METHOD

PHASE CONSUMER WITH TRANSFORMER COUPLED CELLS, HV AC/DC CONVERTER AND ASSOCIATED METHOD

Abstract: It is provided a phase converter (301a-c, 301) for converting between AC and DC. The phase converter comprises: a positive phase DC connection (50i) and a negative phase DC connection (50ii); a first converter cell (400a) and a second converter cell (400b) serially connected between the positive phase DC connection (50i) and the negative phase DC connection (50ii); and a transformer (17a-c, 17) comprising two component windings (62a-b) on a first side and a main winding (63) on a second side. A phase AC connection (69a-b) of the phase converter is provided connected to the main winding (63); wherein each one of the first converter cell (400a) and the second converter cell (400b) comprises a four quadrant converter; an energy storage element (68) and an AC connection (65a-b); the AC connections (62a-b) of the first converter cell (400a) and the second converter cell (400b) are respectively connected to the component windings (62a-b) of the transformer; and the first converter cell (400a) and the second converter cell (400b) are individually controllable in terms of phase angle on their respective AC sides.
THE INVENTION RELATES TO A PHASE CONVERTER, A HIGH VOLTAGE AC/DC CONVERTER AND ASSOCIATED METHOD FOR CONVERTING POWER BETWEEN A HIGH VOLTAGE DC (DIRECT CURRENT) CONNECTION AND A HIGH VOLTAGE AC (ALTERNATING CURRENT) CONNECTION.

BACKGROUND

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

WO 2012/103951 discloses a power electronic converter for high/medium voltage direct current power transmission and reactive power compensation which comprises a primary converter unit and an auxiliary converter unit, the primary converter unit including at least one primary converter limb including first and second DC terminals for connection in use to a DC network and an AC terminal, the or each primary converter limb defining first and second limb portions, each limb portion including at least one primary module, the or each primary module including at least one primary switching element connected to an energy storage device, the auxiliary converter unit including at least one auxiliary converter limb including at least one auxiliary module including a plurality of auxiliary switching elements connected to the energy storage device of a corresponding primary module in the first limb portion of a respective primary converter limb, the primary switching elements of the primary modules being controllable in use to switch the respective energy storage device in and out of circuit to generate a voltage waveform at the respective AC terminal.

However, the presented solution presented there is complicated and mainly relates to reactive power control.
SUMMARY

It is an object to provide AC/DC conversion with greater flexibility than in the prior art, yet with an efficient component structure.

According to a first aspect, it is provided a phase converter for converting between AC and DC, the phase converter comprising: a positive phase DC connection and a negative phase DC connection; a first converter cell and a second converter cell serially connected between the positive phase DC connection and the negative phase DC connection; and a transformer comprising two component windings on a first side and a main winding on a second side, wherein a phase AC connection of the phase converter is connected to the main winding. Each one of the first converter cell and the second converter cell comprises a four quadrant converter; an energy storage element and an AC connection, and the AC connections of the first converter cell and the second converter cell are respectively connected to the component windings of the transformer and the first converter cell and the second converter cell are individually controllable in terms of phase angle on their respective AC sides. Using this structure, the phase of the first converter cell and the second converter cells can be controlled independently. This is useful both for the DC side and AC side. By controlling the phase difference on the AC side between the converter cells, ripple can be greatly reduced. On the AC side, reactive power can be independently controlled. Moreover, greater fault handling capabilities are provided, reducing the need for over-dimensioning of components.

The four quadrant converters of each one of the first converter cell and the second converter cell may comprise a full bridge converter cell.

Each one of the full bridge converter cells may comprise four switch elements and the energy storage element of the respective converter cell.

Each one of the first converter cell and the second converter cell may comprise a half bridge converter cell, arranged in parallel with the full bridge converter cell, respectively. By providing a half bridge converter, in addition
to the full bridge converter, a phase reference signal can be provided. The full bridge converter could then e.g. be controlled such that switches are performed when the voltage across the full bridge converter is zero, or close to zero. In this way switching losses can be made very small or even negligible.

The storage element of each one of the first converter cell and the second converter cell may be shared between the half bridge cell and the full bridge cell, respectively. This allows for efficient energy transfer between the DC side and the AC side.

A magnitude of a first voltage across the AC connection of the first converter cell may be essentially equal to a magnitude of a second voltage across the AC connection of the second converter cell. In this way, full control of the AC side of the phase converter is achieved. For example, this allows a resulting AC side voltage at the origin, which can for example be particularly useful in fault cases on the AC side. In such a case, the AC side can be controlled to be zero while the DC side is fully operational, which reduces or eliminates any need for other phase converters to bear an increased DC load.

According to a second aspect, it is provided a high voltage AC/DC converter arranged to convert between a main DC connection and a multiphase AC connection, the high voltage AC/DC converter comprising at least two phase converters according to any one of the preceding claims. The number of phase converters is equal to the number of phases of the multiphase AC connection.

The high voltage AC/DC converter may comprise three and only three phase converters.

The high voltage AC/DC converter may further comprise a controller arranged to control a phase angle of each converter cell of the phase converters.
The controller may be arranged to control, for each one of the phase converters, the phase angle of each converter cell of the phase converters such that a resultant AC phase and AC magnitude approaches a reference value.

The phase converters may be serially connected between the terminals of the main DC connection.

According to a third aspect, it is presented a method arranged to control a high voltage AC/DC converter, to convert between a main DC connection and a multiphase AC connection, the high voltage AC/DC converter comprising at least two phase converters, each comprising a positive phase DC connection and a negative phase DC connection; a first converter cell and a second converter cell serially connected between the positive phase DC connection and the negative phase DC connection; and a transformer comprising two component windings on a first side and a main winding on a second side, wherein a phase AC connection of the phase converter is connected to the main winding; and each one of the first converter cell and the second converter cell comprises a four quadrant converter; an energy storage element and an AC connection, and the AC connections of the first converter cell and the second converter cell are respectively connected to the component windings of the transformer; wherein the number of phase converters is equal to the number of phases of the multiphase AC connection. The method is performed in a controller of the high voltage AC/DC converter, and comprises the step of: individually controlling a phase angle of each converter cell of the phase converters.

The step of controlling may comprise controlling, for each one of the phase converters, the phase angle of each converter cell of the phase converters such that a resultant AC voltage approaches a reference value in phase and magnitude.
The step of controlling may comprise switching switch elements of the four quadrant converter when a voltage across the respective switch element is essentially zero. In this way, switching losses are low or even negligible.

It is to be noted that any feature of the first, second and third aspects may, when appropriate, be applied to any other one of these aspects.

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 high voltage AC/DC power converter with three phases for converting between DC and AC;

Fig 2 is a schematic diagram of a phase converter of Fig 1;

Fig 3 is a schematic diagram illustrating relationships between voltages of the phase converter of Fig 2;

Fig 4 is a schematic graph illustrating the range of the resultant voltage control in the phase converter of Fig 2;

Figs 5A-B are schematic graphs illustrating how DC ripple can be reduced using the high voltage AC/DC converter of Fig 1;

Fig 6 is a schematic diagram illustrating the phase converter of Fig 2 when a fault occurs on the AC side;
Fig 7 is a flow chart illustrating a method performed in the high voltage AC/DC converter of Fig 1;

Figs 8A-C are schematic diagrams of in line devices of the phase converter of Figs 2, 9 and 10;

Fig 9 is a schematic diagram of a phase converter of Fig 1 according to an alternative embodiment; and

Fig 10 is a schematic diagram of a phase converter of Fig 1 according to another alternative 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 high voltage AC/DC power converter 1 with three phases for converting between AC and DC, i.e. from AC to DC and/or from DC to AC. On one side, the high voltage AC/DC converter 1 has a DC connection comprising a positive DC terminal 2071 and a negative DC terminal 20711. On the other side, there is a multi-phase AC connection comprising three phase connectors 21oa-c. It is to be noted that while there are three phases of the high voltage AC/DC converter 1 presented here, the embodiments presented herein are applicable to any number of phases, including two, four, five, six, etc. phases.

The high voltage AC/DC converter 1 comprises three phase converters 301a-c connected serially between the positive DC terminal 2071 and the negative DC terminal 20711. Each one of the phase converters 301a-c is controlled by a
controller 125 to convert from AC to DC or vice versa. The DC voltage is
divided essentially equally between the three phase converters 30ia-c. As will
be explained in more detail below, the voltage of each phase converter 30ia-c
is controllable in phase angle and magnitude on the AC side. As exemplified
in Figs 2, 9 and 10, the phase converters 30ia-c can comprise two converter
cells, each comprising any suitable four quadrant AC/DC converters.

On the AC side of the three phase converters 30ia-c, one set of terminals on
one side of each phase converter 30ia-c are interconnected (to act as a
common ground) and terminals on the other side provides the respective
phase, connected to each one of the three phase connectors 2iaoa-c.

Fig 2 is a schematic diagram of a phase converter 301 of Fig 1. The phase
converter 301 converts between AC and DC, i.e. from AC to DC and/or from
DC to AC. On a DC side, the phase converter 301 comprises a positive phase
DC connection 501 and a negative phase DC connection 501.'f.

Between the DC connections 501-1'f, there is a first converter cell 400a and a
second converter cell 400b serially connected in a chain link. Each one of the
converter cells 400a-b is a four quadrant AC/DC converter cell and comprises
an in line device 305 and four switch elements 60. While two converter cells
are shown here, the phase converter can be expanded to comprise more
converter cells, which could increase the quality on the DC side by reducing
ripple.

The in line device 305 can comprise only one or more passive devices, such as
an energy storage device as described with reference to Fig 8C below, or the
in line device 305 can comprise an active device, such as a half bridge device,
as described with reference to Figs 8A-B below.

In this example, the converter cells 400a-b comprise four quadrant
converters in form of full bridge converter cells. The switch elements 60
receive control signals from the controller 125 (Fig 1), allowing the controller
125 to individually control each switch element and thus also individually
control each one of the converter cells 400a-b. In this way, the first converter
cell 400a is controlled individually from the second converter cell 400b. Optionally, a respective gate unit (not shown) is connected between the controller 125 and each one of the switch elements 60. The gate unit provides a suitable signal to the respective switch element based on the control signal provided to the gate unit from the controller 125. The four switch elements 60 are any type of switch element with suitable power ratings. For example, the switch elements 60 can be implemented using insulated gate bipolar transistors (IGBT), Integrated Gate-Commutated Thyristors (IGCT), a Gate Turn-Off thyristors (GTO), power Metal-Oxide-Semiconductor Field-Effect-Transistor (MOSFET), power Bipolar Junction Transistor (BJT), Bi-mode Insulated Gate Transistor (BIGT) or any other suitable high power semiconductor component. The switch elements 60 may also comprise a respective anti-parallel free wheeling diode (not shown), which is even inherently included in the case of the switch element 60 being a BIGT.

The in line device 305 is provided in parallel across a first leg of two switch elements 60 and a second leg of two switch elements 60. The full bridge structure allows the synthesis of a voltage capable of assuming both signs, whereby the voltage of each converter cell can either be zero, the voltage of the in line device 305, or a reversed voltage of the in line device 305. In this way, e.g. using pulse width modulation from the controller (125 of Fig 1), an AC voltage can be synthesized on the AC connections 6sa-b of the converter cells 400a-b.

The phase converter 301 also comprises a transformer 17. The transformer 17 comprises two component windings 62a-b on a first side and a main winding 63 on a second side. The phase AC connection 69a-b of the phase converter 301 is connected to the main winding 63. When there are more than two converter cells provided, each one of the converter cell comprises its own component winding on the first side of the transformer 17.

The AC connections 6sa-b of the first converter cell 400a and the second converter cell 400b are respectively connected to the component windings 62a-b.
Fig 3 is a schematic diagram illustrating relationships between voltages of the phase converter 301 of Fig 2. The operation of the phase converter 301 will now be explained with reference to both Figs 2 and 3. The transformer 17 combines the AC connections 6sa-b and transforms this to/from the phase AC connection 69a-b. Since the AC connections 6sa-b are freely synthesized in terms of phase, a resultant voltage $\bar{V}_{tris}$ greatly controllable. In Fig 3, a first component voltage of the first AC connection 65a of the first converter cell 400a is represented by $\bar{V}_1$ and a second component voltage of the second AC connection 65b of the second converter cell 400b is represented by $\bar{V}_2$.

The resultant voltage $\bar{V}_{T}$ is then achieved by a vector addition of the first component voltage $\bar{V}_1$ and the second component voltage $\bar{V}_2$. The magnitude of the first component voltage $\bar{V}_1$ and the second component voltage $\bar{V}_2$ are here essentially equal. Using vector arithmetic, the magnitude of the resultant voltage $\bar{V}_{T}$ can be expressed as:

$$|\bar{V}_{T}| = \sqrt{|\bar{V}_1|^2 + |\bar{V}_2|^2 - 2|\bar{V}_1||\bar{V}_2| \cos(\delta - \epsilon_{21})}$$  \[1\]

where $\epsilon_{21}$ is the differential angle between the first component voltage $\bar{V}_1$ and the second component voltage $\bar{V}_2$ and can be written as:

$$\delta_{21} = \pi - \cos^{-1}\left(\frac{|\bar{V}_1|^2 + |\bar{V}_2|^2 - |\bar{V}_T|^2}{2|\bar{V}_1||\bar{V}_2|}\right)$$  \[2\]

The phase angle of the resultant voltage $\bar{V}_{T}$ with respect to the common reference ref is given by:

$$S_{tr} = \delta_{tr} + \alpha$$  \[3\]

The angle $\alpha$ is:
\[ \alpha = \frac{\pi - \gamma}{2} = \frac{\delta_{21}}{2} \]  

Thus, the phase angle of the first component voltage \( \vec{V}_i \) with respect to the reference \( \text{ref} \) can be calculated in terms of the desired phase angle of the resultant voltage \( \vec{V}_{T_{SLS}} \):

\[ S_{IR} = S_{IR}^{-} \]  

Fig 4 is a schematic graph illustrating the range of the resultant voltage control in the phase converter 301 of Fig 2. Also referring to Fig 3, it can be seen that since the phase voltages of the first component voltage \( \vec{V}_1 \) and the second component voltage \( \vec{V}_2 \) can be freely chosen, the resultant voltage can be selected freely in a space 42 within (and including) a confining circle 40. The scale on the x-axis and y-axis of Fig 4 are relative to the magnitude of one of the component voltages \( \vec{V}_1, \vec{V}_2 \).

One interesting special case of the resultant voltage \( \vec{V}_T \) is on the confining circle 40, where the magnitude of resultant voltage \( \vec{V}_T \) is at a maximum.

Another interesting case is the origin 43, where the resultant voltage \( \vec{V}_T \) is zero. As will be explained with reference to Fig 6 below, this is e.g. of interest when faults occur on the AC side. While the component voltages can be of different magnitudes, which gives the benefits of reactive power control and reduced DC ripple, a resultant voltage of \( \vec{V}_T \) can only be achieved when the component voltages are of essentially the same magnitudes.

Consequently, a reference value can be provided anywhere within the space 42 of possible values, whereby the controller 125 can control the converter cells 40oa-b to approach and eventually reach the reference value. This reference value can e.g. be selected to provide desired reactive power on the AC side or to handle the effects of faults on the AC side, such as short circuits.
Figs 5A-B are schematic graphs illustrating how DC ripple can be reduced using the high voltage AC/DC converter of Fig 1.

By shifting the differential angle \( \epsilon_2 \), between the two component voltages \( \vec{V}_1, \vec{V}_2 \) of each one of the phase converters 30ia-c of the high voltage AC/DC converter 1 of Fig 1, the ripple on the DC side of the converter can be reduced. In the graph shown in Fig 5A, the DC side voltage is shown when \( \delta_{21} = 0 \). This special case is one being equivalent to having a single converter cell and is achieved by the two converter cells 40oa-b of each phase converter 30ia-c being controlled synchronously. In the graph shown in Fig 5A, the DC side voltage is shown when \( \delta_{21} = \pi/6 \). Comparing Figs 5A and 5B it can be seen how the DC ripple is significantly lower in Fig 5B, by controlling the phase angles of the two component voltages \( \vec{V}_1, \vec{V}_2 \).

Fig 6 is a schematic diagram illustrating the phase converter 301 of Fig 2 when a fault occurs on the AC side. A fault 90 here occurs in the phase on the AC side, which here is a short circuit between the two AC connections for that phase.

Since the two converter cells 40oa-b are freely controllable, the controller (125 of Fig 1) can, when the fault is detected, control the two converter cells such that \( \delta_{21} = \pi \), whereby the resultant voltage \( \vec{V}_p \) is in the origin (43 of Fig 4), i.e. 0. In this way, the short circuit fault 90 has no or minimal effect on the phase converter 301. Moreover, since the converter cells 40oa-b are controlled in the same way as in normal operation, the affected phase converter 301 bears its share of the DC voltage (between 2071-1 of Fig 1). In this way, the components of the other phase converters do not need to be over-dimensioned to compensate for a failed phase converter, as is common in the prior art.

Fig 7 is a flow chart illustrating a method performed in the high voltage AC/DC converter of Fig 1. The method is performed in the controller of the high voltage AC/DC converter 1 (see Fig 1).
In a control step 30, the phase angles of each one of the converter cells of the phase converters 30ia-c are individually controlled. This control can e.g. be a control of the phase angle of each converter cell of the phase converters, such that the resultant AC voltage approaches a reference value in phase and magnitude.

The control step 30 may comprise switching switch elements of the four quadrant converter when a voltage across the respective switch element is essentially zero. In this way, switching losses are low or even negligible.

It has thus been shown how embodiments herein can be used in several ways to improve AC/DC conversion. One beneficial effect is that the reactive power of the high voltage AC/DC converter can be controlled independently from the active power control.

Another beneficial effect is that, using a proper phase shift between the converter cells, DC ripple voltage can be reduced which reduces the DC side filter requirements compared to the prior art.

Moreover, the AC fault handling described above reduces component rating requirements and handles faults without increasing the DC side ripple.

Additionally, having six converter cells (in the three phase case) increases redundancy in power conversion, compared to three converter cells.

Figs 8A-C are schematic diagrams of embodiments of the in line devices 305 of the phase converter of Figs 2, 9 and 10.

In Fig 8A, the in line device 305 comprises a half bridge converter 306. The half bridge converter comprises two switch elements 61 and an energy storage element 68.

The switch elements 61 are any type of switch element with suitable power ratings. For example, the switch elements 61 can be implemented using insulated gate bipolar transistors (IGBT), Integrated Gate-Commutated Thyristors (IGCT), a Gate Turn-Off thyristors (GTO), power Metal-Oxide-
Semiconductor Field-Effect-Transistor (MOSFET), power Bipolar Junction Transistor (BJT), Bi-mode Insulated Gate Transistor (BIGT) or any other suitable high power semiconductor component. The switch elements 61 may also comprise a respective anti-parallel free wheeling diode (not shown), which is even inherently included in the case of the switch element 60 being a BIGT.

While the energy storage element 68 is here illustrated using the symbol for a capacitor for reasons of clarity, the energy storage element 68 can be of any suitable type, such as a capacitor, a supercapacitor, an inductor, a battery, etc.

When the in line device 305 comprises an active device, such as the half bridge converter, the in-line device can be controlled in phase. In one embodiment, the output of the in-line device is a rectified sinusoidal voltage (the absolute value of a sinusoidal signal). Using the variations over time, the voltage across the in line device 305 is sometimes zero, or close to zero. When the connected full bridge converter is controlled to switch when the voltage is zero or close to zero, switching losses are greatly reduced or even eliminated. The phase is in this case governed by the control of the in line device 305, and the full bridge converter is configured to follow this control. Hence, in this situation, the usage of the phase shift as explained above is controlled by controlling the in line device 305.

Fig 9 is a schematic diagram of a phase converter 301 of Fig 1 according to an alternative embodiment. In this embodiment, the phase converter 301 comprises a four quadrant AC/DC converter of a different structure than the one shown in Fig 2. Here the first converter cell 400a comprises two serially connected partial component windings 62a connected on either side to respective switch elements 60. The other side of one switch element 60 is connected to one side of the in line device 305. The other side of the in line device 305 is connected to a point between the partial component windings 62a. The second converter cell 400b is of the same structure as the first
converter cell 400a. With this structure, the number of switch elements, and thus also gate units, can be reduced.

Fig 10 is a schematic diagram of a phase converter 301 of Fig 1 according to another alternative embodiment. In this embodiment, the phase converter 301 comprises a four quadrant AC/DC converter of a different structure than the ones shown in Figs 2 and 9. Here, the first converter cell 400a comprises two serially connected in line devices 305. Between two outer points on either side of the two in line devices 305, there is a string of two serially connected switch elements 60. A point between the two in line devices 305 is connected to one side of the first component winding 62a. On the other side, the first component winding 62a is connected to a mid point between the two switch elements 60. The second converter cell 400b is of the same structure as the first converter cell 400a. With this structure the number of switch elements, and thus also gate units, is reduced.

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 defined by the appended patent claims.
CLAIMS

1. A phase converter (30ia-c, 301) for converting between AC and DC, the
phase converter comprising:
   a positive phase DC connection (501) and a negative phase DC
   connection (5011);
   a first converter cell (400a) and a second converter cell (400b) serially
   connected between the positive phase DC connection (501) and the negative
   phase DC connection (5011); and
   a transformer (i7a-c, 17) comprising two component windings (62a-b)
on a first side and a main winding (63) on a second side, wherein a phase AC
connection (69a-b) of the phase converter is connected to the main winding
(63);
   wherein each one of the first converter cell (400a) and the second
converter cell (400b) comprises a four quadrant converter; an energy storage
element (68) and an AC connection (6sa-b);
   the AC connections (62a-b) of the first converter cell (400a) and the
second converter cell (400b) are respectively connected to the component
windings (62a-b) of the transformer; and
   the first converter cell (400a) and the second converter cell (400b) are
individually controllable in terms of phase angle on their respective AC sides.

2. The phase converter (30ia-c, 301) according to claim 1, wherein the four
quadrant converters of each one of the first converter cell (400a) and the
second converter cell (400b) comprises a full bridge converter cell.

3. The phase converter according to claim 2, wherein each one of the full
bridge converter cells comprises four switch elements (60) and the energy
storage element (68) of the respective converter cell (400a-b).

4. The phase converter (30ia-c, 301) according to claim 2 or 3, wherein
each one of the first converter cell (400a) and the second converter cell
(400b) comprises a half bridge converter cell (306), arranged in parallel with
the full bridge converter cell, respectively.
5. The phase converter (30ia-c, 301) according to claim 4, wherein the storage element (68) of each one of the first converter cell (400a) and the second converter cell (400b) is shared between the half bridge cell and the full bridge cell, respectively.

6. The phase converter (30ia-c, 301) according to any one of the preceding claims, wherein a magnitude of a first voltage across the AC connection of the first converter cell (400a) is essentially equal to a magnitude of a second voltage across the AC connection of the second converter cell (400b).

7. A high voltage AC/DC converter (1) arranged to convert between a main DC connection (2071-11) and a multiphase AC connection (2ioa-c), the high voltage AC/DC converter (1) comprising at least two phase converters (301a-c, 301) according to any one of the preceding claims, wherein the number of phase converters is equal to the number of phases of the multiphase AC connection (2ioa-c).

8. The high voltage AC/DC converter (1) according to claim 7, wherein the high voltage AC/DC converter comprises three and only three phase converters (30ia-c, 301).

9. The high voltage AC/DC converter (1) according to claim 7 or 8, further comprising a controller (125) arranged to control a phase angle of each converter cell of the phase converters.

10. The high voltage AC/DC converter (1) according to claim 9, wherein the controller (125) is arranged to control, for each one of the phase converters, the phase angle of each converter cell of the phase converters such that a resultant AC phase and AC magnitude approaches a reference value.

11. The high voltage AC/DC converter (1) according to any one of claims 7 to 10, wherein the phase converters (30ia-c, 301) are serially connected between the terminals of the main DC connection (2071-11).

12. A method arranged to control a high voltage AC/DC converter (1), to convert between a main DC connection (2071-11) and a multiphase AC
connection (2ioa-c), the high voltage AC/DC converter (1) comprising at least two phase converters (30ia-c, 301), each comprising a positive phase DC connection (501) and a negative phase DC connection (5011); a first converter cell (400a) and a second converter cell (400b) serially connected between the positive phase DC connection (501) and the negative phase DC connection (5011); and a transformer (i7a-c, 17) comprising two component windings (62a-b) on a first side and a main winding (63) on a second side, wherein a phase AC connection of the phase converter is connected to the main winding (63); and each one of the first converter cell (400a) and the second converter cell (400b) comprises a four quadrant converter; an energy storage element (68) and an AC connection (6sa-b), and the AC connections (62a-b) of the first converter cell (400a) and the second converter cell (400b) are respectively connected to the component windings (62a-b) of the transformer; wherein the number of phase converters is equal to the number of phases of the multiphase AC connection (2ioa-c), the method being performed in a controller (125) of the high voltage AC/DC converter (1), and comprising the step of:

individually controlling (30) a phase angle of each converter cell of the phase converters.

13. The method according to claim 12, wherein the step of controlling (30) comprises controlling, for each one of the phase converters, the phase angle of each converter cell of the phase converters such that a resultant AC voltage approaches a reference value in phase and magnitude.

14. The method according to claim 12 or 13, wherein the step of controlling (30) comprises switching switch elements of the four quadrant converter when a voltage across the respective switch element is essentially zero.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

H02M7/49
H02M1/15 H02M7/497

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

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

<table>
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<tr>
<th>Category*</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<tr>
<td>X</td>
<td>wo 2004/082115 Al (ABB TECHNOLOGY LTD [CH]; HYTTINEN MATS [SE]) 23 September 2004 (2004-09-23)</td>
<td>1-3, 6-13</td>
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<td>Y</td>
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Date of the actual completion of the international search
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Date of mailing of the international search report
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Kai 1, Maximi 1ian
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<th>Category</th>
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