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U1S S2080

(56) Documents Cited:
WO 2004/100348 A1 **JP 2004312994 A**
JP 2002238246 A **JP 2000316282 A**

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UK CL (Edition X) **G3U, H2F**
INT CL[7] **G05F, H02J, H02M**
Other: **EPODOC, WPI**

(54) Abstract Title: **Regulating the voltage fed to a power converter**

(57) A power conditioning circuit comprises a direct current supply 1, a DC to DC converter 4, a DC to AC inverter 6 which feeds an AC output to a supply line and a controller 5 which regulates the DC link voltage produced by the DC to DC converter 4. Alternating current supplied to the output may be regulated by controlling the DC link voltage which is input to the DC to AC converter 6. Controller 5 may have a first voltage input from the output of the DC to DC converter 4 and a second voltage input from the AC supply line. Controller 5 may control the duty cycle of a power switch (fig 6, M5) and may maintain a phase relationship between the output voltage of the DC-AC inverter 6 and the voltage of the mains power supply line. The circuit may also comprise a reactive element (fig 2b L1) between the output of the DC_AC converter and the AC mains supply line. Switches (fig 2b S1,S2) are controlled to connect and disconnect the circuit from mains supply under conditions judged by controller 5. The circuit may be used to regulate the output of a solar panel or a fuel cell.

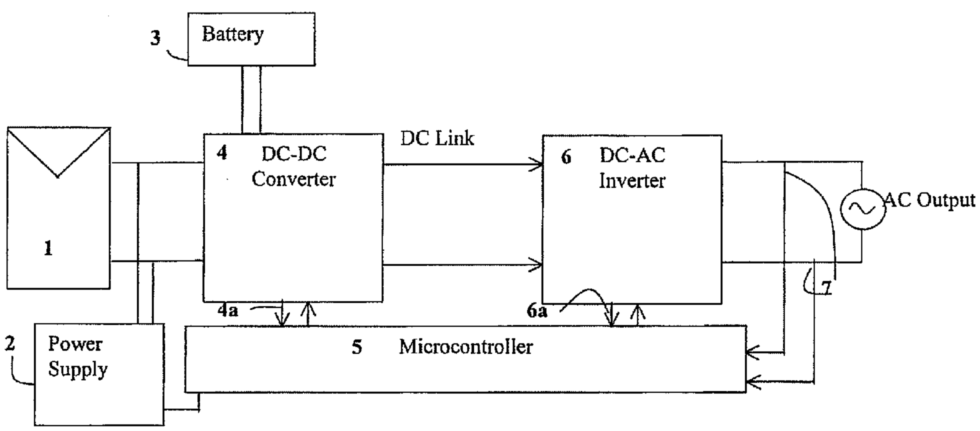


Figure 2a

GB 2 419 968 A

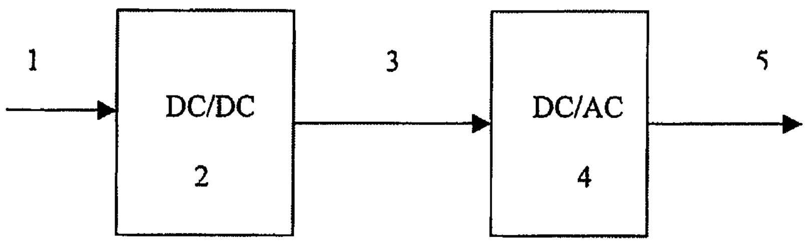
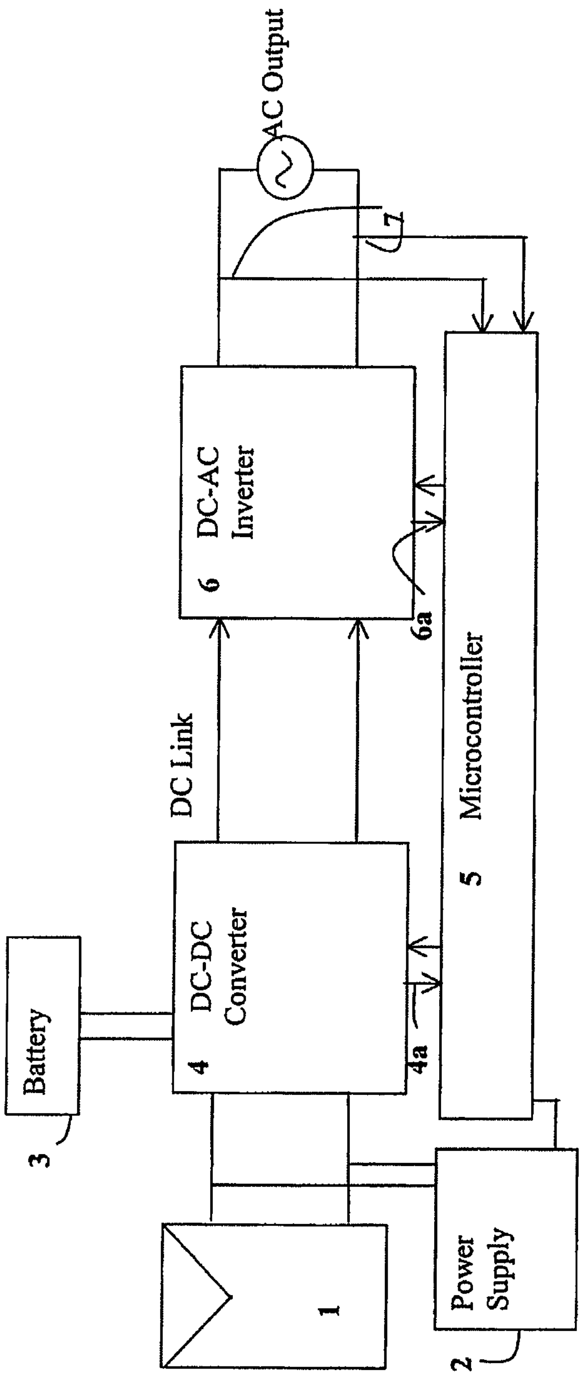


Figure 1



AC Output
7
DC-AC
Inverter
6
6a
DC Link
Microcontroller
5
Battery
3
DC-DC
Converter
4
4a
1
Power
Supply
2

Figure 2a

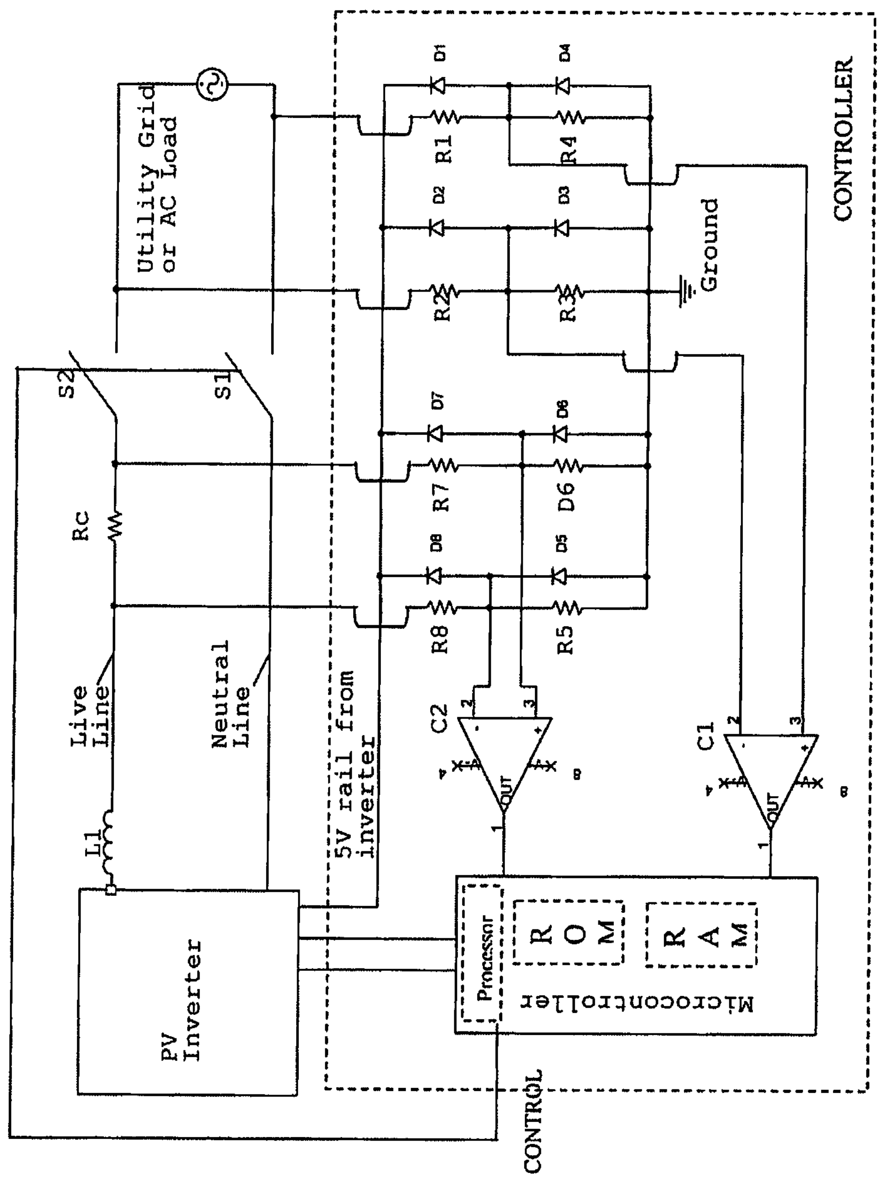

Utility Grid or AC Load
CONTROLLER
Ground
S2
S1
Rc
Live Line
Neutral Line
5V rail from inverter
L1
PV Inverter
C2
C1
R1
R2
R3
R4
R5
R7
R8
D6
D1
D2
D3
D4
D5
D7
D8
Processor
R O M
R A M
Microcontroller
CONTROL

Figure 2b

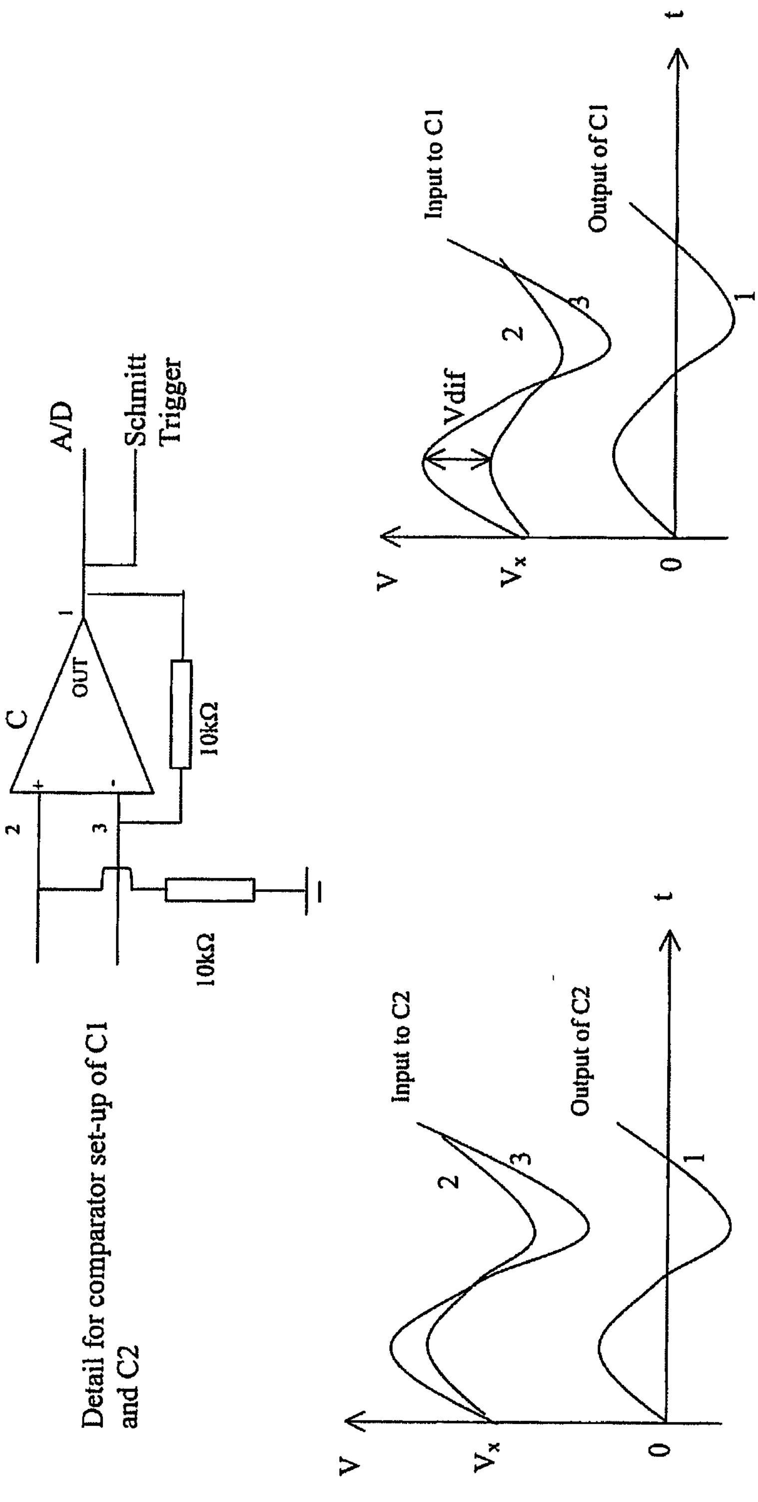

Detail for comparator set-up of C1 and C2
C
OUT
A/D
Schmitt Trigger
10kΩ
10kΩ
Input to C1
Output of C1
Vdif
Input to C2
Output of C2
V
V_x
0
t

Figure 2c

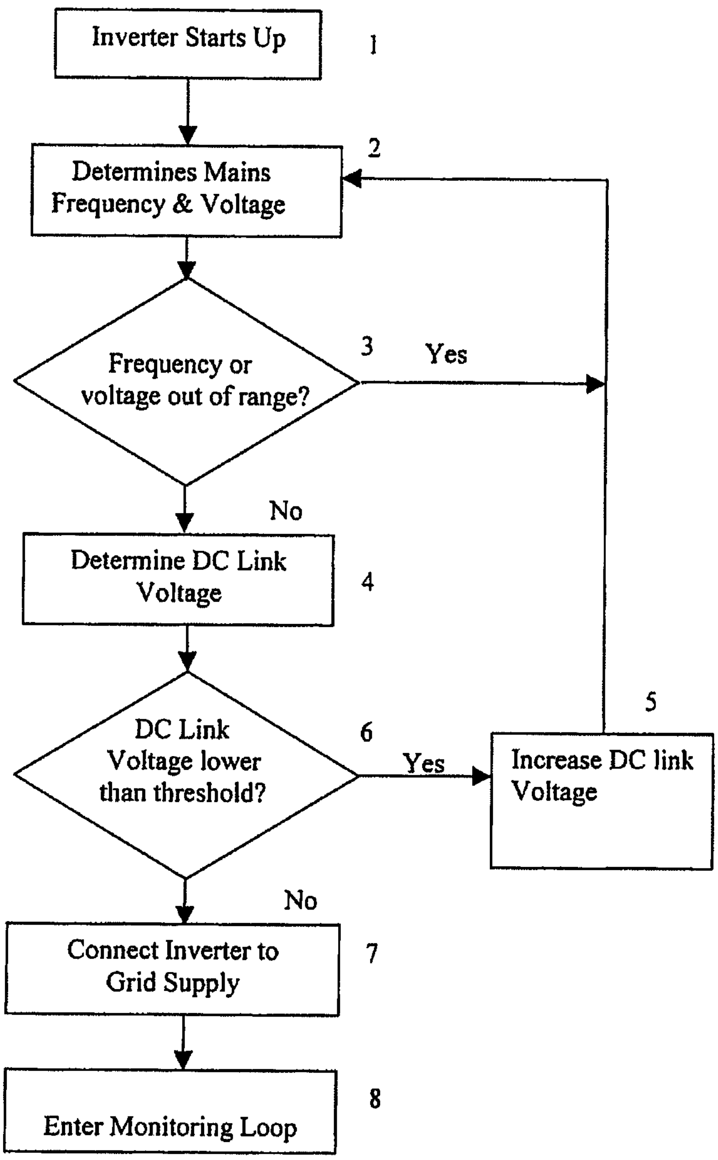

Inverter Starts Up
1
Determines Mains Frequency & Voltage
2
Frequency or voltage out of range?
3
Yes
No
Determine DC Link Voltage
4
DC Link Voltage lower than threshold?
6
Yes
No
Increase DC link Voltage
5
Connect Inverter to Grid Supply
7
Enter Monitoring Loop
8

Figure 3

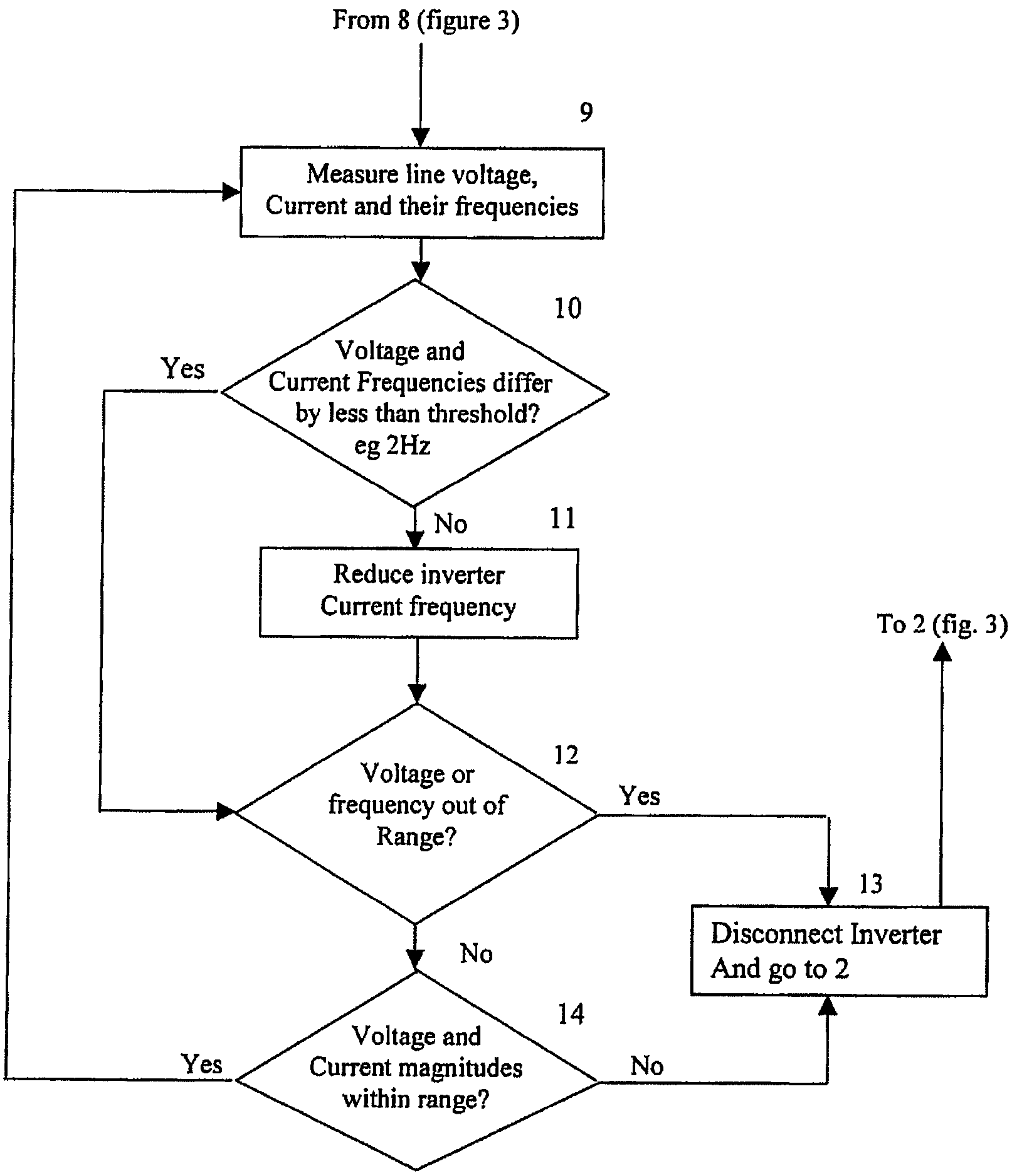

From 8 (figure 3)
9
Measure line voltage,
Current and their frequencies
10
Voltage and
Current Frequencies differ
by less than threshold?
eg 2Hz
Yes
No
11
Reduce inverter
Current frequency
To 2 (fig. 3)
12
Voltage or
frequency out of
Range?
Yes
13
Disconnect Inverter
And go to 2
No
14
Voltage and
Current magnitudes
within range?
Yes
No

Figure 4

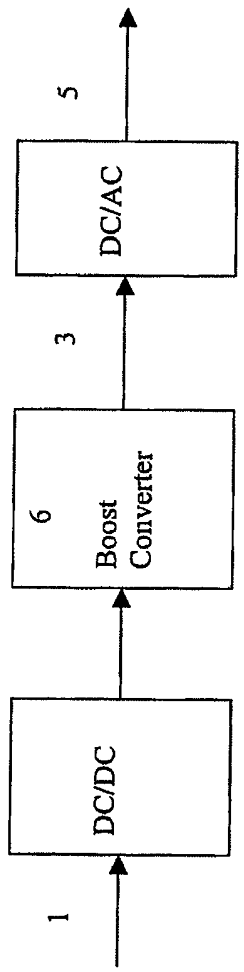


Figure 5

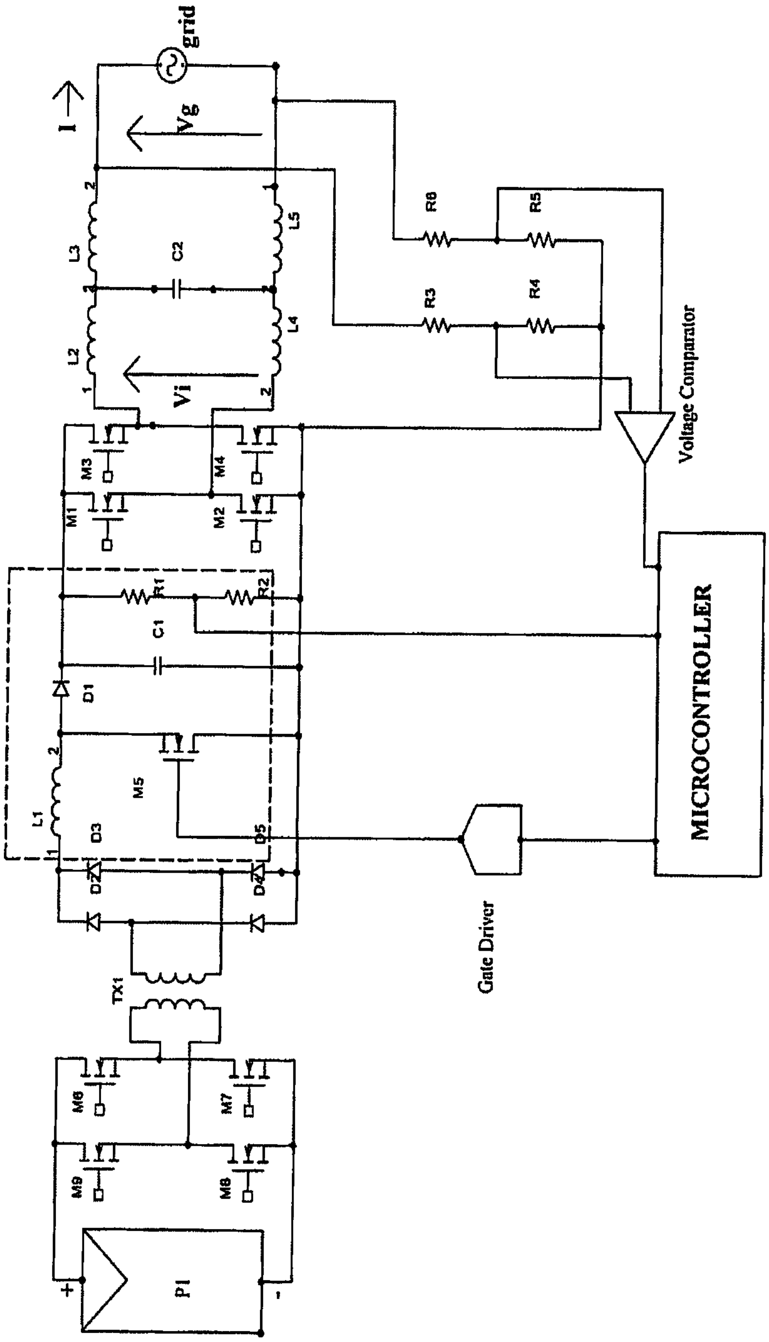

grid
I
Vg
Vi
L1
L2
L3
L4
L5
C1
C2
R1
R2
R3
R4
R5
M1
M2
M3
M4
M5
M7
M9
D1
D3
D5
TX1
P1
Voltage Comparator
MICROCONTROLLER
Gate Driver

Figure 6

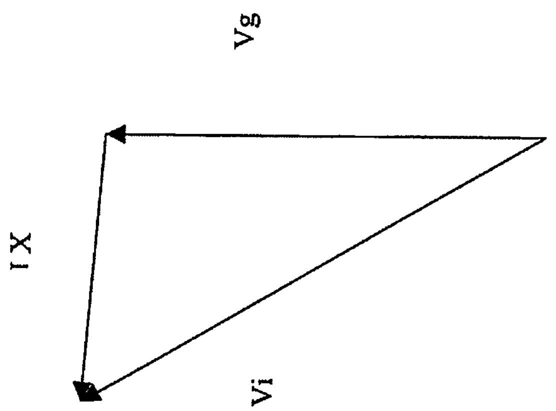


Figure 7

Power Supply Circuits

This invention is generally concerned with power supply circuits, and more particularly, with circuits to supply power to a mains supply, such as domestic grid mains, from a dc supply from a low voltage power source such as a photovoltaic device or fuel cell.

Background prior art relating to power conditioning circuits can be found in: "Grid Connected PV Inverter using a Commercially Available Power IC", A. Mumtaz, N.P. van der Duijn Schouten, L. Chisenga, R.A. MacMahon and G.A.J. Amaratunga presented in October 2002 at the PV in Europe conference in Rome, Italy (referring to the Hitachi ECN 3067 integrated circuit and to the ST Microelectronics L298), AU58687, US 6151234, AU 2073800, EP 1035640, NL 1011483C, US 4626983 A, EP 0628901 A, US 6603672 B, JP 2002 354677 A and JP 4 364378 A.

Broadly speaking, an alternating current mains supply at either 110 volts or 230/240 volts is provided from a fuel cell, photovoltaic device or other supply using an inverter circuit. For example a standard photovoltaic (PV) panel provides approximately 20 volts DC at around 4.5 amps maximum and this voltage must be stepped up and converted to alternating current to provide a mains output. This is generally done using an inverter constructed from discrete electronic components to convert the low DC input voltage to a high AC output voltage. Alternatively, there may be an initial step to step up the DC voltage before converting it to an AC voltage.

Some improved power conditioning circuits are described in the Applicant's co-pending PCT patent application GB2004/001965, the contents of which are hereby incorporated by reference. This describes a power conditioning circuit for providing power from a device such as a photovoltaic (PV) device or fuel cell to an alternating current mains power supply line. The circuit described therein may be used with the typical mains voltages of 110 volts and 230/240 volts or with other mains voltages and, although it is particularly suitable for supplying power to grid-mains, it may also be used to provide a direct mains supply to an appliance, for example a television. The circuit may also include an interface for a rechargeable battery to allow power to be supplied both to the mains and for battery-powered devices.

Figure 1 shows a block diagram of a conventional power conditioning circuit. This comprises a DC input 1 from a power generator such as a photovoltaic module or fuel cell, this providing an input into a DC-to-DC converter 2, typically comprising a high frequency transistor bridge, a transformer, and a rectifier. The output of DC-to-DC converter 2 comprises a DC link voltage 3, this providing an input into a DC-to-AC converter 4, typically comprising one or more transistors which convert the DC link voltage to a suitable low frequency AC voltage, for example at 50Hz, the output 5 of this circuit being provided to a load (not shown).

The arrangement of figure 1 suffices for many power applications but an improved arrangement would be of benefit.

Therefore according to a first aspect of the present invention is provided a power conditioning circuit for providing power from a DC supply to an alternating current mains power supply line, the circuit comprising: a DC input to receive DC power from said DC supply; an AC output for connection to said AC mains power supply line;
a DC-to-DC converter having an input coupled to said DC input and having an output;
a DC-to-AC converter having a DC input and an AC output to convert DC power to AC power for output onto said power supply line; and a DC voltage regulator coupled between the output of said DC-to-DC converter and the input of said DC-to-AC converter to regulate said DC voltage input to said DC-to-AC converter.

By regulating the DC link voltage, in embodiments more accurate regulation of the inverter output voltage can be achieved than with conventional systems. Preferably the regulator is configured to control an AC output current of the circuit by controlling the DC voltage input to the DC-to-AC converter, that is by controlling the DC link voltage. This facilitates DC-to-AC power regulation by regulating the current flow in grid-connected distributed power systems.

Thus the invention also provides a method of controlling an AC output current from a power conditioning circuit providing power from an input DC supply to an AC mains power supply line, the method comprising: converting said input DC supply from a first DC voltage to a second DC voltage; regulating said second DC voltage; and converting said regulated second DC voltage to an AC voltage for output to said AC mains power supply line.

In a related aspect the invention provides a power conditioning circuit for controlling an AC output current from a power conditioning circuit providing power from an input DC supply to an AC mains power supply line, the circuit comprising: means for converting said input DC supply from a first DC voltage to a second DC voltage; means for regulating said second DC voltage; and means for converting said regulated second DC voltage to an AC voltage for output to said AC mains power supply line.

In a further related aspect the invention provides a power conditioning circuit for providing power from a DC supply to an alternating current mains power supply line, the circuit comprising: a DC input to receive DC power from said DC supply; an AC output for connection to said AC mains power supply line; a DC-to-DC converter having an input coupled to said DC input and having an output; a DC-to-AC converter having a DC input and an AC output to convert DC power to AC power for output onto said power supply line; a filter between said DC-to-AC converter AC output and said AC output for connection said mains power supply line; and means to control an AC mains output current from said circuit responsive to a difference between said DC-to-AC converter AC output and said mains power supply line AC voltage.

These and other aspects of the invention will now be further described, by way of example only, with reference to the accompanying figures in which:

Figure 1 shows a block diagram of a conventional power conditioning circuit;

Figures 2a to 2c show, respectively, a block diagram of photovoltaic power supply system, a controller-to-grid interface, and a comparator and associated waveforms for the controller of figure 2a;

Figure 3 shows a flow diagram of an inverter operation sequence;

Figure 4 shows a flow diagram of a grid-connection monitoring process;

Figure 5 shows a block diagram of an embodiment of a power conditioning system according to the present invention;

Figure 6 shows a more detailed circuit diagram of the system of figure 5; and

Figure 7 shows an inverter and grid voltage relationship.

Figures 2 to 4 are taken from GB2004/001965, and are included by way of background.

Referring to figure 2a this shows an overall block diagram of a grid-connected photovoltaic inverter and battery controller. The photovoltaic module is shown as object 1 in figure 1, which is connected to the DC to DC converter. The 5V rail for the microcontroller is generated using the power supply (2), which takes the input directly from the photovoltaic module. The microcontroller is connected to the DC-DC converter 4, DC-AC converter 6 and the output 7. Depending on the condition that the controller senses at 7 point it varies the control of the power conditioning blocks via control connections 4a and 6a accordingly. The illustrated configuration is also designed to charge a battery 3, shown connected from the DC-DC converter block.

Figure 2b shows an example of microcontroller to grid interface configuration. The figure shows how the PV inverter is connected to the mains and shows the configuration of the feedback to inverter via the microcontroller. The microcontroller is used to monitor the power quality of the inverter and the grid interface. This is done by monitoring and controlling the magnitude, phase and frequency of both the current and voltage at the point of connection of the inverter and the grid. The grid is a high voltage/current (typically, 240 V AC) supply or load where as the microcontroller is a low power device (power supply of typically 5V).

R1 through to R8 are potentiometer resistors. These are used to adapt the high line voltages. In one embodiment the upper resistors are 2MΩ whereas the lower ones are either 10KΩ or 40KΩ. Rc is a current sensing resistor which in one embodiment has a value of approximately 2Ω. D1 through to D8 are protection diodes. These diodes ensure that the connection point of each pair of resistors does not attain voltages of over the supply voltage labelled above. The result of this is that the comparators C1, C2, and the microcontroller are protected from the high voltages and currents present in the power lines, live and neutral. C1 and C2 further buffer the magnitude and frequency of the current and voltage signals coming from the potential dividers, before connection to the microcontroller.

Figure 2c shows details a comparator and also input and output waveforms for comparators C1 and C2. The comparator has two inputs (-/+) inverting and non-inverting. Two resistors, one in feedback loop and the other grounded, are used to configure the comparator in an amplifier mode. The output is connected to an onboard microcontroller schmitt trigger and an A/D converter. The two inputs to the comparator are differential and the resultant output from the comparator is no longer floating but zero centred output voltage. For comparator C1 the voltage from the live and neutral lines, which are floating and have a fixed 110V AC or 240V AC magnitude difference, are fed into the comparator. For comparator C2 the voltage difference is due to the voltage drop across the resistor Rc. The frequency of the signals input to the comparators is substantially the same for each case. This output is processed in two ways. It is sampled using an A/D converter on the microcontroller, which allows the frequency of the signals to be calculated. The same output from the comparator is also sent to a Schmitt trigger, which allows the magnitude of the signals to be established.

Figure 3 shows the inverter operation sequence before grid connection. Before the inverter connects or reconnects, by closing switches S1 and S2 (shown in figure 2a), a number of conditions are to be determined and then checked to be within the required limits. The flow diagram in figure 3 shows steps that are performed by the inverter prior to connection. At the time of the microcontroller power-up (step 1), the inverter determines the frequency and voltage of the grid supply (step 2). If the frequency or voltage is found to be outside the desired range (step 3), the inverter stays unconnected in wait mode. At fixed intervals its checks the grid-supply (step 2) to establish if the supply has gone back to normal condition. In the case in which the grid supply voltage and frequencies are found to be desirable, the inverter then checks the DC link voltage to evaluate if it is sufficient to enable connection (step 4). If the DC link voltage happens to be below threshold, the inverter would step the voltage up until threshold is attained (step 5). The DC Link voltage may be varied in two ways. A multi-tap transformer or a boost step up circuit with variable duty cycle can be used. Once all conditions are checked and met, the switches S1 and S2 are closed, which is controlled by the microcontroller and the inverter is connected to the grid (step 7). The system then continues to monitor its operation in case of any abnormal condition, and disconnects if such abnormality prevails. Some of the conditions that are constantly monitored are discussed later (step 8).

Figure 4 shows the flow diagram of the sequence steps involved in the monitoring process, which enable the system to disconnect if conditions occur that may adversely affect operation of the overall system. Some of the abnormal conditions are described below. Once the inverter has been connected, voltages, currents and their frequencies have to be observed (step 9). The frequencies are then compared to check if they are less than the required threshold (step 10). If so then the voltage is checked to find out if is out of the required range (step 12), if it is then the PV inverter is disconnected and returns to sequence before grid-connection (figure 3). If the current and voltage frequencies are not within the required threshold (step 10) then the current frequency is reduced (step 11) and then the voltage frequency is checked (step 12). If the voltage is found to be in range (step 12) then the current/voltage magnitudes are checked to establish if they are in the required range (step 14). If not then the PV inverter is disconnected (step 13) and enters the sequence of figure 3. If the magnitudes are within the necessary range then the PV inverter remains connected and follows through the loop periodically.

Some of the abnormal conditions that may occur in the system include over-current, over-voltage, under-voltage, over-frequency, under-frequency and islanding. The inverter temporarily disconnects when any of these conditions occur by using the above method. The abnormal current, voltage or voltage conditions may be a result of a faulty condition in the system, an overload or an under-load. Over-current is said to occur when more current than normal flows in power lines. Under-voltage is a state in which the line voltage dips below the lower set threshold. Over-voltage is a state in which the line voltage shoots above the lower set threshold. Over-frequency is said to occur when the line frequency goes above the upper threshold. Under-frequency is said to occur when the line frequency goes below the lower threshold

Figure 5 shows a block diagram of an embodiment of a power conditioning system according to the present invention; and Figure 6 shows a more detailed circuit diagram of the system.

Referring to figure 5, like elements to those of figure 1 are indicated by like reference numerals. It can be seen that the design of figure 5 incorporates an active DC link comprising a boost converter 6 which accepts an unregulated DC link voltage input and provides a regulated DC link voltage output. In a conventional design the voltage at the output of the DC-to-DC converter is typically fixed by a transformer having a fixed terms ratio and regulation may also be applied at the DC input 1. However it is difficult to control the inverter AC output voltage in this way, and this technique lacks precision. By incorporating means for regulating the DC link voltage more accurate control can be achieved without significant loss of efficiency.

In a preferred embodiment the boost converter stage 6 may comprise an inductor, a transistor and a diode.

In figure 6, the region enclosed by the dotted rectangled constitutes the boost converter. A feedback loop is used to detect the amplitude of the grid (Vg). Depending on the amplitude, the duty cycle of the gate signal to the transistor M5 is varied to obtain the right inverter voltage Vi. Figure 7 shows the inverter and grid voltage relationship.

In this phasor diagram, Vg is the grid voltage, Vi is the inverter output voltage, I is the current flowing into the grid and X is the reactance of the filter elements (L2-L5 and

C2) and resistance of switching elements M1-M4. The boost converter controls the amplitude of Vi and thereby also setting the magnitude of I.

The DC link Control Circuit comprises R1 and R6, and the comparator, microcontroller and M5 gate driver. R3,R6 and R1 are high resistor values in mega ohms and R2,R4 and R5 are in kilo ohms so that no substantial losses occur in these components. The grid voltage Vg is sensed through the potential divider block of R3-R6 and the voltage comparator. The output of the comparator has the same shape, phase and frequency as Vg but of amplitude between 0 and 5V. This signal forms a reference for the magnitude, frequency and phase of Vg .

The potential divider of R1 and R2 provides a reference for the amplitude of Vi. Assuming the potential difference across C1 to be Vdc, equation 1 shows the relationship between Vi and Vdc:

$$Vi = mVdc \qquad \text{Equation 1}$$

where m is the modulation index, a number between 0 and 1.

Vdc is set by the duty cycle of the gate signal to M5. The microcontroller is configured to adjust the duty cycle depending on Vg and Vdc to ensure that the phasor of figure 7 holds.

The techniques we describe herein are not limited to power conditioning circuits for photovoltaics and/or fuel cells and may also be applied to other type power conditioning circuits. No doubt many other effective alternatives will occur to the skilled person and it should be understood that the invention is not limited to the described embodiments but encompasses modifications within the scope of the claims.

CLAIMS:

1. A power conditioning circuit for providing power from a DC supply to an alternating current mains power supply line, the circuit comprising:

a DC input to receive DC power from said DC supply;

an AC output for connection to said AC mains power supply line;

a DC-to-DC converter having an input coupled to said DC input and having an output;

a DC-to-AC converter having a DC input and an AC output to convert DC power to AC power for output onto said power supply line; and

a DC voltage regulator coupled between the output of said DC-to-DC converter and the input of said DC-to-AC converter to regulate said DC voltage input to said DC-to-AC converter.

2. A power conditioning circuit as claimed in claim 1 wherein said regulator is configured to control an AC output current of said circuit by controlling said DC voltage input to said DC-to-AC converter.

3. A circuit as claimed in claim 1 or 2 further comprising a controller having a first input derived from said AC supply line and a second input derived from said DC voltage regulator output and a control output to said DC voltage regulator for regulating said DC voltage input to said DC-to-AC converter.

4. A circuit as claimed in claim 3 wherein said first input receives an AC voltage and said second input a DC voltage.

5. A circuit as claimed in claim 3 or 4 wherein said controller is configured to control a duty cycle of a power switch of said DC voltage regulator.

6. A circuit as claimed in claim 3, 4 or 5 wherein said controller is configured to control an output voltage of said DC-to-AC converter to maintain a phase relationship between said output voltage of said DC-to-AC converter and a voltage of said AC mains power line.

7. A circuit as claimed in any preceding claim including one or more reactive elements between said AC output of said DC-to-AC converter and a connection to said AC mains power line.

8. A method of controlling an AC output current from a power conditioning circuit providing power from an input DC supply to an AC mains power supply line, the method comprising:

converting said input DC supply from a first DC voltage to a second DC voltage;

regulating said second DC voltage; and

converting said regulated second DC voltage to an AC voltage for output to said AC mains power supply line.

9. A power conditioning circuit for controlling an AC output current from a power conditioning circuit providing power from an input DC supply to an AC mains power supply line, the circuit comprising:

means for converting said input DC supply from a first DC voltage to a second DC voltage;

means for regulating said second DC voltage; and

means for converting said regulated second DC voltage to an AC voltage for output to said AC mains power supply line.

10. A power conditioning circuit for providing power from a DC supply to an alternating current mains power supply line, the circuit comprising:

a DC input to receive DC power from said DC supply;

an AC output for connection to said AC mains power supply line;

a DC-to-DC converter having an input coupled to said DC input and having an output;

a DC-to-AC converter having a DC input and an AC output to convert DC power to AC power for output onto said power supply line;

a filter between said DC-to-AC converter AC output and said AC output for connection said mains power supply line; and means to control an AC mains output current from said circuit responsive to a difference between said DC-to-AC converter AC output and said mains power supply line AC voltage.

The Patent Office

INVESTOR IN PEOPLE

Application No:	GB0424551.0	**Examiner:**	Robert Barrell
Claims searched:	1-9	**Date of search:**	14 July 2005

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
X,P	1,3,5 and 7-9	WO2004/100348 A1 (ENECSYS) See: fig 3; page 9, lines 3-8 and fig 2a.
X	1, 3-5, 8 and 9	JP2002238246 A (SHARP KK) See: fig 1 and PAJ abstract.
X	1,3,4 and 7-9	JP2000316282 A (TOSHIBA FA SYSTEM ENG) See: fig 6 and PAJ abstract.
X	1,8 and 9	JP2004312994 A (TOKYO RIKA DAIGAKU KAGAKU GIJUTSU KOR) See: WPI abstract and figs 1-4.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art
Y	Document indicating lack of inventive step if combined with one or more other documents of same category	P	Document published on or after the declared priority date but before the filing date of this invention.
&	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:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

G3U; H2F

Worldwide search of patent documents classified in the following areas of the IPC^{07}

G05F; H02J; H02M

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

EPODOC, WPI