(12) UK Patent Application (19) GB (11) 2 454 389 (13) A

(43) Date of A Publication 06.05.2009

(21) Application No: 0901815.1

(22) Date of Filing: 13.01.2006

Date Lodged: 05.02.2009

(62) Divided from Application No
0600658.9 under Section 15(9) of the Patents Act 1977

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(51) INT CL:
H02M 7/48 (2007.01) ***H02M 3/315*** (2006.01)

(56) Documents Cited:
GB 2419968 A **EP 1235339 A2**
WO 2004/001942 A1

(58) Field of Search:
UK CL (Edition X) **H2F**
INT CL **H02M**
Other: **Online databases: EPODOC, OPTICS, WPI**

(54) Abstract Title: **Power conditioning unit**

(57) The present invention concerns a power conditioning unit for controlling the transfer of power from a dc energy source such as a solar panel, a fuel cell or a dc wind turbine, into an ac output. The ac output may be connected to the mains or grid utility supply, or used independently. The power conditioning unit comprises a dc-dc power converter 3 for receiving dc power, an energy storage capacitor 4, and a dc-ac power converter 5 for delivering ac power. Synchronised, independent control blocks 7, 8 control the system. The described method of control allows use of a smaller energy storage capacitor 4 than in prior systems. The capacitor 4 may have a value less than 20 microfarads. The energy storage capacitor 4 may thus be a non-electrolytic capacitor, such as a polyester or polypropylene capacitor, rather than a short lifetime aluminium electrolytic capacitor. Capacitor lifetimes of up to 500,000 hours can thus be achieved. The unit includes two control blocks. A first, power extraction control block 51 controls the dc-dc converter 3 to control power extracted from the dc power source and provided to the energy storage capacitor 4. A second, power injection control block 52 controls the dc-ac converter 5 to control power injected into the ac mains power supply from said energy storage capacitor.

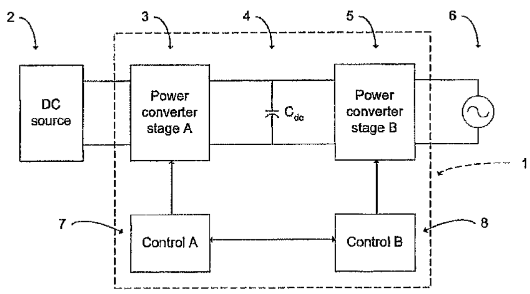

Figure 1

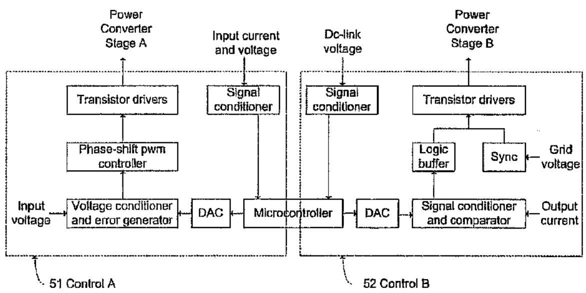

Figure 7

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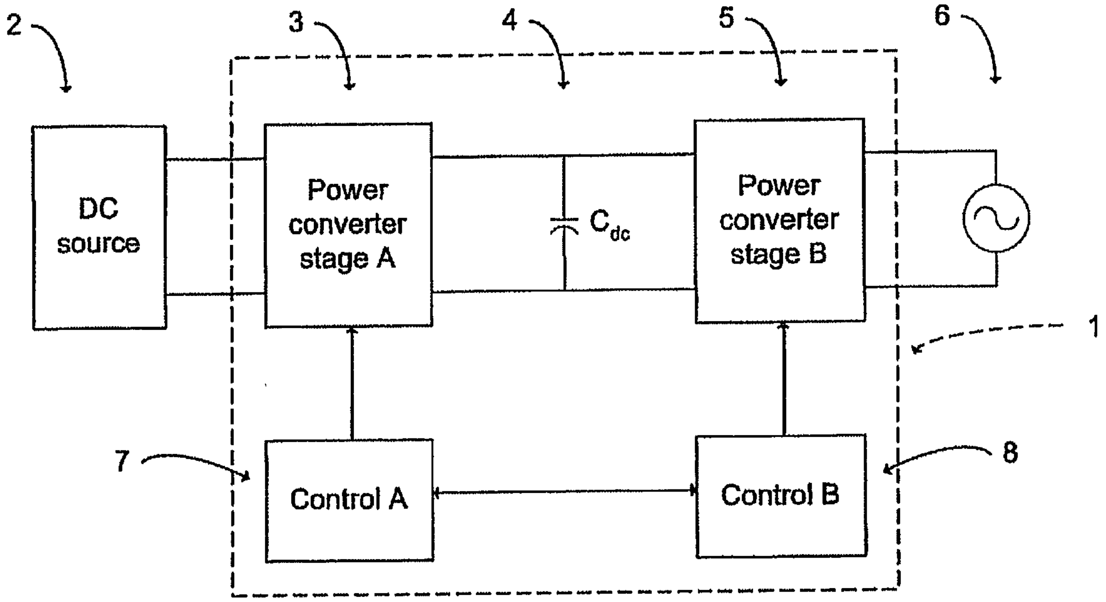

Figure 1

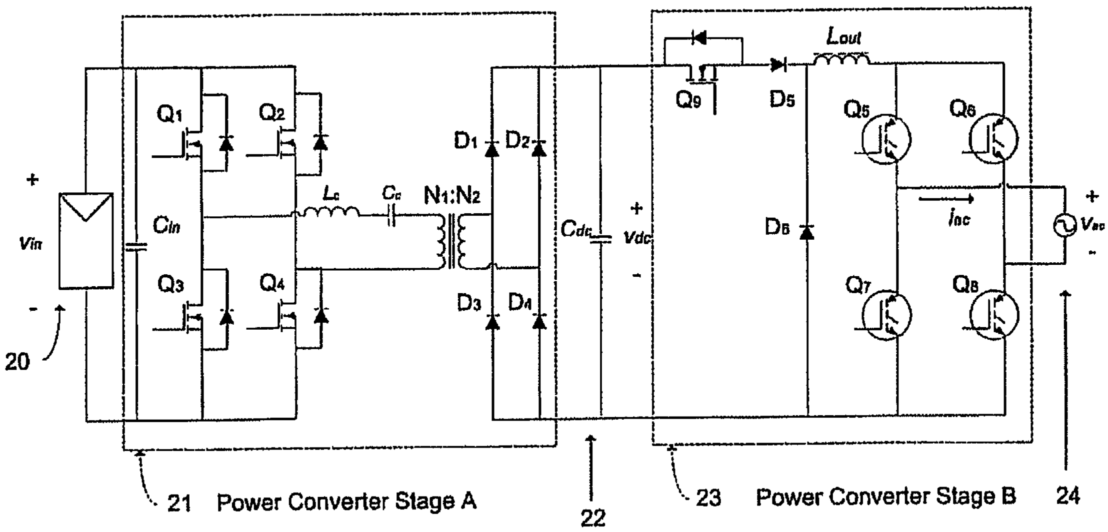

Figure 2

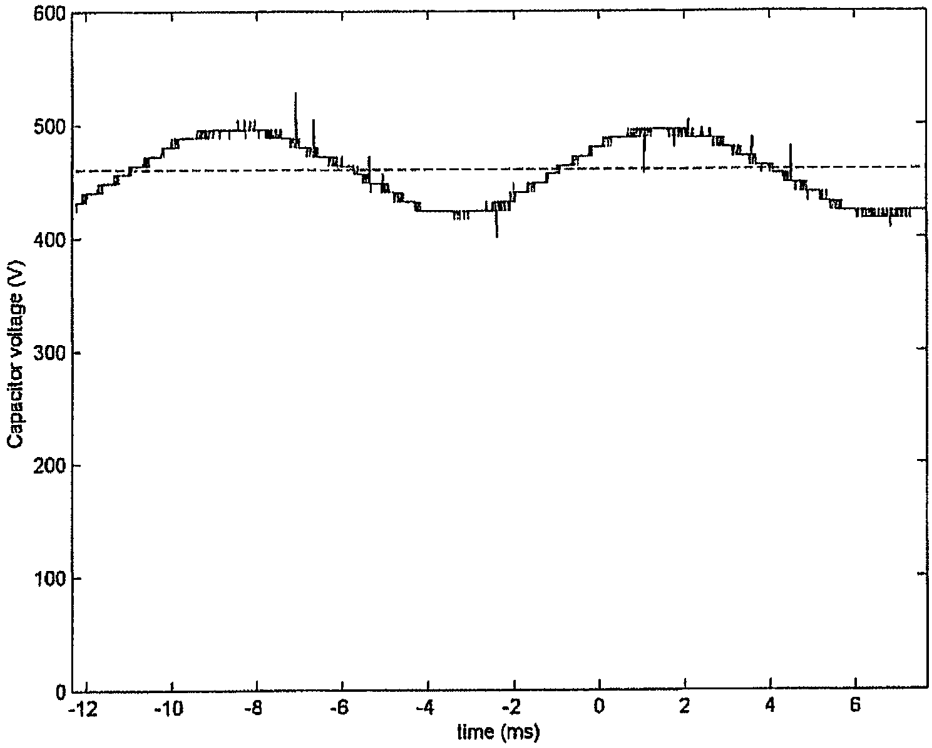

Figure 3

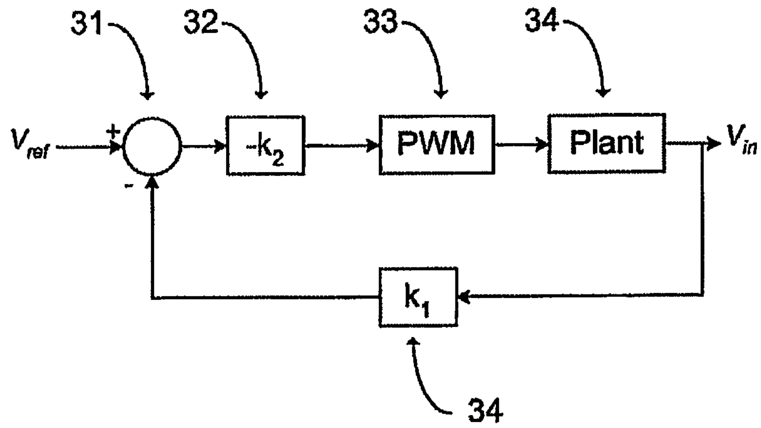

Figure 4

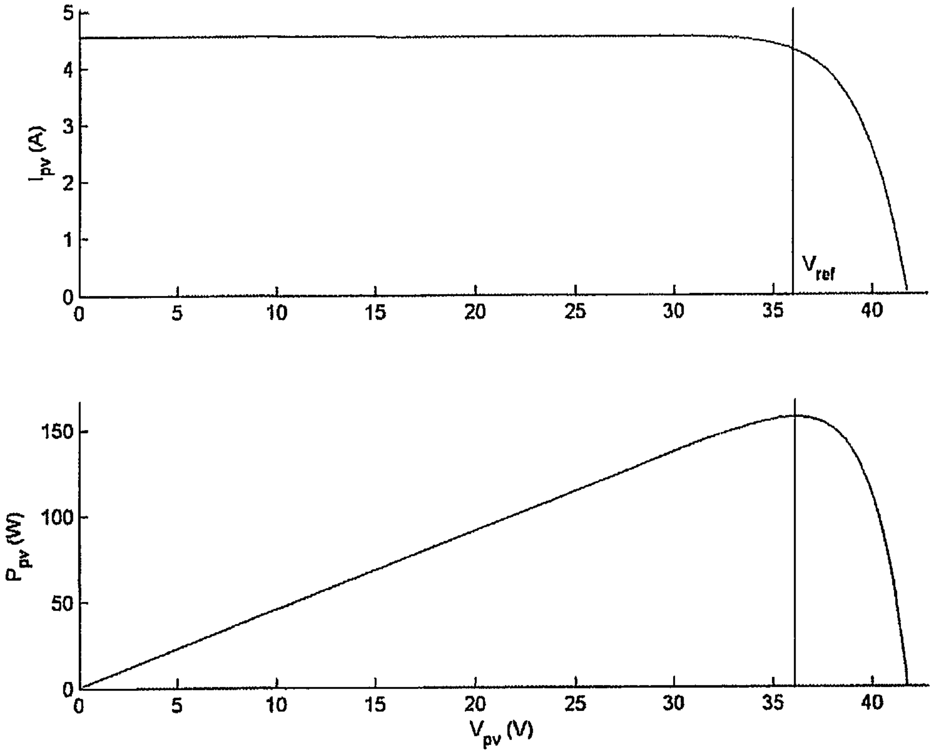

Figure 5

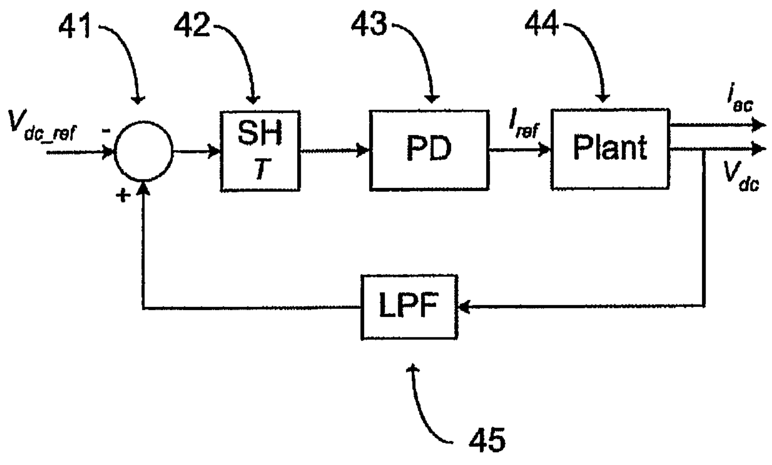

Figure 6

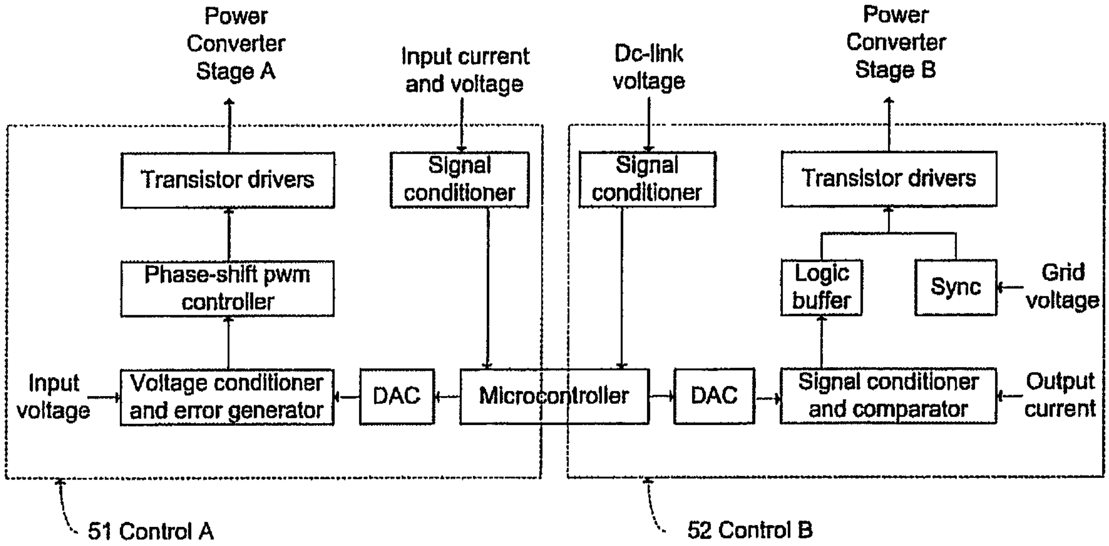

Figure 7

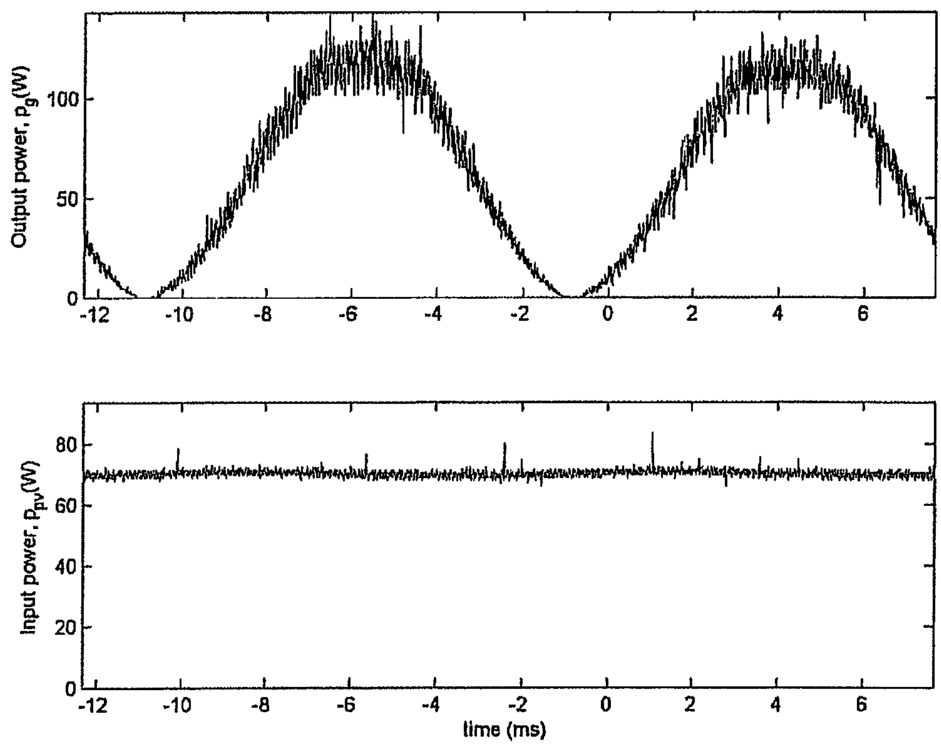

Figure 8

Power Conditioning Unit

The present invention relates to a power conditioning unit for delivering power from a dc power source to an ac output, particularly suitable for ac voltages greater than 50 volts, either for connecting directly to the mains or grid utility supply, or for powering mains devices directly, independent from the mains utility supply.

A number of power electronics converters have been produced in the past for research or commercial purposes, see for example EP0780750, EP0947905, and JP2000020150. In these solutions a capacitor is used as a reservoir and for filtering of high-frequency currents. However, attention is not directly paid into the choice of capacitor and the control of energy input and output. It is common to encounter aluminium electrolytic capacitors in power supplies. These capacitors have lifetimes in the range of 2000 to 12000 hours, that is, up to 1.4 years of continuous service. In contrast other capacitor technologies, such as polyester, can achieve lifetimes of up to 500,000 hours or slightly more than 50 years. Therefore, it would be advantageous to provide a better lifetime of the power converter by using polyester or polypropylene capacitor. This is possible with the method of energy control explained herein.

We will describe a method to control direct current energy sources, in particular a method to control direct current energy sources that utilise power electronics converters to condition the input power into alternating current electricity that is supplied to the mains. Such power electronics converter comprises of a plurality of conversion stages and one energy reservoir in the form of a capacitor. The method presented allows the utilisation of long-lifetime polyester or polypropylene capacitors as opposed to short-lifetime electrolytic capacitors. The method uses two control algorithms: one algorithm controls the power extracted from the energy source that is supplied to the energy reservoir and another controls the transfer of power from the reservoir into the electricity mains.

According to the invention there is provided a power conditioning unit for delivering power from a dc power source to an ac mains power supply output, the power conditioning unit comprising: a power conditioning unit input for receiving power from said dc power source; a power conditioning unit output for delivering ac power; an energy storage capacitor; a dc-to-dc converter having an input connection coupled to said power conditioning unit input and an output connection coupled to the energy storage capacitor; and a dc-to-ac converter having an input connection coupled to said energy storage capacitor and an output connection coupled to said power conditioning unit output; wherein said energy storage capacitor is a non-electrolytic capacitor; and wherein said power conditioning unit comprises two control blocks, a first, power extraction control block to control said dc-to-dc converter to control power extracted from said dc power source and provided to said energy storage capacitor, and a second, power injection control block to control said dc-to-ac converter to control power injected into said ac mains power supply from said energy storage capacitor; and wherein said power extraction control block has an input coupled to said power conditioning unit input for receiving power from said dc power source and has an output to control said dc-to-dc converter and is configured to regulate a voltage of said dc power source to control power extracted from said dc power source to said energy storage capacitor.

The ac mains power supply output may be connected to the utility grid, so that the power conditioning unit delivers power into the grid, or it may be a standalone power supply output for supplying power to electrical appliances.

The dc-to-dc converter may be configured to draw a substantially constant power from the dc power source regardless of a voltage on the energy storage capacitor. It may be configured to perform maximum power point tracking (MPPT) of the dc power source, and this may be achieved by maintaining a voltage or current from the dc power source substantially at a reference voltage or current. This may comprise controlling transistors in the dc-to-dc converter responsive both to the voltage or current from the dc power source and to a voltage or current to the energy storage capacitor.

The dc-to-ac converter may be configured to deliver a substantially sinusoidal current or voltage to the ac mains power supply output regardless of a voltage on the energy storage capacitor. This may be achieved by maintaining a current or voltage to the power supply output substantially at a reference sinusoid current or voltage. This may comprise controlling transistors in the dc-to-ac converter responsive both to a voltage or current from the energy storage capacitor and to the current or voltage to the power supply output.

The energy storage capacitor may comprise a non-electrolytic capacitor such as a film-type capacitor (for example polyester or polypropylene). The value of the capacitance may be directly proportional to the maximum power transfer capability, that is, the rated power of the apparatus. This value may be lower than that of the capacitor in a conventional power conditioning unit with the same power rating. For example, less than 20 microfarads, less than 15 microfarads, less than 10 microfarads, less than 5 microfarads or another size available for a non-electrolytic capacitor.

We also describe a dc-to-dc converter for delivering power from a dc power source to a dc output, the converter being configured to maintain a voltage on the dc power source substantially constant over a range of dc output voltages, the converter comprising an input for receiving power from said dc power source, an output for delivering dc power, at least one power device for transferring power from the input to the output, a sensing circuit for sensing a voltage on said input, and a driver circuit for driving said at least one power device responsive to said sensing to control said power transfer.

We also describe an inverter for delivering power from a dc power source to an ac output, the inverter being configured to maintain a substantially sinusoidal output voltage or current over a range of dc power source voltages, the inverter comprising an input for receiving power from said dc power source, an output for delivering ac power, at least one power device for transferring power from the input to the output, a low-pass filter coupled to said input, a sensing circuit for sensing an output from the low-pass filter and comparing with a reference, and a driver circuit for driving said at least one power device responsive to said sensing to control said power transfer.

We also describe a power conditioning unit for delivering power from a dc power source to an ac mains power supply output, wherein a link capacitor of the power conditioning unit connected in parallel between an output of a dc-to-dc converter of said power conditioning unit and an input of a dc-to-ac converter of said power conditioning unit is not an electrolytic capacitor.

We also describe a method of controlling a power conditioning unit for delivering power from a dc source into an ac electricity supply, the power conditioning comprising: an input for connecting the dc power source; an output for connecting the electricity supply; a first, dc-to-dc power conversion stage for voltage conditioning of the dc power source; a second power conversion stage for power injection into the ac electricity supply; and a dc link energy storage capacitor for energy buffering from the dc power source to the electricity supply; wherein the method comprises controlling said second power conversion stage to control an amplitude of an ac current provided to said ac electricity supply output such that an amount of power transferred to said ac mains power supply output is dependent on a peak amplitude of a fluctuating sinusoidal component of a dc voltage on said energy storage capacitor.

Embodiments of the invention will now be described in detail, with reference to the accompanying drawings, in which:

Figure 1 shows a dc to ac system according to an embodiment of the present invention.

Figure 2 shows an example of a power conditioning unit suitable for control by the system of Figure 1.

Figure 3 shows DC capacitor voltage according to an embodiment of the present invention.

Figure 4 shows control block A according to an embodiment of the present invention.

Figure 5 shows characteristics of photovoltaic panel array as known in the art.

Figure 6 shows control block B according to an embodiment of the present invention.

Figure 7 shows an exemplary implementation of control blocks A and B according to an embodiment of the present invention.

Figure 8 shows output and input powers according to an embodiment of the present invention.

The present invention relates to a method of controlling the transfer of power from a dc energy source, such as a solar panel, fuel cell, dc wind turbine, etc, into the electricity mains supply, and in particular, this method allows the replacement of short-lifetime energy reservoirs by long-lifetime polyester or polypropylene capacitors.

The energy control method can be used in any power electronics converter device (1) as shown in Figure 1. This apparatus (1) is made of three major elements: a power converter stage A (3), one reservoir capacitor C_{dc} (4), and one power converter stage B (5). The apparatus (1) has a plurality of inputs connected to a direct current (dc) source, such as a solar or photovoltaic panel array (2) comprising one or more dc sources connected in series and/or in parallel. The apparatus (1) is also connected to the electricity supply (6) so that the energy extracted from the dc source (1) is transferred into the mains (6).

The power converter stage A (3) may be of different types: it can be a step-down converter where the voltage at the input is decreased using some power electronics topology; it can be a step-up converter where the input voltage is amplified using a different type of power electronics circuit; or it can do both amplify and attenuate the input voltage. In addition, it may provide electrical isolation by means of a transformer or a coupled inductor. In whatever case, the electrical conditioning of the input voltage should be such that the voltage across the capacitor C_{dc} (4) remains higher than the grid voltage (6) magnitude at all times. Also, this block contains one or more transistors, inductors, and capacitors. The transistor(s) are driven through a pulse width modulation (PWM) generator. The PWM signal(s) have variable duty cycle, that is, the ON time is variable with respect to the period of the signal. This variation of the duty cycle effectively controls the amount of power transferred across the power converter stage A (3).

The power converter stage B (5) injects current into the electricity supply (6). Therefore, the topology utilises some means to control the current flowing from the capacitor C_{dc} (4) into the mains (6). The circuit topology can be either a voltage source inverter or a current source inverter.

Figure 2 shows an example of a power conditioning unit to which the control system of Figure 1 may be applied. Control A (7 in Figure 1) may be connected to the control connections (e.g. gates or bases) of transistors in power converter stage A (21) to control the transfer of power from the dc energy source (20). The input of this stage is connected to the dc energy source and the output of this stage is connected to dc link capacitor 22. This capacitor stores energy from the dc energy source for delivery to the mains supply (24). Control A may be configured to draw a substantially constant power from the dc energy source regardless of the dc link voltage V_{dc} on C_{dc}.

Control B (8 in Figure 1) may be connected to the control connections of transistors in power converter stage B (23) to control the transfer of power to the mains supply. The input of this stage is connected to the dc link capacitor and the output of this stage is connected to the mains supply. Control B may be configured to inject a substantially sinusoidal current into the mains supply regardless of the dc link voltage V_{dc} on C_{dc}.

The capacitor C_{dc} (4) acts as an energy buffer from the input to the output. Energy is supplied into the capacitor via the power stage A (3) at the same time that energy is extracted from the capacitor via the power stage B (5). The system provides a control method that balances the average energy transfer and allows a voltage fluctuation, resulting from the injection of ac power into the mains (6), superimposed to the average dc voltage of the capacitor C_{dc} (4), as shown in Figure 3. The figure shows an average voltage of 475V and a 100Hz fluctuation of peak amplitude of 30V. The peak amplitude depends on the amount of power being transferred from the input (2 in Figure 1) to the output (6). The frequency of the oscillation can be either 100Hz or 120Hz depending on the line voltage frequency (50Hz or 60Hz respectively).

Two synchronised and independent control blocks control the system (1): a control block A (7) that directly controls the power stage A (3), and a control block B (8) that directly controls the power stage B (5).

Control block A (7) has the configuration shown in Figure 4. It comprises an adder (31), a negative proportional gain (32), a PWM generator (33), the system plant (34), and a feedback gain (35). This control block regulates the voltage across the dc source (2). This voltage, v_m, is measured and adjusted by gain k_1 (35). It is then subtracted to a voltage reference, v_{ref}, using the adder (31). The error, (v_{ref}-$k_1 v_m$), is then amplified by a factor of $-k_2$. The resulting signal is negatively proportional to the error. Therefore, a positive error generates a decrement in the driving signal and conversely. This driving signal is input to a PWM generator (33) that can be a microcontroller, or a PWM integrated circuit. This block generates digital pulses that, in turn, drive the transistors of the power stage A (3) that is equivalent to the plant (34).

Controlling the dc source (2) voltage directly controls the power being transferred across power stage A (3) as is shown in Figure 5 for a photovoltaic panel array.

Control block B (8) has the configuration shown in Figure 6. It comprises an adder (41), a sample and hold (SH) with period T block (42), a proportional-derivative (PD) compensator (43), the system plant (44), a low-pass filter (LPF) feedback block (45). This control block regulates the average voltage across capacitor C_{dc} (4). Because the voltage, v_{dc}, contains the sum of a constant voltage and a fluctuating sinusoidal component, the signal is scaled and filtered using the LPF block (45). This generates a constant voltage that is compared against a reference, v_{dc_ref}, using adder (41). The error is measured every T seconds using a Sample and Hold, SH, block (42). The resulting sampled error is forwarded to a PD compensator (43) that sets the amplitude of the current injected to the mains (6) via power stage B (5). The update of this current reference, I_{ref}, amplitude is done every T seconds, which is the inverse of the line voltage frequency. Hence, it can take the values of 0.02 or 0.0167 seconds for a line frequency of 50 or 60 Hz respectively. This is needed in order to prevent current injection distortion.

An implementation of control blocks A and B is shown in Figure 7. Both blocks operate independently but share a common microcontroller for simplicity. The microcontroller performs the control strategy depicted in Figure 6 for block B. In addition the microcontroller could incorporate some means of maximum power point tracking control in case the input source is a photovoltaic panel in block A in order to generate a reference input voltage used in Figure 4. Consequently the input voltage and current and the dc-link voltage are fed into the microcontroller via an arrangement of operational amplifiers or signal conditioning blocks.

The control shown in Figure 4 for block A is implemented using analogue electronics in the form of operational amplifiers and the phase-shift PWM controller depicted in Figure 7 (51). As mentioned before, the input voltage reference is obtained through the microcontroller via a digital to analogue converter (DAC). The proportional error is obtained inside the phase-shift PWM controller that, in turn, generates PWM signals for the transistors of stage A (21).

Implementation of control B (52) includes a current transducer that senses the rectified output current. This signal is conditioned to appropriate voltage levels using operational amplifiers and is then compared against a reference current. The reference current is generated in the microcontroller by an algorithm shown in Figure 6 and the resulting digital word is sent to a DAC in order to get an analogue, instantaneous, current reference. Changes to the current magnitude are done in a periodic basis (with period equal to the grid voltage period) in order to avoid current distortion. The result of the comparison between the reference and the actual current is buffered through a D flip-flop which, in turn, drives transistor Q9 in Figure 2. Transistors Q5-Q8 form a full-bridge that switches at line frequency using an analogue circuit synchronised with the grid voltage. Transistors Q5 and Q8 are on during the positive half cycle of the grid voltage and Q6 and Q7 are on during the negative half cycle of the grid voltage.

Figure 8 shows the output and input powers using the aforementioned control. Clearly, the instantaneous power output is a sinusoid superimposed to an average positive value. In contrast, the input is constant throughout the period of the line voltage. The power difference creates an energy mismatch that is absorbed in capacitor C_{dc}. This effectively appears as a fluctuation across the capacitor, as is shown in Figure 3.

No doubt many other effective alternatives will occur to the skilled person. It will be understood that the invention is not limited to the described embodiments and encompasses modifications apparent to those skilled in the art lying within the scope of the claims appended hereto.

CLAIMS: GBP290556A

1. A power conditioning unit for delivering power from a dc power source to an ac mains power supply output, the power conditioning unit comprising:

a power conditioning unit input for receiving power from said dc power source;

a power conditioning unit output for delivering ac power;

an energy storage capacitor;

a dc-to-dc converter having an input connection coupled to said power conditioning unit input and an output connection coupled to the energy storage capacitor; and

a dc-to-ac converter having an input connection coupled to said energy storage capacitor and an output connection coupled to said power conditioning unit output;

wherein said energy storage capacitor is a non-electrolytic capacitor; and

wherein said power conditioning unit comprises two control blocks, a first, power extraction control block to control said dc-to-dc converter to control power extracted from said dc power source and provided to said energy storage capacitor, and a second, power injection control block to control said dc-to-ac converter to control power injected into said ac mains power supply from said energy storage capacitor; and

wherein said power extraction control block has an input coupled to said power conditioning unit input for receiving power from said dc power source and has an output to control said dc-to-dc converter and is configured to regulate a voltage of said dc power source to control power extracted from said dc power source to said energy storage capacitor.

2. A power conditioning unit as claimed in claim 1 wherein said power injection control block has an input coupled to said energy storage capacitor and an output

coupled to control said dc-to-ac converter and is configured to control an amplitude of an ac current provided to said ac mains power supply output.

3. A power conditioning unit as claimed in claim 1 or 2 wherein said power injected into said ac mains supply has a sinusoidal shape, and wherein said first control block is configured to extract a substantially constant power from said dc power source over a period of said sinusoidal shape.

4. A power conditioning unit as claimed in claim 3, wherein an instantaneous ac power output of said power conditioning unit has a sinusoidal shape, wherein said power extracted from said dc power source is substantially constant over a cycle of said ac power output, and wherein a difference between said power extracted from said dc power source and said instantaneous ac power output defines an energy mismatch which appears as said fluctuating sinusoidal component of said dc voltage on said energy storage capacitor.

5. A power conditioning unit according to any one of claims 1 to 4 wherein said dc-to-dc converter comprises:

at least one power transistor for transferring power from the input connection of the dc-to-dc converter to the output connection of the dc-to-dc converter; and

wherein said power extraction control block comprises:

a sensing circuit for sensing a voltage on said input connection; and

a driver circuit for driving said at least one power transistor device responsive to said sensing to control said power transfer.

6. A power conditioning unit according to claim 5, wherein the power extraction control block further comprises a reference voltage generator, and wherein the driver circuit is configured to substantially minimise a difference between a reference voltage from said reference voltage generator and the sensed voltage.

7. A power conditioning unit as claimed in any preceding claim wherein said fluctuating sinusoidal component of said dc voltage on said energy storage capacitor has a frequency of twice that of said ac power.

8. A power conditioning unit according to any preceding claim, wherein said energy storage capacitor has a capacitance of less than 15 microfarads, preferably less than 10 microfarads, more preferably less than 5 microfarads.

9. A power conditioning unit according to any preceding claim, wherein said energy storage capacitor has a capacitance of less than twenty microfarads.

10. A power conditioning unit according to any preceding claim, wherein said energy storage capacitor comprises a film-type capacitor.

Application No:	GB0901815.1	**Examiner:**	Bill Riggs
Claims searched:	1 - 10	**Date of search:**	24 February 2009

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
A	-	WO 2004/001942 A1 (Powerlynx A/S) see whole doc.
A	-	EP 1235339 A2 (Canon KK) see whole doc.
A	-	GB 2419968 A (Enecsys Ltd.) see whole doc.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
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&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application

Field of Search:

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Worldwide search of patent documents classified in the following areas of the IPC

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The following online and other databases have been used in the preparation of this search report

Online databases: EPODOC, OPTICS, WPI

International Classification:

Subclass	Subgroup	Valid From
H02M	0007/48	01/01/2007
H02M	0003/315	01/01/2006