outlet. This inlet is normally pre-filtered by a conventional noise filter to suppress noise entering from the line. A capacitor (C_1) may be optionally connected across the rectifier array output so as to filter high frequency components of the rectified voltage to ground. The first structural element is the input inductor **32** (L_{in}), which may tapped and may consist from additional inductor, in case when a snubber is used. This inductor is being connected between the rectifier module and the SCA module.

[0037] The second module is the Switch and Control Assembly (SCA) **33**, consists from all the semiconductor components of the switching, control, rectifier and power supply circuitry. The inlet of this module is being connected to the output of the first module **31** via the input inductor **32** (L_{in}), and the outlet to the load. The SCA module may optionally comprise a turn-on snubber. According to the invention, the SCA module may have three terminals, one for input, one for output and one for ground.

[0038] The second structural element is the output capacitor **34** (C_0), being connected across the outlet of the SCA, in parallel with the load. This modular construction is simpler than prior art implementations, with very few interconnections and with a simple forward flow of power and signals. In addition, the physical location of the three power dissipating elements, the input rectifier array **31** (D_1), the input inductor **32** (L_{in}), and the SCA **33** is not critical, so they may be mounted separately, with the best possible heat removal.

[0039] Fig. 7 illustrates a different construction, according to another preferred embodiment of the present invention. In this implementation, SCA **35** is connected to the same construction described if Fig. 6 above, but as a two port network. This construction provides sensing of the input current within the SCA, thereby simplifying the control circuitry.

[0040] According to another preferred embodiment of the present invention, the high frequency output rectifier diode **36** (D_2) is separated from SCA **37,** as shown in Fig. 8. This construction allows better cooling and mounting.

[0041] The SCA may by realized differently with respect to its internal circuitry, packaging and production technology. Fig. 9 illustrates a typical realization of an SCA circuitry, according to the invention, where all microelectronics compatible components are grouped together. The internal power supply (V_{CC}) required for SCA operation may be obtained from the output voltage using an auxiliary circuit, which comprises a current source **38** (I_{aux}), a zener diode **39** (Dz_{aux}) for power supply stabilization, and a smoothing capacitor **40** (C_{aux}). In case of high power applications, the smoothing capacitor **40** (C_{aux}) may be an electrolytic capacitor located outside the SCA module. This SCA implementation employs a typical PWM modulator, controlled by a control circuit as described above with reference to Fig. 4.

[0042] According to another preferred embodiment of the present invention, a further improved APFC stage may be constructed, by adding a turn-on snubber to the circuit. This approach is illustrated in Fig. 10. The tapped inductor **45** (L_{in}), diodes **46** (Ds_1) and **47** (Ds_2), together with snubber elements (inductor **48** [L_r], and capacitor **49** [C_r]) reduce the switching losses during turn-on time. Still, the modular design presented in the invention is retained, even after adding the described snubbing circuitry or any other snubbing circuitry.

[0043] Production concept of SCA modules may vary according to the required quantities and power levels. Fig. 11 illustrates a construction of the APFC stage described in Fig. 6 above, according to a preferred embodiment of the invention. The SCA module is fabricated as a monolithic (chip) IC, packaged in a four pin package **50**. This construction is suitable mainly for low power applications.

[0044] Fig. 12 illustrates construction of the APFC stage described in Fig. 7 above, according to another preferred embodiment of the invention. Here too, the SCA module is fabricated as a monolithic (chip) IC, packaged in a five pin package **51.** This construction as well, is suitable mainly for low power applications.

[0045] Fig. 13 illustrates construction of the APFC stage, according to another preferred embodiment of the invention. The SCA module is fabricated as a multichip hybrid circuit, packaged in a three pin package **52**, with an associate Printed Circuit Board (PCB) based sub-assembly **53**. This construction is suitable mainly for medium and high power applications.

[0046] In case when the user prefers to use an (already) available power supply, an extra pin for external power supply may be easily provided, as shown in Fig. 11 and 12 above. However, the main feature is related to minimal number of interconnections between the SCA module and other components.

Example 1

[0047] Fig. 14 is a complete schematic diagram of an APFC stage structure, where the SCA module 78 includes internal power supply and turn-on snubber circuits, according to the invention, and is fabricated as a multi-chip hybrid circuit. The rectifier array is contained in a separate module **60**. The input inductor **61** (L_{in}), which in this case is a tapped inductor, as well as the snubbing circuit inductor **62** (L_r), and the snubbing circuit capacitor **64** (C,) are excluded from the SCA module, since they are not compatible with IC or hybrid technology. The control circuit controlling the switching transistor **77** (Q_1) is implemented using IC components. The voltage V_{ref} is generated from V_{cc} by a resistor R_2 and a zener diode D_{z2}, feeding the error amplifier **68** (U_3). The resulting error is fed into the multiplier **72** (U_4) together with the voltage across the sampling resistor **71** (R_5). The output voltage V_m from the multiplier is fed into comparator **66** (U_1), together with a ramp voltage V_{ramp}, which varies between a peak value of V_p and zero, thereby determining the switching frequency f_s (f_s=1/T_s).

[0048] The peak value of the ramp voltage V_p is determined from V_{cc} by resistor **75** (R,) and zener diode **76** (D_{z1}). A current source **65** (U_5) charges the capacitor **69** (C_{ramp}) to V_{ramp}. V_{ramp} is fed together with V_p into another comparator **67** (U_2), which discharges C_{ramp} by driving transistor **70** (Q_2) for a short determined period whenever V_{ramp} exceeds V_m. In this way, the time T_{off} during which the switching transistor **77** (Q_1) is not conducting, is proportional to V_m, and hence, to the input current i_{ina} (using Eq. 7 above). Using this construction, all the elements within the SCA module **78,** ICs, semiconductors, resistors, capacitors and inductor **63** (L_x) may be integrated into one hybrid circuit.

Example 2

[0049] A full APFC stage construction presented by

Fig. 14 is illustrated in Fig. 15. Both rectifier array **80,** and SCA **84** modules are ICs and/or hybrid circuits, packaged each in a heat dissipating package (Alumina, for instance) with metallic leads, and mounted on heat-sink **90** by drilling suitable holes **81** and **92** in the PCB **89**, respectively, by gluing with heat conductive adhesive or soldering. The PCB **89** is mounted to the case by using screw(s) **91,** or by soldering.

[0050] Printed copper traces **88** are used to connect between terminals of different components. The input tapped inductor **82** (L_{in}), the snubber inductor **83** (L_r), the snubber capacitor **86** (C_r), and the output capacitor **87** (C_o), are glued or soldered on the PCB material. Capacitor **93** (C_1) used for filtering high frequency components of the rectified voltage is optionally connected across the rectifier array **80** output. Each terminal of these components is soldered to a corresponding copper pad on the PCB.

[0051] Of course, the above examples and description has been provided only for the purpose of illustrations, and are not intended to limit the invention in any way. As will be appreciated by the skilled person, the invention can be carried out in a great variety of ways, employing more than one technique from those described above, all without exceeding the scope of the invention.

Claims

1. Modular apparatus for regulating the harmonics of current drawn from power lines by an electric load, comprising:

    a) a first rectifier circuit module consisting of an array of rectifying diodes, the inlet of which is connected to the power lines;
    characterized in that is further comprises:
    b) a second Switch and Controller Assembly (SCA) module for controlling said current to follow the voltage across said power lines by only sampling the current drawn from said power lines and the output voltage of said second SCA, said second SCA module consisting of a power switch and controller and their interconnections, the inlet of which is connected to the outlet of said first rectifier circuit module through at least one serially connected input inductor, for filtering the current drawn from the rectifier module; and
    c) at least one output capacitor connected in parallel with the output of said SCA and said load, for filtering the output voltage ripple at said load.

2. Apparatus according to claim 1, wherein the SCA comprises:

    a) a switching transistor connected in parallel with the SCA inlet;
    b) a high frequency rectifier diode connected in series with the SCA outlet;
    c) an input current sampling resistor connected in series with the SCA inlet; and
    d) a control circuit for controlling the switching transistor, one inlet of said control circuit being connected to said current sampling resistor, and the other inlet being connected to the SCA outlet.

3. Apparatus according to claim 1, wherein a non-dissipative turn-on snubber for soft switching is connected to the switching and control circuit assembly, the inlet and outlet of said snubber being connected to the input and output of the SCA, respectively.

4. Apparatus according to claim 3, wherein the snubber comprises:

    a) two rectifier diodes connected between a tap of the input inductor and the output;
    b) an inductor connected in series with the SCA inlet; and
    c) a capacitor connected between the SCA inlet and the common terminal between the two rectifier diodes.

5. Apparatus according to claims 3 and 4, wherein the two rectifier diodes of the snubber being integrated into the SCA module.

6. Apparatus according to claim 1, wherein the control circuit comprises:

    a) a reference voltage source;
    b) a pulse width modulator fed by a multiplier, said pulse width modulator being connected to the gate of the switching transistor controlling the switching duty cycle according to the multiplier output;
    c) a multiplier being fed by the error voltage and the voltage across the input current sampling resistor; and
    d) an amplifier being connected to the output voltage and the reference voltage, said amplifier feeding the multiplier with an error voltage proportional to the difference between the output voltage and the reference voltage.

7. Apparatus according to claim 2, wherein the SCA contains an internal power supply circuit for the control circuit.

8. Apparatus according to claim 2, wherein an external power supply for the control circuit is connected to the SCA, via an inlet thereto.

9. Apparatus according to claim 1, wherein the switching and control assembly module is implemented as a three terminal unit, comprising one input, one output and one common terminal.

10. Apparatus according to claim 1, wherein the switching and control assembly module is implemented as a four terminal two port unit, comprising one input port and one output port.

11. Apparatus according to claims 6 to 10, wherein only semiconductor components are contained within the switching and control assembly module, said module being fabricated as a monolithic integrated circuit.

12. Apparatus according to claims 6 to 10, wherein switching and control assembly module being fabricated as a multi-chip hybrid circuit, thereby increasing the power handling capability.

13. Apparatus according to claims 11 and 12, wherein the switching and control assembly is a monolithic integrated circuit.

14. Apparatus according to claim 13, wherein the package is a metallic or a ceramic heat dissipating package.

15. Apparatus according to claim 1, wherein the two modules are mounted separately, thereby enabling increased heat dissipation and increasing the regulated power handling of the apparatus.

16. Apparatus according to claim 12, wherein the high frequency rectifying diode is excluded from the third module, mounted separately on a heat-sink, thereby enabling increased heat dissipation and further increasing the regulated power handling of the apparatus.

17. Apparatus according to claim 7, wherein the power supply is fed from the output voltage, comprises:

   a) a current source, connected to the output voltage terminal;
   b) a zener diode, fed by the current source of step a) above; and
   c) a smoothing capacitor, connected in parallel with the zener diode of step b) above.

18. Apparatus according to claim 1, wherein a capacitor for filtering high frequency components is optionally connected across the outlet of the rectifier circuit module outlet.

19. Apparatus according to claim 1, wherein any required electrical connection between terminals of modules and terminals of structural components or of other modules are connected using wires and/or printed circuit boards.

Patentansprüche

1. Modulare Vorrichtung zum Regulieren der Oberschwingungen von Strom, der durch eine elektrische Last von Stromleitungen entnommen wird, umfassend:

   a) ein erstes Gleichrichter-Schaltkreismodul, bestehend aus einer Gruppe von Gleichrichterdioden, deren Einlass mit den Stromleitungen verbunden ist; **dadurch gekennzeichnet, dass** sie weiter umfasst:
   b) ein zweites Schalter- und Regler-Baugruppenmodul für die Steuerung des Stroms, sodass er der Spannung zwischen den Stromleitungen folgt, indem nur der von den Stromleitungen entnommene Strom und die Ausgangsspannung der zweiten Schalter- und Regler-Baugruppe abgetastet werden, wobei das zweite Schalterund Reglerbaugruppemodul aus einem Stromschalter und Regler und ihren Verbindungen besteht, dessen Einlass durch mindestens eine in Serie angeschlossene Eingangsdrossel zum Filtern des vom Gleichrichtermodul entnommenen Stroms mit dem Auslass des ersten Gleichrichter-Schaltkreismoduls verbunden ist; und
   c) mindestens einen Ausgangskondensator, der in Parallelschaltung mit dem Ausgang der Schalter- und Reglerbaugruppe und der Last verbunden ist, zum Filtern der Ausgangsspannungswelligkeit der Last.

2. Vorrichtung nach Anspruch 1, wobei die Schalterund Reglerbaugruppe umfasst:

   a) einen Schalttransistor, der in Parallelschaltung mit dem Einlass der Schalter- und Reglerbaugruppe verbunden ist;
   b) eine Hochfrequenz-Gleichrichterdiode, die in Serie mit dem Auslass der Schalter- und Reglerbaugruppe verbunden ist;
   c) einen Eingangsstrom-Abtastwiderstand, der in Serie mit dem Einlass der Schalter- und Reglerbaugruppe verbunden ist; und
   d) einen Steuerschaltkreis zur Steuerung des Schalttransistors, wobei ein Einlass des Steuerschaltkreises mit dem Strom-Abtastwiderstand verbunden ist und der andere Einlass mit dem Auslass der Schalter- und Reglerbaugruppe verbunden ist.

3. Vorrichtung nach Anspruch 1, wobei ein verlustfrei-

er Einschaltbegrenzer für weiche Beschaltung mit der Schalt- und Steuerschaltkreisbaugruppe verbunden ist, wobei der Einlass und Auslass des Begrenzers mit dem Eingang bzw. dem Ausgang der Schalter- und Reglerbaugruppe verbunden sind.

4. Vorrichtung nach Anspruch 3, wobei der Begrenzer umfasst:

a) zwei Gleichrichterdioden, die zwischen einem Abgriff der Eingangsdrossel und dem Ausgang angeschlossen sind;
b) eine Drossel, die in Serie mit dem Einlass der Schalter- und Reglerbaugruppe verbunden ist; und
c) einen Kondensator, der zwischen dem Einlass der Schalter- und Reglerbaugruppe und der gemeinsamen Klemme zwischen den beiden Gleichrichterdioden angeschlossen ist.

5. Vorrichtung nach Anspruch 3 und 4, wobei die beiden Gleichrichterdioden des Begrenzers im Schalterund Reglerbaugruppenmodul integriert sind.

6. Vorrichtung nach Anspruch 1, wobei der Steuerschaltkreis umfasst:

a) eine Referenz-Spannungsquelle;
b) einen Impulsbreitenmodulator, der von einem Multiplikator gespeist wird, wobei der Impulsbreitenmodulator mit dem Gate des Schalttransistors, der den Schaltarbeitszyklus gemäß dem Multiplikatorausgang steuert, verbunden ist;
c) einen Multiplikator, der von der Fehlerspannung und der Spannung über dem Eingangsstrom-Abtastwiderstand gespeist wird; und
d) einen Verstärker, der mit der Ausgangsspannung und der Referenzspannung verbunden ist, wobei der Verstärker dem Multiplikator eine Fehlerspannung, die proportional ist zur Differenz zwischen der Ausgangsspannung und der Referenzspannung, zuführt.

7. Vorrichtung nach Anspruch 2, wobei die Schalterund Reglerbaugruppe einen internen Spannungsversorgungsschaltkreis für den Steuerschaltkreis enthält.

8. Vorrichtung nach Anspruch 2, wobei eine externe Spannungsversorgung für den Steuerschaltkreis mit der Schalter- und Reglerbaugruppe über einen Einlass dorthin verbunden ist.

9. Vorrichtung nach Anspruch 1, wobei das Schaltund Regelbaugruppenmodul als Einheit mit drei Klemmen, die einen Eingang, einen Ausgang und eine gemeinsame Klemme umfassen, ausgeführt ist.

10. Vorrichtung nach Anspruch 1, wobei das Schaltund Regelbaugruppenmodul als Einheit mit vier Klemmen und zwei Anschlüssen, die einen Eingangsanschluss und einen Ausgangsanschluss umfassen, ausgeführt ist.

11. Vorrichtung nach Anspruch 6 bis 10, wobei in dem Schalt- und Regelbaugruppenmodul nur Halbleiter-Bauteile enthalten sind und das Modul als monolithisch integrierter Schaltkreis gefertigt ist.

12. Vorrichtung nach Anspruch 6 bis 10, wobei das Schalt- und Regelbaugruppenmodul als ein Multichip-Hybridschaltkreis gefertigt ist, wodurch die Belastbarkeit erhöht wird.

13. Vorrichtung nach Anspruch 11 und 12, wobei das Schalt- und Regelbaugruppenmodul ein monolithisch integrierter Schaltkreis ist.

14. Vorrichtung nach Anspruch 13, wobei das Gehäuse ein Wärmeabführungsgehäuse aus Metall oder Keramik ist.

15. Vorrichtung nach Anspruch 1, wobei die beiden Module separat montiert sind, wodurch eine erhöhte Wärmeabführung ermöglicht, und die regulierte Belastbarkeit der Vorrichtung erhöht wird.

16. Vorrichtung nach Anspruch 12, wobei die Hochfrequenz-Gleichrichterdiode vom dritten Modul ausgeschlossen und separat auf einem Wärmeabführungselement montiert ist, wodurch eine erhöhte Wärmeabführung ermöglicht und die regulierte Belastbarkeit der Vorrichtung weiter erhöht wird.

17. Vorrichtung nach Anspruch 7, wobei die Spannungsversorgung von der Ausgangsspannung gespeist wird, umfassend:

a) eine Stromquelle, die mit der Ausgangsspannungsklemme verbunden ist;
b) eine Zener-Diode, die von der Stromquelle des obigen Schrittes a) gespeist wird; und
c) ein Glättungskondensator, der in Parallelschaltung mit der Zener-Diode des obigen Schrittes b) verbunden ist.

18. Vorrichtung nach Anspruch 1, wobei optional ein Kondensator zum Filtern von Hochfrequenzkomponenten über den Auslass des Gleichrichterschaltkreismodul-Auslasses angeschlossen ist.

19. Vorrichtung nach Anspruch 1, wobei erforderliche elektrische Verbindungen zwischen den Klemmen von Modulen und den Klemmen von Bauteilen oder anderen Modulen unter Verwendung von Drähten und/oder gedruckten Leiterplatten verbunden sind.

Revendications

1. Dispositif modulaire pour réguler les harmoniques d'un courant absorbé à partir de lignes d'énergie par une charge électrique, comprenant :

   a) un premier module de circuit de redressement consistant en une matrice de diodes redresseuses, dont l'entrée est connectée aux lignes d'énergie ;

   caractérisé en ce qu'il comprend en outre :

   b) un deuxième module d'Ensemble de Commutateur et de Commande (SCA) pour commander ledit courant afin qu'il suive la tension aux bornes desdites lignes d'énergie en échantillonnant uniquement le courant absorbé à partir desdites lignes d'énergie et la tension de sortie dudit deuxième SCA, ledit deuxième module SCA consistant en un commutateur et un régulateur de puissance et leurs interconnexions, dont l'entrée est connectée à la sortie dudit premier module de circuit de redressement par au moins un inducteur d'entrée connecté en série, pour filtrer le courant absorbé à partir du module de redressement ; et
   c) au moins un condensateur de sortie connecté en parallèle avec la sortie dudit SCA et ladite charge, pour filtrer l'ondulation de la tension de sortie au niveau de ladite charge.

2. Dispositif selon la revendication 1, dans lequel le SCA comprend :

   a) un transistor de commutation connecté en parallèle avec l'entrée du SCA ;
   b) une diode de redressement haute fréquence connectée en série avec la sortie du SCA ;
   c) une résistance d'échantillonnage de courant d'entrée connectée en série avec l'entrée du SCA ; et
   d) un circuit de commande pour commander le transistor de commutation, une entrée dudit circuit de commande étant connectée à ladite résistance d'échantillonnage de courant, et l'autre entrée étant connectée à la sortie du SCA.

3. Dispositif selon la revendication 1, dans lequel un circuit d'amortissement de mise en marche non dissipatif de commutation douce est connecté à l'ensemble de circuits de commutation et de commande, l'entrée et la sortie dudit circuit d'amortissement étant connectées respectivement à l'entrée et à la sortie du SCA.

4. Dispositif selon la revendication 3, dans lequel le circuit d'amortissement comprend :

   a) deux diodes de redressement connectées entre une prise de l'inducteur d'entrée et la sortie ;
   b) un inducteur connecté en série avec l'entrée du SCA ; et
   c) un condensateur connecté entre l'entrée du SCA et la borne commune entre les deux diodes de redressement.

5. Dispositif selon les revendications 3 et 4, dans lequel les deux diodes de redressement du circuit d'amortissement sont intégrées dans le module SCA. 2

6. Dispositif selon la revendication 1, dans lequel le circuit de commande comprend :

   a) une source de tension de référence ;
   b) un modulateur de largeur d'impulsion alimenté par un multiplicateur, ledit modulateur de largeur d'impulsion étant connecté à la grille du transistor de commutation commandant le rapport cyclique de commutation conformément à la sortie du multiplicateur ;
   c) un multiplicateur alimenté par la tension d'erreur et la tension aux bornes de la résistance d'échantillonnage de courant d'entrée ; et
   d) un amplificateur connecté à la tension de sortie et à la tension de référence, ledit amplificateur alimentant le multiplicateur avec une tension d'erreur proportionnelle à la différence entre la tension de sortie et la tension de référence.

7. Dispositif selon la revendication 2, dans lequel le SCA contient un circuit d'alimentation interne pour le circuit de commande.

8. Dispositif selon la revendication 2, dans lequel une alimentation externe du circuit de commande est connectée au SCA, par l'intermédiaire d'une entrée de celui-ci.

9. Dispositif selon la revendication 1, dans lequel le module d'ensemble de commutation et de commande est mis en oeuvre sous forme d'unité à trois bornes, comprenant une borne d'entrée, une borne de sortie et une borne commune.

10. Dispositif selon la revendication 1, dans lequel le module d'ensemble de commutation et de commande est mis en oeuvre sous forme d'unité à quatre bornes et deux ports, comprenant un port d'en-

trée et un port de sortie.

11. Dispositif selon les revendications 6 à 10, dans lequel seuls des composants semi-conducteurs sont contenus dans le module d'ensemble de commutation et de commande, ledit module étant fabriqué sous forme de circuit intégré monolithique.

12. Dispositif selon les revendications 6 à 10, dans lequel le module d'ensemble de commutation et de commande est fabriqué sous forme de circuit hybride multipuce, augmentant ainsi la capacité de tenue en puissance.

13. Dispositif selon les revendications 11 et 12, dans lequel le module d'ensemble de commutation et de commande est un circuit intégré monolithique.

14. Dispositif selon la revendication 13, dans lequel le boîtier est un boîtier à dissipation thermique métallique ou céramique.

15. Dispositif selon la revendication 1, dans lequel les deux modules sont montés séparément, permettant ainsi une dissipation de chaleur accrue et augmentant la tenue en puissance régulée du dispositif.

16. Dispositif selon la revendication 12, dans lequel la diode de redressement à haute fréquence est exclue du troisième module, montée séparément sur un dissipateur thermique, permettant ainsi une dissipation thermique accrue et augmentant en outre la tenue en puissance régulée du dispositif.

17. Dispositif selon la revendication 7, dans lequel l'alimentation est alimentée à partir de la tension de sortie, comprend :

a) une source de courant, connectée à la borne de tension de sortie ;
b) une diode Zener, alimentée par la source de courant de l'étape a) ci-dessus, et
c) un condensateur de lissage, connecté en parallèle avec la diode Zener de l'étape b) ci-dessus.

18. Dispositif selon la revendication 1, dans lequel un condensateur de filtrage des composantes haute fréquence est connecté facultativement aux bornes de la sortie du module de circuit de redressement.

19. Dispositif selon la revendication 1, dans lequel toute connexion électrique requise entre les bornes des modules et les bornes des composants structurels ou d'autres modules est réalisée au moyen de fils et/ou de cartes à circuit imprimé.

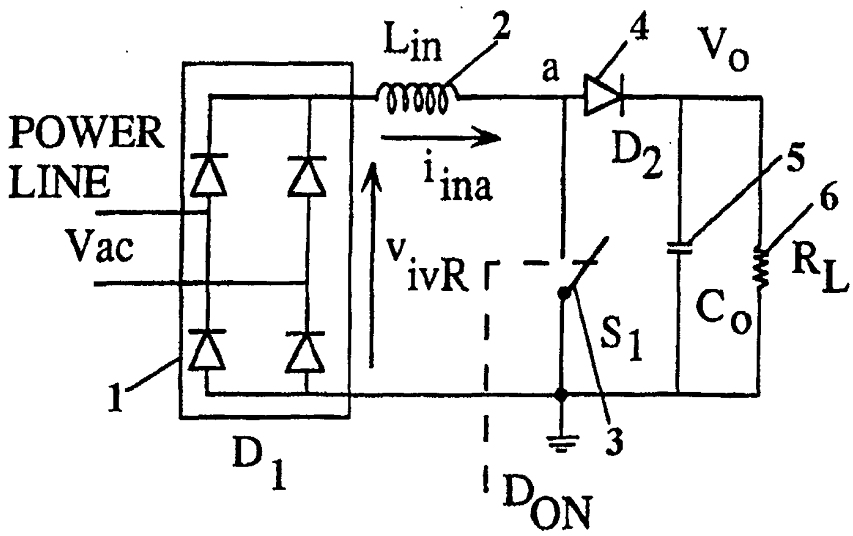

Fig. 1(prior art)

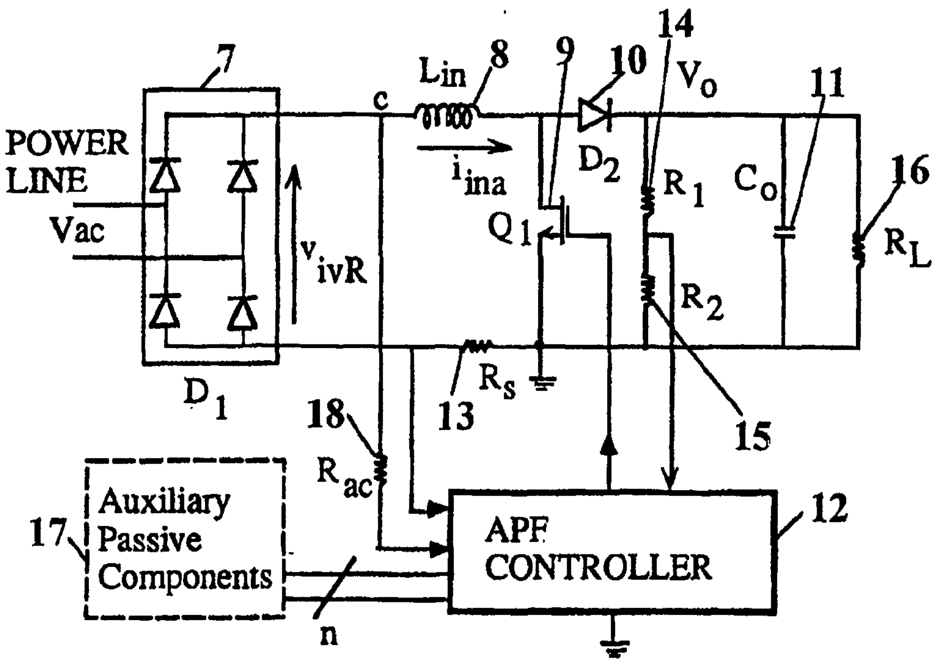

Fig. 2(prior art)

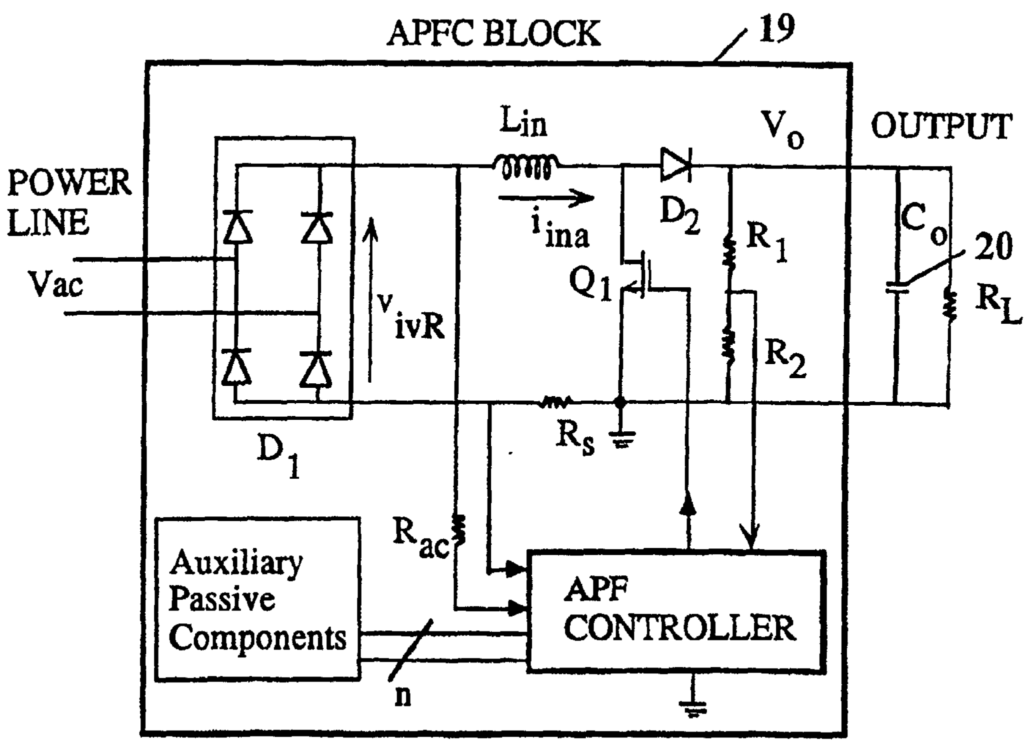

Fig. 3(prior art)

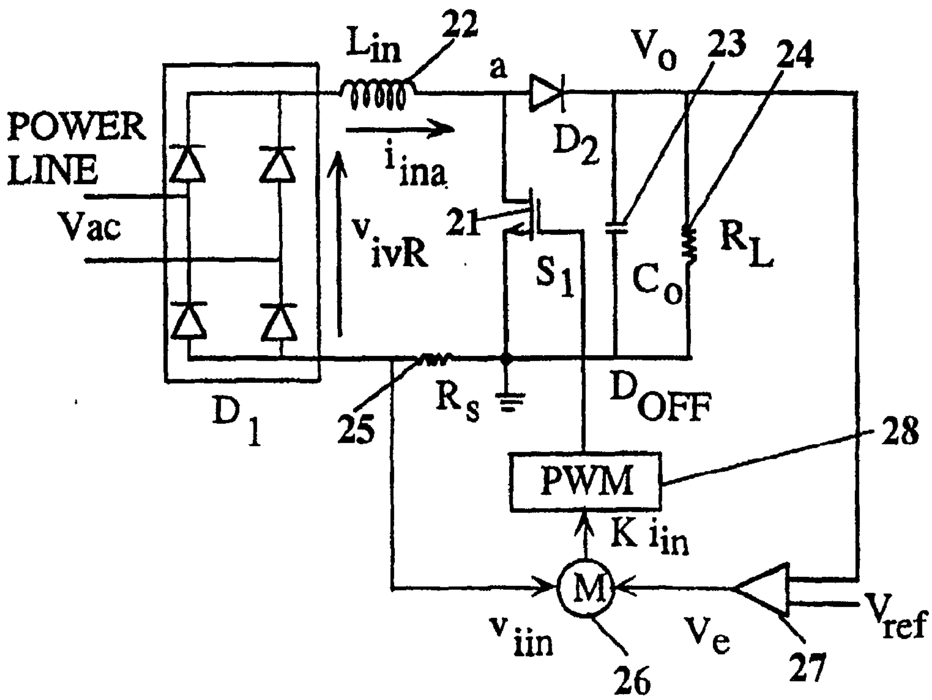

Fig. 4(prior art)

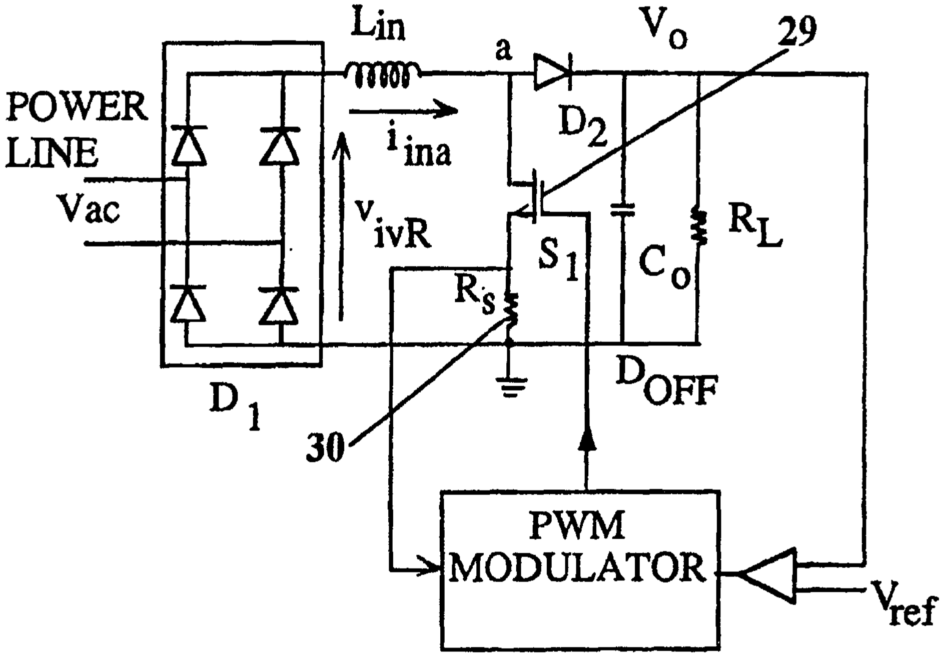

Fig. 5(prior art)

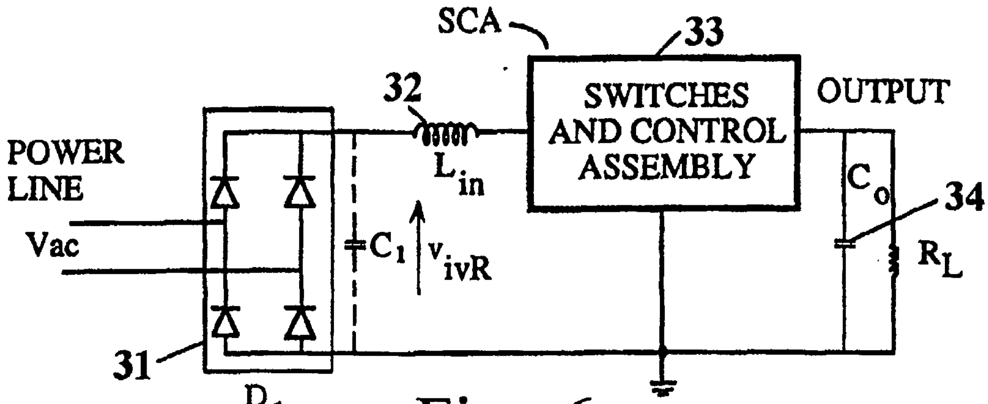

Fig. 6

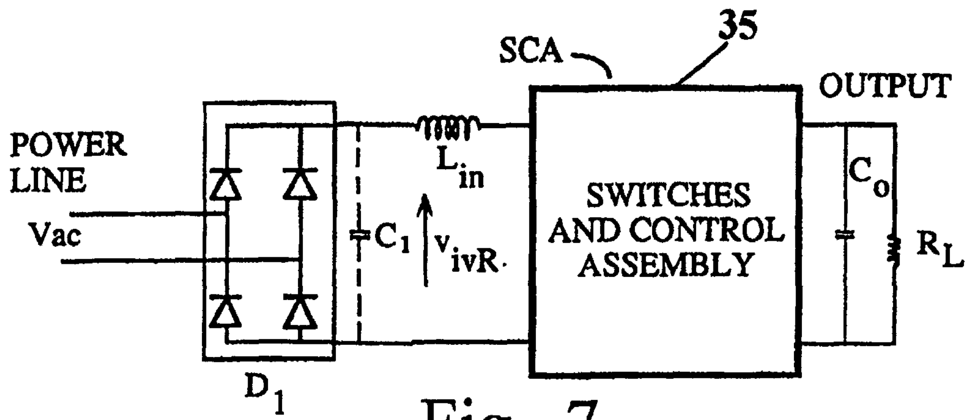

Fig. 7

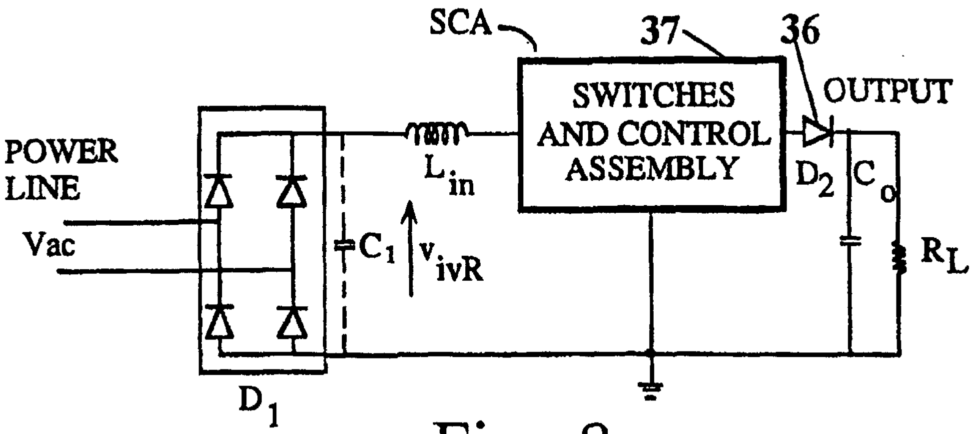

Fig. 8

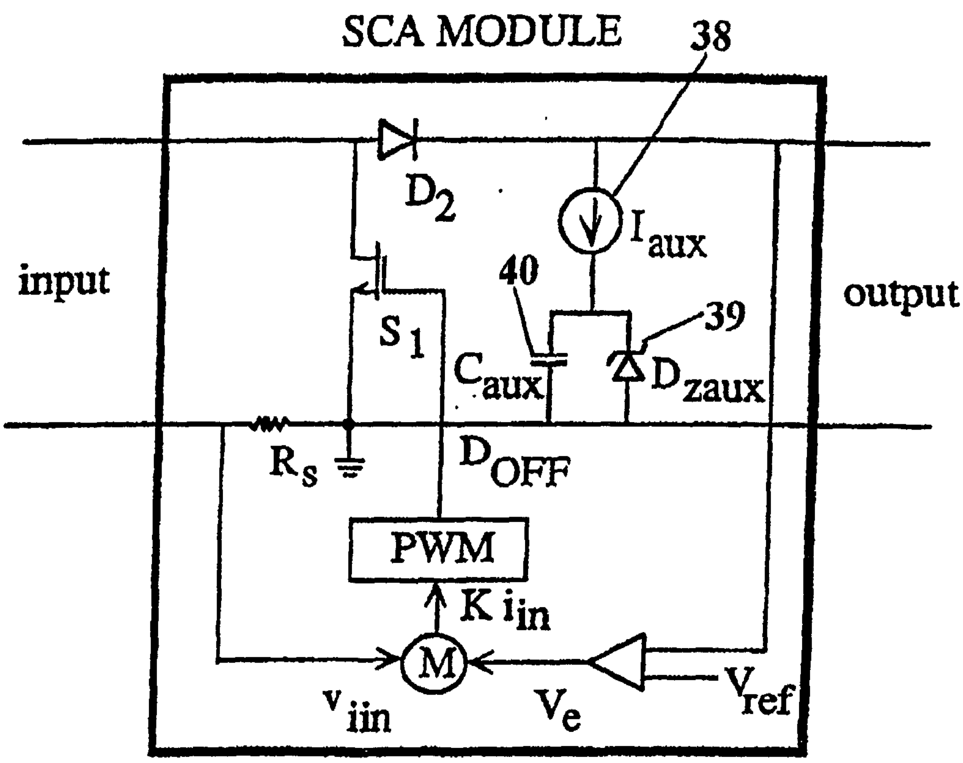
SCA MODULE
38
input
output
D2
Iaux
40
39
S1
Caux
Dzaux
Rs
DOFF
PWM
K iin
M
viin
Ve
Vref

Fig. 9

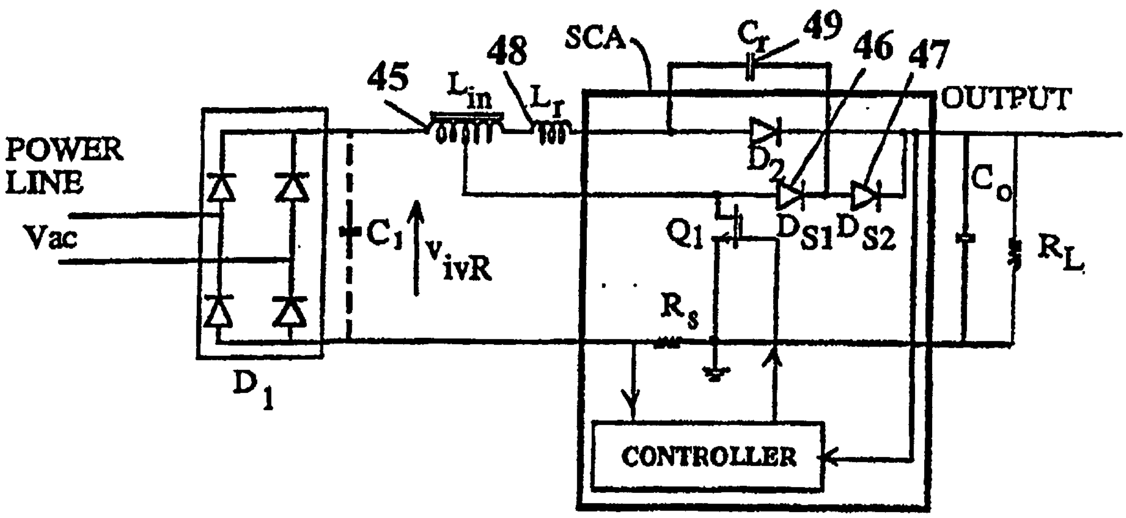
45
48
SCA
Cr
49
46
47
Lin
Lr
OUTPUT
POWER
LINE
Vac
D2
C1
ViVR
Q1
DS1
DS2
Co
RL
Rs
D1
CONTROLLER

Fig. 10

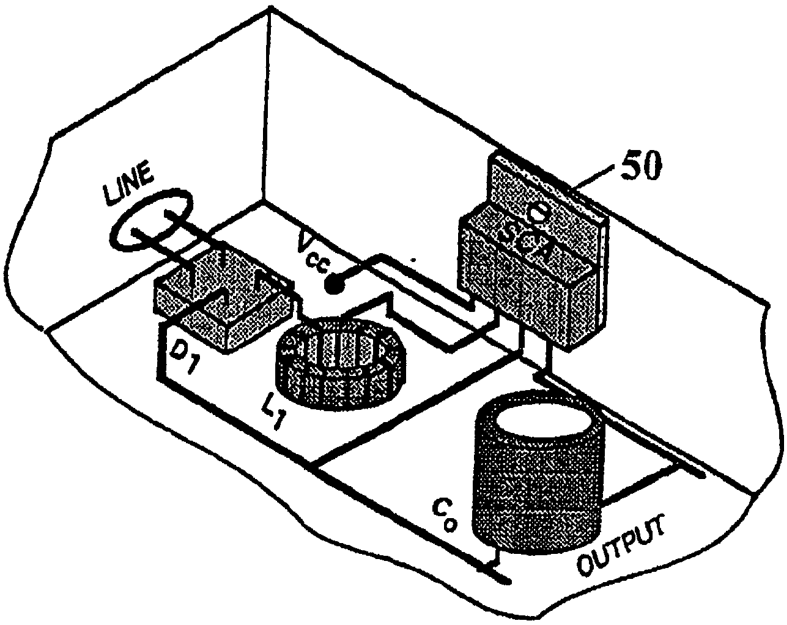

Fig. 11

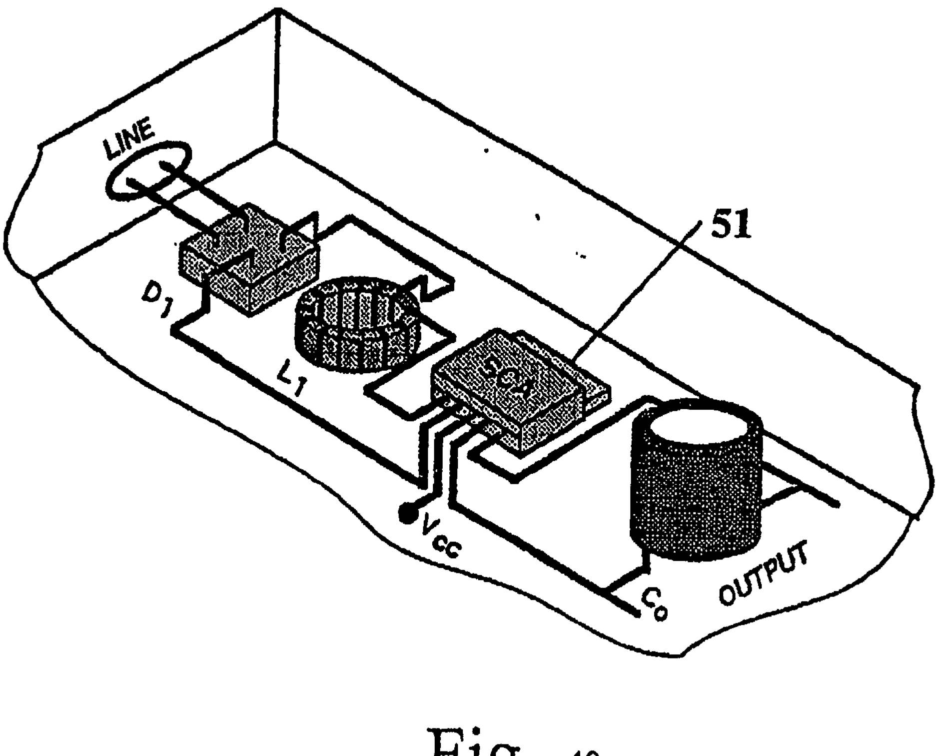

Fig. 12

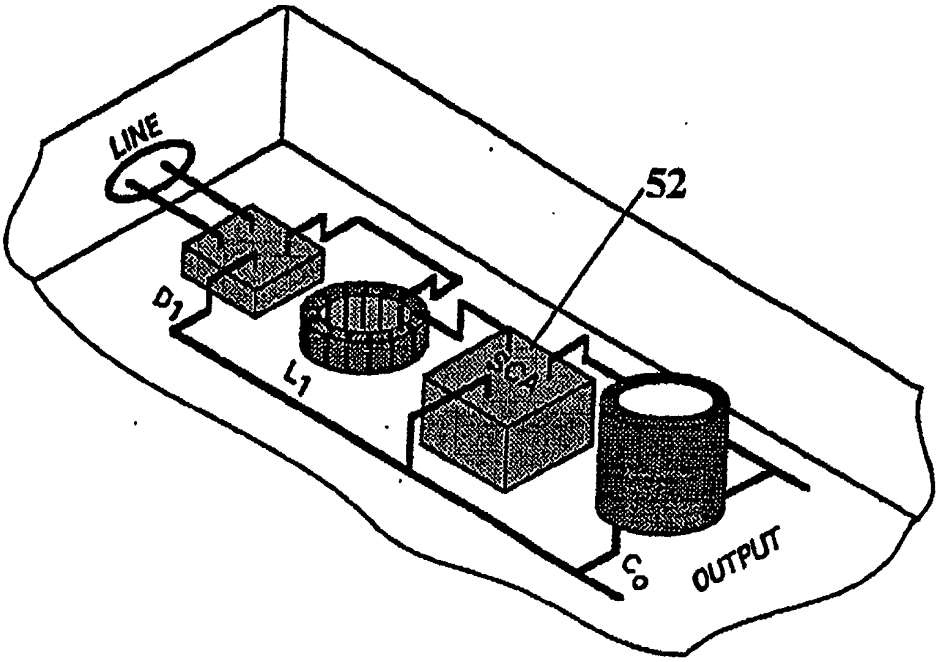

Fig. 13

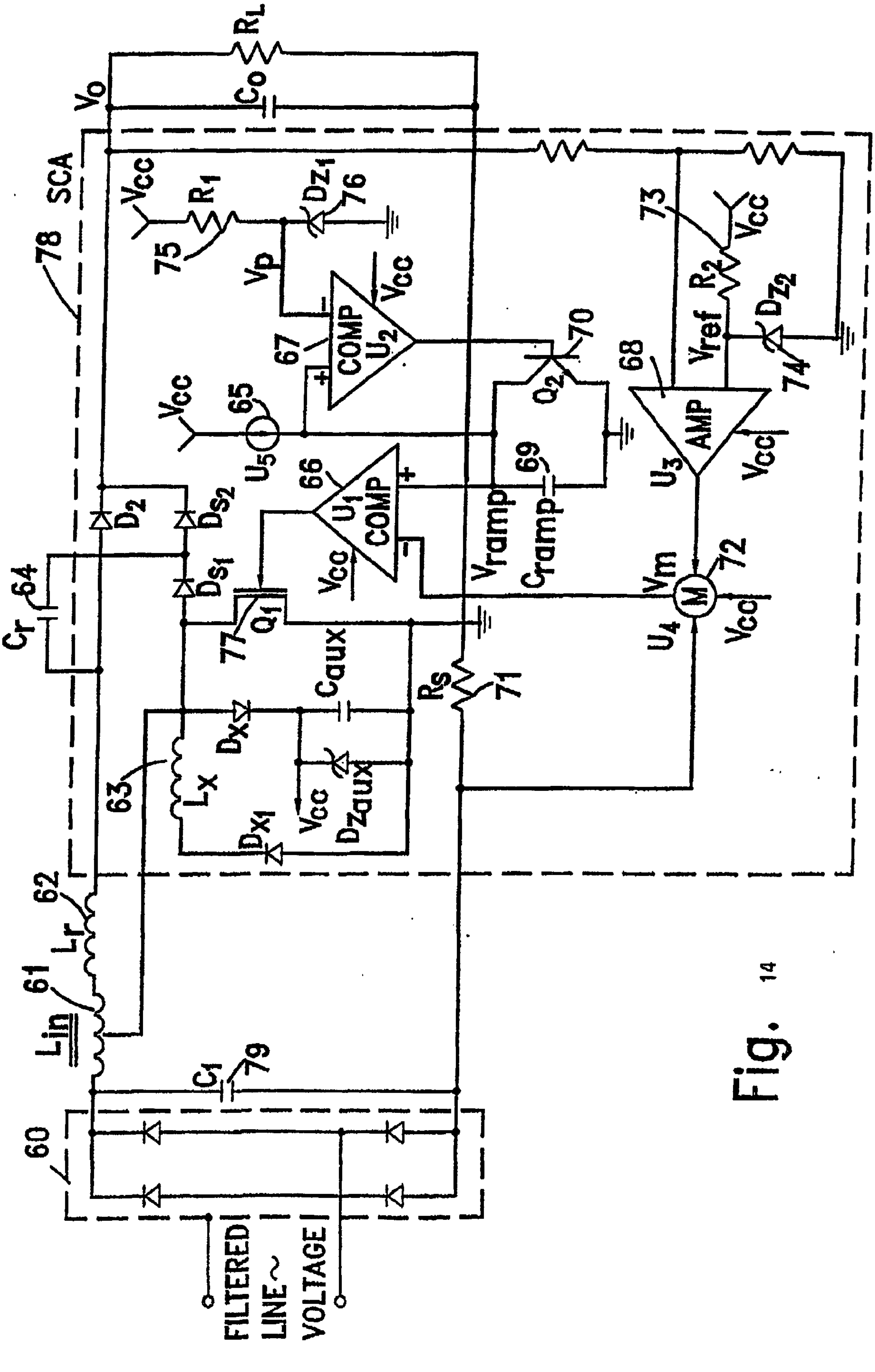
FILTERED
LINE~
VOLTAGE
60
79
C1
Lin
61
Lr
62
63
Lx
Dx
Dx1
Cr
64
D2
Ds1
Ds2
Caux
Vcc
Dzaux
Rs
71
Q1
77
COMP
U1
66
Vcc
Vramp
Cramp
69
U5
65
Vcc
COMP
U2
67
Vp
R1
75
Dz1
76
Q2
70
AMP
U3
68
Vref
R2
73
Dz2
74
M
72
U4
Vm
Vcc
SCA
78
Vo
Co
RL

Fig. 14

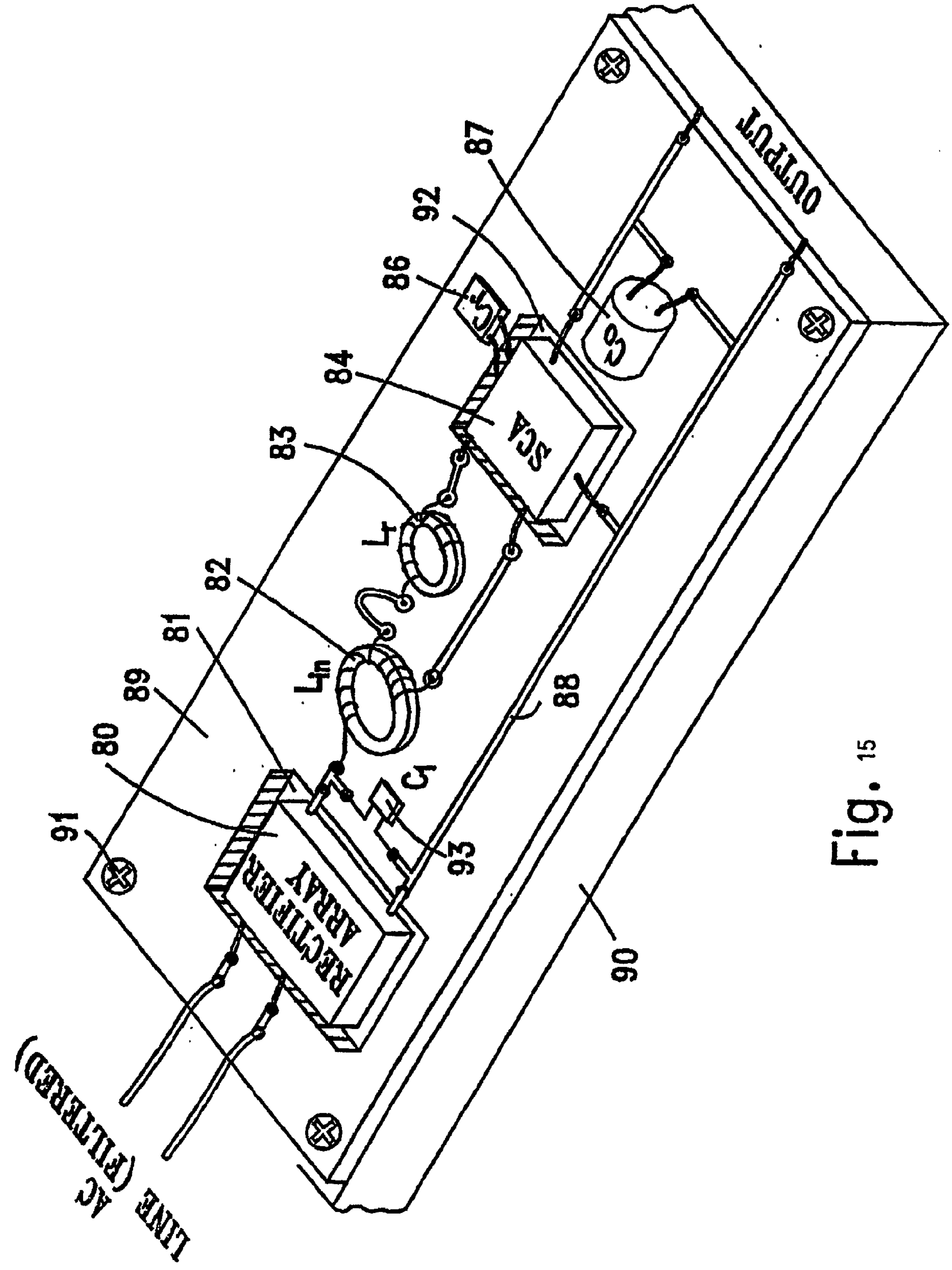
91
80
89
81
82
83
84
86
92
87
OUTPUT
SCA
C2
Lr
Lin
C1
93
88
90
RECTIFIER ARRAY
LINE AC (FILTERED)

Fig. 15