A POWER CONVERTER

Fig. 4
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A POWER CONVERTER

TECHNICAL FIELD

The invention relates to a power converter for converting power to or from a high voltage AC (Alternating Current) connection, a first high voltage DC (Direct Current) connection, and a second high voltage DC connection.

BACKGROUND

High voltage power conversion between AC and DC is known in the art for a variety of different applications. One such application is for links related to HVDC (high voltage DC).

WO2009/149742 presents a plant for transmitting electric power through HVDC which comprises two converter stations interconnected by a bipolar direct voltage network and each connected to an alternating voltage network. Each converter station has a Voltage Source Converter with switching cells each including at least one energy storing capacitor. In Fig 4, it is shown how AC to DC conversion can be performed.

However, for some applications, a second DC port would be beneficial. Adapting the AC/DC converter of WO2009/149742, however, is cumbersome and it is not apparent how this should be done.

It is thus desired to find an AC/DC/DC converter suitable for high voltage applications.

SUMMARY

An object of embodiments herein is to eliminate or at least alleviate the problems discussed above.

It is presented a power converter for transferring power between a first high voltage DC connection, a second high voltage DC connection, and a high voltage AC connection.

The power converter comprises a power converter assembly comprising: a first voltage source converter and a second voltage source converter connected serially in the mentioned order between a positive terminal and a negative terminal of the first high voltage DC connection, wherein respective AC sides of the first voltage source
converter and the second voltage source converter are connected to a common AC bus; a DC blocking device between the AC side of at all but one of the voltage source converters and the AC bus; and a phase shift device between the AC side of the second voltage source converter and the AC side of the first voltage source converter; wherein the positive terminal of the second high voltage DC connection is connected on one side of the second voltage source converter and the negative terminal of the second high voltage DC connection is connected to another side of the second voltage source converter; and the AC connection is connected to the AC bus for active power transfer with an AC grid. This is an efficient way of providing a DC/DC/AC power converter with monopole to monopole DC/DC/AC conversion.

The power converter assembly may further comprise a third voltage source converter serially arranged between the second voltage source converter and the negative terminal of the first high voltage DC connection, wherein an AC side of the third voltage source converter is connected to the AC bus.

The power converter assembly may further comprise a fourth voltage source converter serially arranged between the second voltage source converter and the third voltage source converter such that the negative terminal of the second high voltage DC connection is connected between the third voltage source converter and the fourth voltage source converter. An AC side of the fourth voltage source converter is connected to the AC bus.

There may be a phase shift device provided between each one of the voltage source converters and the AC bus.

There may be a DC blocking device provided between each one of the voltage source converters and the AC bus.

The phase shift device may comprise an inductor.

The AC port may be provided through an electromagnetic coupling to the inductor.

The phase shift device may comprise a transformer.

The phase shift device may comprise a capacitor.
The DC blocking device may comprise a transformer.

The DC blocking device may comprise a capacitor.

The power converter according may comprise a plurality of the power converter assemblies. For instance, the power converter may comprise three power converter assemblies.

Each power converter assembly may provide its own high voltage AC connection, such that each power assembly corresponds to one phase of a combined multiphase AC connection.

A first capacitor may be connected between the terminals of the first high voltage DC connection and a second capacitor may be connected between the terminals of the second high voltage DC connection.

Generally, all terms used in the claims are to be interpreted according to their ordinary meaning in the technical field, unless explicitly defined otherwise herein. All references to "a/an/the element, apparatus, component, means, step, etc." are to be interpreted openly as referring to at least one instance of the element, apparatus, component, means, step, etc., unless explicitly stated otherwise. The steps of any method disclosed herein do not have to be performed in the exact order disclosed, unless explicitly stated.

**BRIEF DESCRIPTION OF THE DRAWINGS**

The invention is now described, by way of example, with reference to the accompanying drawings, in which:

Fig 1 is a schematic diagram of a power converter for converting between DC, DC and AC;

Fig 2 is a schematic diagram of a three phase power converter for converting between DC, DC and AC;

Fig 3 is a schematic diagram of a first embodiment of a power assembly of Figs 1-2;

Fig 4 is a schematic diagram of a second embodiment of the power assembly of Figs 1-2;
Fig 5 is a schematic diagram of a third embodiment of a power assembly of Figs 1-2;

Fig 6 is a schematic diagram of a fourth embodiment of a power assembly of Figs 1-2;

Figs 7A-B are schematic graphs illustrating the power flow in the power converter through a phase shift device of Figs 3-6;

Fig 8 is a schematic diagram illustrating possible converter cell arrangements of voltage source converters of Figs 3-6 and 11-14;

Figs 9A-C are schematic diagrams illustrating embodiments of converter cells of the voltage source converters of Fig 8;

Figs 10A-F are schematic diagrams illustrating embodiments of the power transfer devices of the embodiments of Figs 3-6 and 11-14;

Fig 11 is a schematic diagram of the power converter 1 of Fig 4 from a slightly different perspective;

Fig 12 is a schematic diagram of a power converter according to one embodiment;

Fig 13 is a schematic diagram of a power converter according to one embodiment; and

Fig 14 is a schematic diagram of a power converter according to one embodiment.

DETAILED DESCRIPTION

The invention will now be described more fully hereinafter with reference to the accompanying drawings, in which certain embodiments of the invention are shown.

This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided by way of example so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout the description.

Fig 1 is a schematic diagram of a power converter 1 for converting between DC, DC and AC. The power converter 1 converts power in either direction between the first high voltage DC connection DC₁ and the second high voltage DC connection DC₂.
first high voltage DC connection DQ comprises a positive terminal DQ+ and a
negative terminal DQ-. Analogously, the second high voltage connection comprises a
positive terminal DC₂⁺ and a negative terminal DC₂⁻. Furthermore, there is a high voltage
AC connection AC which can either consume or provide (active) power. Hence, each
one of the connections DQ, DC₂ and AC can either consume or provide power, as
long as there is at least one of these that consumes power and at least one of these that
provides power. The power converter 1 comprises a power assembly 9 which performs
the actual power conversion.

Fig 2 is a schematic diagram of a three phase power converter 1 for converting between
DC, DC and AC. The three phase power converter 1 here comprises three power
assemblies 9a-c. In this way, the AC connection here comprises three connectors AQ,
AC₂ and AC₃ to be able to provide a three phase connection, e.g. to an AC grid, an AC
power source or an AC power load.

Fig 3 is a schematic diagram of a first embodiment of a power assembly 9 of Figs 1-2.
The power assembly 9 comprises a first voltage source converter 3a and a second
voltage source converter 3b connected serially in the mentioned order between the
positive terminal DQ⁺ and the negative terminal DQ⁻ of the first high voltage DC
connection DQ. Hence, the first voltage source converter 3a is connected between the
positive terminal DQ⁺ and the second voltage source converter 3b, and second voltage
source converter 3b is connected between the negative terminal DQ⁻ and the first
voltage source converter 3a.

Each one of these two voltage source converters 3a-b have two DC sides, situated on
the upper and lower parts in Fig. 3, and one AC side, situated on the left side in Fig. 3.
The respective AC sides 5a-b of the first voltage source converter 3a and the second
voltage source converter 3b are connected to a common AC bus 7.

A power transfer device 20 is provided between the AC side of the first voltage source
converter 3a and the AC bus 7. This embodiment of the power transfer device 20
comprises a phase shift device and a DC blocking device.

The positive terminal DQ⁺ of the second high voltage DC connection DQ is connected
on one side of the second voltage source converter 3b, between the first and second
voltage source converters 3a-b. The negative terminal DQ of the second high voltage DC connection DC2 is connected to the other side of the second voltage source converter 3b, i.e. to the negative terminal DQ− of the first high voltage DC connection DQ. The AC connection (AC) is connected to the AC bus for active power transfer with an AC grid.

Optionally, a first capacitor 2 is provided between the two terminals DQ+, DQ− of the first high voltage DC connection DQ and a second capacitor 12 is provided between the two terminals DQ+, DQ− of the second high voltage DC connection DQ. The capacitors facilitate circulation of any AC current without affecting the high voltage DC connections DQ, DQ and reduces AC ripple on the high voltage DC connections. If there are several power assemblies provided in a power converter, e.g. as shown in Fig 2, the need for the first and second capacitors 12 is reduced, as the AC current can circulate between the power assemblies.

Since the power transfer device 20 comprises a phase shift device, there is a transfer of active AC power through the power transfer device. The DC blocking device of the power transfer device 20 allows for different DC biases on the AC sides of the two voltage source converters 3a-b.

The structure of the power assembly 9 of Fig 3 provides an asymmetric to asymmetric DC conversion as part of the DC/DC/AC power conversion. Purely as an example, DQ + could have a voltage of about 320 kV, DQ − could have a voltage of about 0 kV while DQ + could have a voltage of 150 kV and DQ − is the same as DQ +, i.e. 0 kV.

Fig 4 is a schematic diagram of a second embodiment of the power assembly 9 of Figs 1-2. This embodiment is similar to the one shown in Fig 3, but here there is a third voltage source converter 3c connected between the second voltage source converter 3b and the negative terminal DQ− of the first high voltage DC connection DQ. Also, the negative terminal DQ− of the second high voltage DC connection DQ, is connected between the second and third voltage source converters 3b-c.

Optionally, capacitors (not shown) are connected between the terminals of the first high voltage DC connection and/or the second high voltage DC connection, as illustrated in Fig 3.
In the power assembly of Fig 4, the common DC bus is connected to each one of the first, second and third voltage source converters 3a-c though respective power transfer devices 20a-c. It is to be noted that only two of the three power transfer devices 20a-c need to have a DC blocking device, as the AC bus 7 can carry a DC bias from the AC side of one (but not more) of the voltage source converters 3a-c. Nevertheless, it is still possible that each one of the three power transfer devices 20a-c comprises its own DC blocking device. Moreover, only two of the three power transfer devices 20a-c need to comprise a phase shift device. In the event that one of the power transfer devices does not comprise a DC blocking device and one of the power transfer devices does not comprise a phase shift device, this can be the same or different power transfer devices.

Further embodiments of power assemblies comprising three voltage source converters are shown in Figs 11-14.

Fig 5 is a schematic diagram of a third embodiment of a power assembly 9 of Figs 1-2. The embodiment is similar to the second embodiment of Fig 4. Here, however, the negative terminal DC₁ of the first high voltage DC connection DQ₁ is connected between the second and third voltage source converters 3b-c. Furthermore, the negative terminal DC₂ of the second high voltage DC connection DQ₂ is connected to the lower side of the third voltage source converter 3c. This provides a different voltage relationship between the first high voltage DC connection DQ and the second high voltage DC connection DC₂ than the second embodiment of Fig 4.

A grounded connection DC₂ of the second high voltage connection DC₂ is also provided, connected via capacitors 12a, 12b, to the positive terminal DC₂⁺ and the negative terminal DQ₂ of the second high voltage connection DC₂. In this way, the second high voltage connection DC₂ can be a bipole connection.

Fig 6 is a schematic diagram of a fourth embodiment of a power assembly 9 of Figs 1-2. The power assembly according to the fourth embodiment is similar to the second embodiment of Fig 4. In this embodiment, a fourth voltage source converter 3d is inserted between the second and third voltage source converter. A fourth power transfer device 20d is connected between the fourth voltage source converter 3d and the AC bus 7.
Similarly to what was described for the second embodiment of Fig 4, only three of the four power transfer devices 20a-d need to have a DC blocking device, as the AC bus 7 can carry a DC bias from the AC side of one of the voltage source converters 3a-d. Nevertheless, it is still possible that each one of the four power transfer devices 20a-d comprises its own DC blocking device. Moreover, only three of the four power transfer devices 20a-d need to comprise a phase shift device. In the event that one of the power transfer devices does not comprise a DC blocking device and one of the power transfer devices does not comprise a phase shift device, this can be the same or different power transfer devices.

A grounded connection DC\(^{2}\)\(^{\circ}\) of the second high voltage connection DC\(^{2}\) is provided, connected via capacitors 12a, 12b, to the positive terminal DC\(^{2}\)\(^{+}\) and the negative terminal DQ\(^{-}\) of the second high voltage connection DC\(^{2}\). In this way, the second high voltage connection DC\(^{2}\) can be a bipole connection. Alternatively, the grounded connection DC\(^{2}\)\(^{\circ}\) of the second high voltage DC connection DC\(^{2}\) can be provided through a connection to a point between the second voltage source converter 3b and the fourth voltage source converter 3d (not shown).

For the first high voltage DC connection DQ, a grounded connection DQ\(^{\circ}\) is provided, connected to a point between the second voltage source converter 3b and the fourth voltage source converter 3d. In this way, also the first high voltage connection DQ can be a bipole connection. Alternatively, the grounded connection DQ\(^{\circ}\) of the second high voltage DC connection DC\(^{2}\) can be provided through a connection via capacitors to the positive terminal DQ\(^{+}\) and the negative terminal DQ\(^{-}\) of the first high voltage connection DQ (not shown), analogously to what is shown in Fig 6 for the second high voltage DC connection DQ.

Figs 7A-B are schematic graphs illustrating the power flow through the power transfer device 20 of Fig 3. The same principle applies for any other of the power transfer devices, whenever it comprises a phase shift device. Fig 7A is shows the voltage \(v_1\) at one side of the power transfer device and the voltage \(v_2\) at the other side of the power transfer device over time.

Fig 7B shows the current \(i_2\) from one side of the power transfer device to the other side of the power transfer device over time. The time scales of Figs 7A and 7B are the same.
It can thus be seen at time t1, v1 is equal to v2 whereby the derivative of current i1 is equal to zero and going negative corresponding to the current being at its maximum point. At a time t2, there is a maximum difference between the voltages v1 and v2 whereby the derivative of current i2 is maximum which corresponds to zero crossing of the current.

At a time t3, v2 is again equal to v1, whereby the derivative of current i2 is zero and going positive corresponding to the current being at a minimum (negative) point.

The phase difference between v1 and v2 is handled by the power transfer device, whereby its phase shift device needs to be dimensioned in accordance with expected phase differences. In other words, a larger phase difference results in a larger voltage difference and larger current, whereby the phase shift device of the power transfer device in this case needs to be rated higher to support a higher current.

Fig 8 is a schematic diagram illustrating possible converter cell arrangements of voltage source converters of Figs 3-6 and 11-14. Fig 8 illustrates the structure of any one of the voltage source converters 3a-f, 3a'-f', 3a''-f'', here represented by a single voltage source converter 3. The voltage source converter 3 comprises two converter arms 33, each comprising a plurality of converter cells 32a-d, wherein each converter cell 32a-d is controlled by the controller 50. The converter cells 32a-d can be connected in series to increase voltage rating and/or in parallel to increase current rating. The serially connected converter cells 32a-d can optionally be individually controlled by the controller 50 to achieve a finer granularity in the conversion, e.g. to achieve a more sinusoidal (or square, saw tooth shaped, etc.) power conversion. While the voltage source converter 3 is here illustrated to have four converter cells 32a-d, any number of converter cells is possible, including one, two, three or more. In one embodiment, the number of converter cells in each voltage source converter 3 is in the range from 30 to 1000 converter cells.

Optionally, a smoothing inductor 31 is provided in the voltage source converter to provide a smoother current.

Figs 9A-C are schematic diagrams illustrating embodiments of converter cells 32a-d of the voltage source converters of Fig 8. Any one of the converter cells 32a-d is here represented as a single converter cell 32. A converter cell 32 is a combination of semiconductor switches, such as transistors, and energy storing elements, such as
capacitors, supercapacitors, inductors, batteries, flywheels etc. Optionally, a converter cell can be a multilevel converter structure such as a flying capacitor or MPC (Multi-Point-Clamped) or ANPC (Active - Neutral-Point-Clamped) multilevel structure.

Fig 9A illustrates a converter cell comprising an active component in the form of a switch 40 and an energy storage component 41 in the form of a capacitor. The switch 40 can for example be implemented using an insulated gate bipolar transistor (IGBT), Integrated Gate-Commutated Thyristor (IGCT), a Gate Turn-Off thyristor (GTO), or any other suitable high power semiconductor component. In fact, the converter cell 32 of Fig 9A can be considered to be to be a more general representation of the converter cell shown in Fig 9B, which will be described here next.

Fig 9B illustrates a converter cell 32 implementing a half bridge structure. The converter cell 32 here comprises a leg of two serially connected active components in the form of switches 40a-b, e.g. IGBTs, IGCTs, GTOs, etc. A leg of two serially connected diodes 42a-b is connected with the leg of serially connected switches 40a-b as shown in the figure. An energy storage component 41 is also provided in parallel with the leg of transistors 40a-b and with the leg of diodes 32a-b. The output voltage synthesized by the converter cell can thus either be zero or the voltage of the energy storage component 41.

Fig 9C illustrates a converter cell 32 implementing a full bridge structure. The converter cell 32 here comprises four switches 40a-d, e.g. IGBTs, IGCTs, GTOs, etc. An energy storage component 41 is also provided in parallel across a first leg of two transistors 40a-b and a second leg of two transistors 40c-d. Compared to the half bridge of Fig 9B, the full bridge structure allows the synthesis of an output voltage capable of assuming both signs, whereby the voltage of the converter cell can either be zero, the voltage of the energy storage component 41, or a reversed voltage of the energy storage component 41.

Figs 10A-F are schematic diagrams illustrating embodiments of the power transfer devices 20 of the embodiments of Figs 3-6 and 11-14.

In Fig 10A, the power transfer device 20 comprises a transformer 21. The transformer 21 blocks DC and provides a phase shift. Hence, the power transfer device 20 can be
considered to comprise both a DC blocking device and a phase shift device, embodied in a single transformer 21.

In Fig 10B, the power transfer device 20 comprises a capacitor 22. Also the capacitor 22 blocks DC and provides a phase shift. Hence, the power transfer device 20 can be considered to comprise both a DC blocking device and a phase shift device.

In Fig 10C, the power transfer device 20 comprises a capacitor 22 and an inductor 23. The capacitor 22 blocks DC and provides a phase shift. Moreover, the inductor 23 provides its own phase shift. The phase shift effect of the power transfer device 20 here depends on the combined (and counteracting) phase shifts of the capacitor 22 and the inductor 23. Again, the power transfer device 20 can be considered to comprise both a DC blocking device and a phase shift device.

In Fig 10D, the power transfer device 20 comprises an inductor 23. Also the inductor 23 does not block DC but does provide a phase shift. In this embodiment, the power transfer device 20 can thus be considered to comprise a phase shift device but not a DC blocking device.

In Fig 10E, the power transfer device 20 only comprises a galvanic conductor. The conductor is not considered to shift the phase significantly and does not block DC. In this embodiment, the power transfer device 20 thus neither comprises a phase shift device nor a DC blocking device.

Fig 11 is a schematic diagram of the power converter assembly 9 of Fig 4 from a slightly different perspective. The power converter assembly 9 converts power in either direction between the first high voltage DC connection DQ and the second high voltage DC connection, DQ. The first high voltage DC connection DQ comprises a positive terminal DQ+ and a negative terminal DQ-. Analogously, the second high voltage connection comprises a positive terminal DQ+ a negative terminal DQ-. Optionally, a first capacitor 2 is provided between the two terminals DQ+, DQ- of the first high voltage DC connection and a second capacitor 12 is provided between the two terminals DQ+, DQ- of the second high voltage DC connection. The capacitors facilitate circulation of AC current without affecting the high voltage DC connections and reduces AC ripple on the high voltage DC connections.
A first voltage source converter 3a comprises a first converter arm 33a and a second converter arm 33b, serially connected between the positive terminal $\text{DC}_{1+}$ of the first high voltage DC connection and the positive terminal $\text{DC}_{2+}$ of the second high voltage DC connection. A first logical connection point a is provided between the first converter arm 33a and the second converter arm 33b. The first converter arm 33a and the second converter arm 33b can optionally be part of an M2C (modular multilevel converter) converter.

Analogously for the negative terminals of the first and second high voltage DC connections, a third voltage source converter 3c comprises a third converter arm 33c and a fourth converter arm 33d, serially connected between the negative terminal $\text{DC}_{1-}$ of the first high voltage DC connection and the negative terminal $\text{DC}_{2-}$ of the second high voltage DC connection. A second logical connection point d is provided between the third converter arm 33c and the fourth converter arm 33d. The third converter arm 33c and the fourth converter arm 33d can optionally be part of an M2C converter.

Similarly, for the second high voltage DC connection, a second voltage source converter 3b comprises a fifth converter arm 33e and a sixth converter arm 33f, serially connected between the positive terminal $\text{DC}_{2+}$ and the negative terminal $\text{DC}_{2-}$ of the second high voltage DC connection. A third logical connection point c is provided between the fifth converter arm 33e and the sixth converter arm 33f. The fifth converter arm 33e and the sixth converter arm 33f can optionally be part of an M2C converter.

A power transfer device is provided between a fourth logical connection point b and the third logical connection point c. The fourth logical connection point b is provided between the first logical connection point a and second logical connection point d. Two capacitors 4a-b are provided between the fourth logical connection point b and the first logical connection point a and the second logical connection point d, respectively. In this example, the power transfer device is an inductor 6.

The converter arms are controlled such that there is an AC voltage at the first connection point with a positive DC offset and a corresponding AC voltage at the second connection point with a negative DC offset. These two AC voltages are in phase. The capacitors 4a-b remove any DC component from the first logical connection.
point a and the second logical connection point d, whereby the AC at the fourth logical connection point is symmetrical around zero.

Optionally, the fourth logical connection point b or the third logical connection point c can be used for an AC connection. This AC connection can be bidirectional. In one embodiment, an AC port is provided by letting the inductor 6 be a primary winding of a transformer 10, where the AC port is provided using the secondary winding of the transformer 10.

Fig 12 is a schematic diagram of a power converter assembly 9 according to one embodiment. Here, there are two capacitors 12a-b connected serially between the positive and negative terminals DC$_{2+}$, DC$_{2-}$ of the second high voltage DC connection. A fifth logical connection point e is provided between the two capacitors 12a-b.

In this embodiment, the power transfer device is a transformer 13. The primary winding of the transformer 13 is connected serially between the two capacitors 4a-b which are connected serially between the first logical connection point a and the second logical connection point d. The secondary winding of the transformer 13 is connected between the third logical connection point c and the fifth logical connection point e.

With this structure, depending on the turns ratio of the transformer, the transformer allows a greater difference in voltage between the first and second high voltage DC connections.

Fig 13 is a schematic diagram of a power converter assembly 9 according to one embodiment. The structure shown in Fig 13 is similar to the structure shown in Fig 12. The main difference is that the primary winding of the transformer 13 is connected between the fourth logical connection point and one of the terminals of the first high voltage DC connection, in this example the positive terminal of the high voltage DC connection. An inductor 9 is shown which represents a leakage inductor.

As with the structure of Fig 12, the turns ratio of the transformer 13 can give a greater difference in voltage between the first high voltage DC connection and the second high voltage DC connection.
Fig 14 is a schematic diagram of a power converter 1 according to one embodiment. In this example, three power converter assemblies are provided in parallel. The number of power converter assemblies can be selected to achieve a desired power capacity. In fact, more power converter assemblies can be added as desired.

One advantage of having multiple power converter assemblies is that a circulating AC current from one power converter assembly can be taken care of by the other power converter assemblies. This reduces the need for capacitors between the terminals of the first high voltage DC connection and the second high voltage DC connection, respectively. However, in order to reduce ripple the first and second high voltage DC connections, such capacitors can still be provided (not shown here).

While each one of the power assemblies shown in Fig 14 is essentially the power assembly of the embodiment of Fig 11, the power assemblies of Fig 13 or 14 could equally well be used.

The power converter 1 of Fig 14 could also provide an AC port at the fourth logical connection point d, whereby each power assembly can provide an AC port for one phase of a multiphase AC connection. In the example of three power assemblies, this conveniently provides a three phase AC connection. Even in a power converter with three power assemblies, more power assemblies could be added to increase capacity of the DC/DC conversion. However, to preserve the phase angle difference on the AC ports, power assemblies are added in groups of the same number of phases as the AC connection, which, in this example, implies groups of three.

Here now follows a structured list of embodiment clauses enumerated using roman numerals.

i. A power converter (1) for converting power between a first high voltage direct current, DC, connection, a second high voltage DC connection, the power converter comprising a power converter assembly (9) comprising:

(a) a first converter arm (33a) and a second converter arm (33b) serially connected between a positive terminal (DC1+) of the first high voltage DC connection and a positive terminal (DC2+) of the second high voltage DC connection, wherein a first logical connection point (a) is provided between the first converter arm (33a) and the
second converter arm (33b);

a third converter arm (33c) and a fourth converter arm (33d) serially connected between a negative terminal \( (DC_{-}) \) of the first high voltage DC connection and a negative terminal \( (DC_{-}) \) of the second high voltage DC connection, wherein a second logical connection point (d) is provided between the third converter arm (33c) and the fourth converter arm (33d); and

a fifth converter arm (33e) and a sixth converter arm (33f) serially connected between the positive terminal \( (DC_{+}) \) and the negative terminal \( (DC_{-}) \) of the second high voltage DC connection, wherein a third logical connection point (c) is provided between the fifth converter arm (33a) and the sixth converter arm (33f);

wherein a power transfer device is provided between a fourth logical connection point (b) and the third logical connection point (c), the fourth logical connection point (b) being provided between the first logical connection point (a) and second logical connection point (d).

ii. The power converter (1) according to clause i, wherein the power converter assembly (9) further comprises:

an inductor (5a) between the first converter arm (33a) and the first logical connection point (a), an inductor (5b) between the second converter arm (33b) and the first logical connection point (a), an inductor (5c) between the third converter arm (33c) and the second logical connection point (d), an inductor (5d) between the fourth converter arm (33d) and the second logical connection point (d), an inductor (5e) between the fifth converter arm (33e) and the third logical connection point (c), and an inductor (5f) between the sixth converter arm (33f) and the third logical connection point (c).

iii. The power converter (1) according to clause i or ii, wherein the power transfer device is an inductor (6) connected between the fourth logical connection point (b) and the third logical connection point (c).

iv. The power converter (1) according to clause i or ii, wherein the power transfer device is a transformer (13).

v. The power converter (1) according to clause iv, wherein the transformer (13) comprises a primary winding connected to the fourth logical connection point (b) and a
secondary winding connected between the third logical connection point (c) and a point between two capacitors (12a-b) serially connected between the positive terminal (DC\(_2^+\)) and the negative terminal (DC\(_2^-\)) of the second high voltage DC connection.

vi. The power converter (1) according to clause v, wherein the primary winding is connected between the fourth logical connection point (b) and a neutral point between the terminals (DC\(_1^+, \) DC\(_1^-\)) of the first high voltage DC connection.

vii The power converter (1) according to clause vi, wherein the neutral point is a point between two capacitors (2a, 2b) which are serially connected between the terminals (DC\(_1^+, \) DC\(_1^-\)) of the first high voltage DC connection.

viii. The power converter (1) according to any one of the preceding clauses, comprising a plurality of a power converter assemblies (9).

ix. The power converter (1) according to clause viii, comprising three power converter assemblies.

x. The power converter (1) according to any one of the preceding clauses, wherein an alternating current, AC, port is provided on an AC terminal on either side of the power transfer device.

xi. The power converter (1) according to any one of the preceding clauses, wherein the AC terminal is provided at the fourth logical connection point (b).

xii. The power converter (1) according to any one of the preceding clauses, wherein the AC terminal is provided at the third logical connection point (c).

xiii. The power converter (1) according to any one of clauses i to viii, wherein an alternating current, AC, port is provided through an indirect coupling to the power transfer device.

xiv. The power converter (1) according to any one of clauses xi to xii when dependent on clause ix, wherein each power converter assembly (9) provides its own AC port, such that each power assembly corresponds to one phase of a combined multiphase AC connection.
xv. The power converter (1) according to any one of the preceding clauses, wherein a first capacitor is connected between the terminals (DC1+, DC1-) of the first high voltage DC connection and a second capacitor is connected between the terminals (DC2+, DC2-) of the second high voltage DC connection.

The invention has mainly been described above with reference to a few embodiments. However, as is readily appreciated by a person skilled in the art, other embodiments than the ones disclosed above are equally possible within the scope of the invention, as defined by the appended patent claims.
CLAIMS

1. A power converter (1) for transferring power between a first high voltage DC connection (DC₁⁺, DC₁⁻), a second high voltage DC connection (DC₂⁺, DC₂⁻), and a high voltage AC connection (AC), the power converter (1) comprising a power converter assembly (9) comprising:

   a first voltage source converter (3a) and a second voltage source converter (3b) connected serially in the mentioned order between a positive terminal (DC₁⁺) and a negative terminal (DC₁⁻) of the first high voltage DC connection, wherein respective AC sides (5a-b) of the first voltage source converter (3a) and the second voltage source converter (3b) are connected to a common AC bus (7);

   a DC blocking device (21, 22) between the AC side of at all but one of the voltage source converters and the AC bus (7); and

   a phase shift device (21, 22, 23) between the AC side of the second voltage source converter and the AC side of the first voltage source converter;

   wherein the positive terminal (DC₂⁺) of the second high voltage DC connection is connected on one side of the second voltage source converter (3b) and the negative terminal (DC₂⁻) of the second high voltage DC connection is connected to another side of the second voltage source converter (3b); and

   the AC connection (AC) is connected to the AC bus for active power transfer with an AC grid.

2. The power converter (1) according to claim 1, wherein the power converter assembly (9) further comprises a third voltage source converter (3c) serially arranged between the second voltage source converter (3b) and the negative terminal (DC₁⁻) of the first high voltage DC connection, wherein an AC side (5c) of the third voltage source converter (3c) is connected to the AC bus (7).

3. The power converter (1) according to claim 2, wherein the power converter assembly (9) further comprises a fourth voltage source converter (3d) serially arranged between the second voltage source converter (3b) and the third voltage source converter (3c) such that the negative terminal (DC₂⁻) of the second high voltage DC connection is connected between the third voltage source converter (3c) and the fourth voltage source convert
converter (3d), wherein an AC side (5d) of the fourth voltage source converter (3d) is connected to the AC bus (7).

4. The power converter (1) according to any one of the preceding claims, wherein there is a phase shift device (21, 22, 23) provided between each one of the voltage source converters and the AC bus (7).

5. The power converter (1) according to any one of the preceding claims, wherein there is a DC blocking device (21, 22) provided between each one of the voltage source converters and the AC bus (7).

6. The power converter (1) according to any one of the preceding claims, wherein the phase shift device comprises an inductor (23).

7. The power converter (1) according to claim 6, wherein the AC port is provided through an electromagnetic coupling (24) to the inductor.

8. The power converter (1) according to any one of the preceding claims, wherein the phase shift device comprises a transformer (21).

9. The power converter (1) according to any one of the preceding claims, wherein the phase shift device comprises a capacitor (22).

10. The power converter (1) according to any one of the preceding claims, wherein the DC blocking device comprises a transformer (21).

11. The power converter (1) according to any one of the preceding claims, wherein the DC blocking device comprises a capacitor (22).

12. The power converter (1) according to any one of the preceding claims, comprising a plurality of the power converter assemblies (9a-c).

13. The power converter (1) according to claim 12, comprising three power converter assemblies (9a-c).

14. The power converter (1) according to any one of claims 12 to 13, wherein each power converter assembly (9a-c) provides its own high voltage AC connection (AC, converter (3d), wherein a n A C side (5d) o f the fourth voltage source converter (3d) i s connected t o the A C bus (7).
$A C_2, A C_3$, such that each power assembly corresponds to one phase of a combined multiphase AC connection.

15. The power converter (1) according to any one of the preceding claims, wherein a first capacitor (2) is connected between the terminals ($D_{C_1}^+, D_{C_1}^-$) of the first high voltage DC connection and a second capacitor (12) is connected between the terminals ($D_{C_1}^+, D_{C_1}^-$) of the second high voltage DC connection.
ANY REFERENCE TO FIGURE 10F SHALL BE CONSIDERED AS NON-EXISTENT
### A. CLASSIFICATION OF SUBJECT MATTER

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According to International Patent Classification (IPC) or to both national classification and IPC

### B. FIELDS SEARCHED

#### Minimum documentation searched (classification system followed by classification symbols)

- H02M
- H02J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

- EPO-Internal
- PAJ
- WPI Data

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

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[X] Further documents are listed in the continuation of Box C.  
[×] See patent family annex.

* Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier application or patent but published on or after the international filing date
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- "Z" document member of the same patent family

Date of the actual completion of the international search: 23 May 2012

Date of mailing of the international search report: 01/06/2012

Authorized officer: Kai 1, Maximi 1
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