

AC-AC CONVERTER DEVICE

FIELD OF THE INVENTION

The present invention relates to an AC-AC converter device.

BACKGROUND OF THE INVENTION

5 AC-DC-AC converters are used for line conditioning by converting an AC input power, for example the mains, to a controlled AC output power supplied to a load. The load is typically a load requiring a reliable AC voltage and a reliable frequency, such as IT equipment for critical mission applications. The DC voltage can be provided from a battery or any other type of energy storage. The DC voltage can
10 also originate from a solar panel or a wind generator provided with a suitable energy conversion module. AC-input could be the utility AC-line voltage and the output could be any AC-load.

An AC-AC converter typically consists of an AC-DC converter and a DC-AC converter. These two converters are linked together by a DC voltage which is
15 filtered and kept constant over the line period by a large amount of capacitance or any given energy storage device. The DC-voltage is required to be larger than the maximum peak value of the positive and negative half cycle of the line voltage. In an UPS application, it is probably required that the neutral line is common for the load and the line voltage and the load voltage to be in phase with line voltage. One
20 example is shown in "Space vector Modulation for Single Phase On-Line Three-Leg UPS", Pinheiro et al, 2000 IEEE. One popular technique to achieve this is to have a pair of line frequency commutated switches connected in a half bridge configuration connecting either the negative branch of the intermediate DC-voltage to the neutral during positive half-period of the line voltage, and connect the positive branch of
25 the intermediate DC-voltage to the neutral during negative half-period of the line voltage. The input AC/DC converter acts like a boost regulator, stepping the line input AC voltage to a higher DC-voltage, while controlling the input current to be sinusoidal and the DC voltage to be constant. The output DC/AC converter acts like a step-down regulator, controlling the output AC voltage to be sinusoidal and in
30 phase with the input voltage. A typical three – leg single phase UPS configuration is shown in figure 1. The legs are indicated by dashed boxes Bin, Bout, Bc.

However there is a considerable drawback with this type of circuit since the center leg CL of the center half bridge Bc is common for the in/out rectifier stage (box Bin) and the output inverter stage (box Bout). The timing for controlling the
35 switches connected to the center leg needs to be performed with extreme high precision because no phase shift between line and load voltage can be tolerated.

The prior art AC-AC converter device shown in figure 2 is known from "A study of the High Performance Single Phase UPS", Tamotsu Ninomiya et al, 0-7803-4489-8/98 IEEE. Figure 2 shows a four leg converter with the input stage (boxes Bin1, Bin2) and output stage (boxes Bout1, Bout2) completely decoupled.

5 Figure 3 shows a four leg AC-DC-AC converter with line and load neutral connected, i.e. the second AC input terminal ACin2 is connected to the second AC output terminal ACout2. This circuit is rather complex, having 4 legs and 4 inductors.

10 Fig. 4 shows a circuit where the four legs of fig. 3 has been reduced to 3 legs and 3 inductors and which maintains the ability of independent control of AC – output with respect to AC input with some restrictions. As for fig. 1, one half bridge leg Bc is common for the input/output stage. Here, one half bridge Bin is connected to the first AC input terminal ACin1 via an input inductor Lin1, another half bridge Bout is connected to the first AC output terminal ACout1 via an output inductor Lout1,
15 while the common half bridge Bc is connected to the second AC input terminal ACin2 via a common inductor Lc. As shown in fig. 4, the second AC input terminal ACin2 is directly connected to the second AC output terminal ACout2, and hence, the common half bridge Bc is considered also to be connected to the second AC input terminal ACin2 via the common inductor Lc. The switches need to be able to
20 block positive voltage and conduct negative current. MOSFETs are therefore suitable having the desired properties, since there is a parasitic body-drain diode capable of conducting current in the negative direction, see figure 5.

A disadvantage of having a combination of two MOSFET switches in a half-bridge configuration switching with high frequency is the excessive switching losses
25 coming from the recovery of the slow body-drain diodes. To overcome this problem and allow for high frequency switching, and get all the benefits from high frequency switching in combination with high efficiency one has to prevent the body drain diodes to conduct and allow the current to flow (free-wheel) in another branch.

30 One object of the present invention is to provide an AC-AC converter device which is achieving high efficiency and still keep the advantage of having a circuit that allows for a phase shift between line input and load output voltage. Another object of the invention is to provide an AC-AC converter device with reduced losses and thus higher efficiency.

SUMMARY OF THE INVENTION

35 The present invention is related to a AC-AC converter device, comprising:

- first and second AC input terminals;
- first and second AC output terminals;
- an input device connected between an input node, a common node, a positive DC

terminal and a negative DC terminal, where the input node is connected to the first AC input terminal via a first input inductor,

- an output device connected between an output node, the positive DC terminal and the negative DC terminal, where the output node is connected to the first AC output

5 terminal via an output inductor;

- a common device connected between the common node, the positive DC terminal and the negative DC terminal, where the common node is connected to the second AC input terminal via a common inductor;

- a control device for controlling the switches of the output device and the common
10 device;

- a DC device is connected between the positive DC terminal and the negative DC terminal;

where the output device comprises first and second output switches;

where the common device comprises first and second common switches;

15 where the second AC input terminal is connected to the second AC output terminal;
where the input device comprises first and second diodes and a bi-directional switch connected between the input node and the common node, where the control device is also controlling the bi-directional switch.

20 In one aspect, the first diode is connected with its anode to the input node and its cathode to the positive DC terminal, the second diode is connected with its anode to the negative DC terminal and its cathode to the input node.

In one aspect, the bidirectional switch comprises a first BS switch and switch diodes (DBS1, DBS2, DBS3, DBS4). Here, a drain terminal of the first BS switch is connected to an anode of a first switch diode and to an anode of a second switch
25 diode; a source terminal of the first BS switch is connected to a cathode of a third switch diode and to a cathode of a fourth switch diode; a cathode of the first switch diode and an anode of the third switch diode is connected to the first node; a cathode of the second switch diode and an anode of the fourth switch diode is connected to the second node; a control terminal of the first BS switch is connected
30 to the control circuit.

In one aspect, the bidirectional switch comprises a first BS switch and a second BS switch, each comprising control terminals connected to the control circuit.

35 In one aspect, a drain terminal of the first BS switch is connected to the first node, a drain terminal of the second BS switch is connected to the third node, a source terminal of the first BS switch is connected to a source terminal of the second BS switch.

In one aspect, a source terminal of the first BS switch is connected to the first node, a source terminal of the second BS switch is connected to the third node, a drain

terminal of the first BS switch is connected to a drain terminal of the second BS switch.

In one aspect, the DC device is a capacitor or a battery. In addition, the DC device may comprise an additional DC source.

- 5 In one aspect, the common switches are MOSFETs or IGBTs with an antiparallel diode. In one aspect, the first BS switch of the bidirectional switch is a MOSFET or IGBT. In one aspect, the first and second BS switches of the bidirectional switch are MOSFETs.

DETAILED DESCRIPTION

- 10 Embodiments of the invention will now be described in detail with reference to the enclosed drawings, where:

Figs. 1 -5 illustrate prior art AC-AC converter devices;

Fig. 6 illustrates a first embodiment of the AC-AC converter device;

Fig. 7 illustrates a second embodiment of the AC-AC converter device;

- 15 Fig. 8a illustrates an enlarged view of the bidirectional switch of fig. 2b;

Fig. 8b illustrates an enlarged view of an alternative embodiment of the bidirectional switch;

Fig. 8c illustrates an enlarged view of yet an alternative embodiment of the bidirectional switches;

- 20 Fig. 9 shows the simulation model used in PSPICE for simulation of the circuit of fig. 7;

Fig. 10a) – 10e) illustrates waveforms from the simulation;

Fig. 11 illustrates the simulated currents through the inductors of the circuit.

- 25 It is now referred to fig. 6 , illustrating an AC-AC converter device 1. The AC-AC converter device 1 comprises first and second AC input terminals ACin1, ACin2 and first and second AC output terminals ACout1, ACout2.

In fig. 6, there are three dashed boxes, indicating an input device Bin, an output device Bout and a common device Bc.

The input device Bin is connected between an input node 11, a common node 12, a positive DC terminal DCP and a negative DC terminal DCN. The input node 11 is connected to the first AC input terminal ACin1 via a first input inductor Lin1.

First, the output device Bout and the common device Bc will be described in detail.

- 5 The output device Bout is connected between an output node 13, the positive DC terminal DCP and the negative DC terminal DCN. The output node 13 is connected to the first AC output terminal ACout1 via an output inductor Lout1. The output device Bout comprises first and second output switches Sout1, Sout2. The first output switch Sout1 is connected between the output node 13 and the positive DC terminal DCP and the second output switch Sout2 is connected between the negative DC terminal DCN and the output node 13. In fig. 7, the source terminal of the first output switch Sout1 is connected to the output node 13, and the drain terminal of the first output switch Sout1 is connected to the positive DC terminal DCP. Moreover, the source terminal of the second output switch Sout2 is connected to the negative DC terminal DCN and the drain terminal of the second output switch Sout2 is connected to the output node 13.

The common device Bc is connected between the common node 12, the positive DC terminal DCP and the negative DC terminal DCN. The common node 12 is connected to the second AC input terminal ACin2 via a common inductor Lc.

- 20 It should be noted that the second AC input terminal ACin2 is connected directly to the second AC output terminal ACout2. Hence, the common node 12 is also connected to the second AC output terminal ACout2 via the common inductor Lc, thereby causing the components inside the box Bc to be “common” for both the input and the output side of the device 1.

- 25 The common device Bc comprises first and second common switches Sc1, Sc2. The first common switch Sc1 is connected between the common node 12 and the positive DC terminal DCP and the second common switch Sc2 is connected between the negative DC terminal DCN and the common node 12.

- 30 In fig. 7, the source terminal of the first common switch Sc1 is connected to the common node 12, and the drain terminal of the first common switch Sc1 is connected to the positive DC terminal DCP. Moreover, the source terminal of the second common switch Sc2 is connected to the negative DC terminal DCN and the drain terminal of the second common switch Sc2 is connected to the common node 12.

- 35 In the following, the input device Bin will be described in detail. The input device Bin comprises first and second diodes Din1, Din2 and a bi-directional switch BS. The bi-directional switch BS is connected between the input node 11 and the

common node 12. The first diode Din1 is connected with its anode to the input node 11 and its cathode to the positive DC terminal DCP. The second diode Din2 is connected with its anode to the negative DC terminal DCN and its cathode to the input node 11. Preferably, the first and second diodes Din1, Din2 are fast recovery diodes, such as silicon carbide diodes.

The device 1 further comprises a control device for controlling the switches of the output device Bout and the common device Bc. Hence, the gate terminals of the first and second output switches Sout1, Sout2 are connected to the control device and the gate terminals of the first and second common switches Sc1, Sc2 are connected to the control device. The control device is also controlling the bi-directional switch BS.

The device 1 further comprises a DC device Cdc is connected between the positive DC terminal DCP and the negative DC terminal DCN. The DC device Cdc may be a capacitor or a battery. The DC device may also comprise an additional DC source.

Alternatives of the bidirectional switch BS will now be described. In the first embodiment shown in fig. 7 and in fig. 8a, the bidirectional switch BS comprises a first BS switch S1 and a second BS switch S2, each comprising control terminals GS1, GS2 connected to the control circuit. A drain terminal DS1 of the first BS switch S1 is connected to the first node 11, a drain terminal DS2 of the second BS switch S2 is connected to the third node 22, and a source terminal SS1 of the first BS switch S1 is connected to a source terminal SS2 of the second BS switch S2.

In a second embodiment shown in fig. 8b, the bidirectional switch BS also comprises a first BS switch S1 and a second BS switch S2. Here, a source terminal SS1 of the first BS switch S1 is connected to the first node 11, a source terminal SS2 of the second BS switch S2 is connected to the third node 22, and a drain terminal DS1 of the first BS switch S1 is connected to a drain terminal DS2 of the second BS switch S2.

In a third embodiment shown in fig. 8c, the bidirectional switch BS comprises a first BS switch S1 and switch diodes DBS1, DBS2, DBS3, DBS4. Here, a drain terminal DS1 of the first BS switch S1 is connected to an anode of a first switch diode DBS1 and to an anode of a second switch diode DBS2. A source terminal SS1 of the first BS switch S1 is connected to a cathode of a third switch diode DBS3 and to a cathode of a fourth switch diode DBS4. A cathode of the first switch diode DBS1 and an anode of the third switch diode DBS3 is connected to the first node 11. A cathode of the second switch diode DBS2 and an anode of the fourth switch diode DBS4 is connected to the second node 22. A control terminal GS1 of the first BS switch S1 is connected to the control circuit.

In the description above, the common switches Sc1, Sc2 and the output switches Sout1, Sout2 are MOSFET switches or IGBT switches with an antiparallel diode. Preferably, the switches are silicon carbide MOSFETs or gallium nitride MOSFETs. In fig. 8c, also the first BS switch S1 of the bidirectional switch BS is a MOSFET or IGBT. In fig. 8a and 8b, also the first and second BS switches S1, S2 of the bidirectional switch BS are MOSFET switches.

The AC/AC converter device of fig. 6 and fig. 7 shows that it is possible to replace one of the three half-bridge legs of the converter device in fig. 5 with a bidirectional switch and two diodes. Since the input boost converter Bin utilizes the discrete diodes D1 and D2 for freewheeling the current when the bidirectional switch BS is turned off, the internal body drain diode in the MOSFETs are not in use and thus the problem with reverse recovery losses in the slow body drain diodes is eliminated. Instead it is now possible to use fast recovery diodes or silicon carbide diodes, i.e. the first and second diodes D1 and D2 which exhibit very low reverse recovery losses, if any at all. Therefore it is possible to raise the switching frequency of the input boost converter Bin without suffering from drastically reduced efficiency. Hence, an efficient converter device is achieved, while at the same time all the advantages that come with higher switching frequency, such as smaller filter components, less ripple in the input inductor L1 etc are also achieved.

In fig. 10a-c the control signals for the switches of fig. 9 are shown. In fig. 10d the ripple currents of inductors Lin1 and Lout1 is shown, in fig. 10e the ripple currents of the common inductor Lc is shown. The ripple currents do exhibit twice the frequency compared with the frequency of the control signals. Hence, it is shown that the ripple current is reduced by synchronization of control signals, so that the inductors see twice the switching ripple.

In fig. 11 it is shown that the common inductor Lc is providing cancelation of the line frequency component.

CLAIMS

1. AC-AC converter device (1), comprising:

- first and second AC input terminals (ACin1, ACin2);

- first and second AC output terminals (ACout1, ACout2);

5 - an input device (Bin) connected between an input node (11), a common node (12), a positive DC terminal (DCP) and a negative DC terminal (DCN), where the input node (11) is connected to the first AC input terminal (ACin1) via a first input inductor (Lin1);

10 - an output device (Bout) connected between an output node (13), the positive DC terminal (DCP) and the negative DC terminal (DCN), where the output node (13) is connected to the first AC output terminal (ACout1) via an output inductor (Lout1);

- a common device (Bc) connected between the common node (12), the positive DC terminal (DCP) and the negative DC terminal (DCN), where the common node (12) is connected to the second AC input terminal (ACin2) via a common inductor (Lc);

15 - a control device for controlling the switches of the output device (Bout) and the common device (Bc);

- a DC device (Cdc) is connected between the positive DC terminal (DCP) and the negative DC terminal (DCN);

20 where the output device (Bout) comprises first and second output switches (Sout1, Sout2);

where the common device (Bc) comprises first and second common switches (Sc1, Sc2);

where the second AC input terminal (ACin2) is connected to the second AC output terminal (ACout2);

25 where the input device (Bin) comprises first and second diodes (Din1, Din2) and a bi-directional switch (BS) connected between the input node (11) and the common node (12), where the control device is also controlling the bi-directional switch (BS).

30 2. AC-AC converter device according to claim 1, where the first diode (Din1) is connected with its anode to the input node (11) and its cathode to the positive DC terminal (DCP), the second diode (Din2) is connected with its anode to the negative DC terminal (DCN) and its cathode to the input node (11).

3. AC-AC converter device according to claim 1 or 2, where the bidirectional switch (BS) comprises a first BS switch (S1) and switch diodes (DBS1, DBS2, DBS3, DBS4).
4. AC-AC converter device according to claim 3, where:
- 5 - a drain terminal (DS1) of the first BS switch (S1) is connected to an anode of a first switch diode (DBS1) and to an anode of a second switch diode (DBS2);
- a source terminal (SS1) of the first BS switch (S1) is connected to a cathode of a third switch diode (DBS3) and to a cathode of a fourth switch diode (DBS4);
- 10 - a cathode of the first switch diode (DBS1) and an anode of the third switch diode (DBS3) is connected to the first node (11);
- a cathode of the second switch diode (DBS2) and an anode of the fourth switch diode (DBS4) is connected to the second node (22);
- a control terminal (GS1) of the first BS switch (S1) is connected to the control circuit.
- 15 5. AC-AC converter device according to claim 1 or 2, where the bidirectional switch (BS) comprises a first BS switch (S1) and a second BS switch (S2), each comprising control terminals (GS1, GS2) connected to the control circuit.
6. AC-AC converter device according to claims 4, where a drain terminal (DS1) of the first BS switch (S1) is connected to the first node (11), a drain terminal (DS2) of the second BS switch (S2) is connected to the third node (22), a source terminal (SS1) of the first BS switch (S1) is connected to a source terminal (SS2) of the second BS switch (S2).
- 20 7. AC-AC converter device according claim 5, where a source terminal (SS1) of the first BS switch (S1) is connected to the first node (11), a source terminal (SS2) of the second BS switch (S2) is connected to the third node (22), a drain terminal (DS1) of the first BS switch (S1) is connected to a drain terminal (DS2) of the second BS switch (S2).
- 25 8. AC-AC converter device according claim 1, where the DC device (Cdc) is a capacitor or a battery.
- 30 9. AC-AC converter device according claim 8, where the DC device comprises an additional DC source.
10. AC-AC converter device according claim 1, where the common switches (Sc1, Sc2) are MOSFETs or IGBTs with an antiparallel diode.
11. AC-AC converter device according claim 1, where the first BS switch (S1) of the bidirectional switch (BS) is a MOSFET or IGBT.
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12. AC-AC converter device according to claim 3, where the first and second BS switches (S1, S2) of the bidirectional switch (BS) are MOSFETs.