The invention concerns a method, voltage source converter and computer program product for limiting the current in a DC power transmission system. The voltage source converter is provided with an alternating current terminal, a DC terminal and has a phase leg with a phase arm stretching between the alternating current terminal and DC terminal. The phase arm of the voltage source converter comprises a first switching element (Ti) together with an anti-parallel first rectifying element (Di) and a further switching element (FT) together with anti-parallel further rectifying element (FD), and an overvoltage protecting element (ZA) in parallel with the further switching element. The overvoltage protecting element (ZA) can be connected into a fault current path section in the phase arm between the alternating current terminal and said DC terminal for limiting the current at the DC terminal.
FIELD OF INVENTION

The present invention generally relates to voltage source converters. More particularly the present invention relates to a method, voltage source converter and computer program product for limiting the current in a DC power transmission system.

BACKGROUND

Direct Current (DC) power transmission systems are of interest to use in various situations, for instance when transferring electrical power over long distances.

It is here possible to provide a DC power transmission system as a grid being connected to one or more Alternating Current (AC) systems or AC grids via one or more voltage source converters.

A DC system can here be connected to an AC system in several different ways. It is for instance possible that the DC system is connected via one voltage source converter and a transformer such that there is no grounding on the DC side. It is also possible to connect a DC system to an AC system using separate voltage source converters connected on the DC side between a positive DC potential and ground and a negative DC potential and ground, respectively. In the first case a fault current from the AC side occurs when there are pole-to-pole faults, while in the second case
a fault current from the AC side also occurs when there are pole-to-ground faults. The first case may also result in fault current at a pole-to-ground fault if the transformer is grounded on both sides or if no transformer is used. One problem with large DC grids is related to selective disconnection of faulty components. If there is for instance a "large" bipolar DC grid, then if a pole-to-ground fault occurs, the voltages on this pole will be severely depressed everywhere in the grid due to the low resistance in the DC grid as compared to the network impedances in a corresponding AC grid. As a consequence essentially no power can be transmitted on this pole as long as the fault is not disconnected. In order to minimize impact on surrounding AC grids and connected end-users, it is important to quickly disconnect the fault. Furthermore, in order to have as much power transfer capability available in the period following the fault, it is important to only disconnect the faulty piece of equipment.

It is now also more and more common to use voltage source converters regardless of the topology used. Voltage source converters exhibit a weakness with regard to their behaviour in case the DC side is shorted, for instance due to a pole-to-pole short circuit in a HVDC transmission system where the converters are employed. Once the impedance between the DC poles has been significantly reduced as a consequence of the short circuit, there will always be a free path for the current from the AC side and the converter will act essentially as a short-circuited diode bridge. This will result in significant short-
circuit currents, which poses challenges if the converters are part of a DC grid.

There may therefore exist a need for limiting the fault current. However, the whole fault current should in some cases not be removed. There may for practical reasons exist a need for a small fault current in the DC system. This may be needed in order to be able to perform selective detection followed by disconnection of faulty parts. Furthermore, there may exist a need for a certain current to charge cable capacitances once the faulted equipment is disconnected.

One way of limiting the above-mentioned fault currents is known from N M MacLeod, A C Lancaster and C D M Oates, "The development of a Power Electronic Building Block for use in Voltage Source Converters for HVDC transmission applications", Cigre SC B4 2009 Bergen Colloquium, 2009. Here it is proposed that a voltage source converter made up of full-bridge cells should be used instead of one with half-bridge cells. The use of full-bridges enables the use of cell voltages to counteract the AC voltage on the AC side of the converter in order to limit the fault current. Full bridge cells can always produce a voltage regardless of the current direction. However, using full bridge cells implies a significant increase in cost compared to half-bridge cells.

A further way of limiting the mentioned fault currents is described in Rainer Marquardt, "Modular Multilevel Converter: An universal concept for HVDC-Networks and extended DC-Bus-applications", IPEC 2010 conference,
2010. Here a cell combination made up of two half-
bridge cells connected as a full bridge cell is
described. This combination has a further switching
element with antiparallel diode connected in parallel
between the capacitors of the half bridge cells. The
combination can either be operated as two half-bridge
cells or as one full-bridge cell depending on the state
of this further switching element. In case of a DC side
fault, the further switching element is opened and the
cell will be able to assist in limiting the fault
current.

It can be seen that in order to limit the fault
current, both documents in essence use the capacitor
charge of a full bridge cell to counter a fault current
caused by a voltage difference between the AC side and
the DC side of the converter.

However, the use of full-bridges is for many reasons
not desirable, for instance because of costs, and there
is therefore a need for an alternative way to limit
fault currents on the DC side of a voltage source
converter.

SUMMARY OF THE INVENTION

The present invention is directed towards reducing
fault currents by means of control of switching
elements in voltage source converters.

One object of the present invention is to provide a
method for limiting the fault current in a direct
current power transmission system, which uses the
elements of a voltage source converter for limiting the current.
This object is according to a first aspect of the present invention achieved through a method for using a
voltage source converter including a phase leg with a phase arm stretching between an alternating current
terminal and a direct current terminal of the converter, the phase arm including at least one first switching element together with an anti-parallel first rectifying element, the method comprising the steps of:
detecting a fault in the direct current power transmission system,
blocking the switching elements of the converter, and
connecting at least one overvoltage protecting element into a fault current path section stretching in the phase arm between the alternating current terminal and the direct current terminal, the step of connecting being performed based on the detected fault for limiting the current at the direct current terminal of the converter.

Another object of the present invention is to provide a voltage source converter for limiting the fault current in a direct current power transmission system, which converter includes elements that can be used for the fault current limitation.

This object is according to a second aspect of the present invention achieved through a voltage source converter for limiting the current in a direct current power transmission system, the voltage source converter being provided with an alternating current terminal and at least one direct current terminal and having a phase
leg with a phase arm stretching between the alternating current terminal and the direct current terminal, the phase arm of the voltage source converter comprising: a first switching element together with an anti-
parallel first rectifying element,
a further switching element together with an anti-
parallel further rectifying element, and
an overvoltage protecting element in parallel with the further switching element.

Another object of the present invention is to provide a computer program product for limiting the fault current in a direct current power transmission system, which uses the elements of a voltage source converter for the fault current limitation.

This object is according to a third aspect of the present invention achieved through computer program product for limiting the current in a direct current power transmission system using a voltage source converter including a phase leg having a phase arm stretching between an alternating current terminal and a direct current terminal of the converter, the phase arm including a first switching element together with an anti-parallel first rectifying element,
the computer program being loadable into a control unit of the voltage source converter and comprising computer program code provided on a data carrier, which computer program code causes the control unit to, when the program is loaded into the control unit,
detect a fault in the direct current power transmission system,
block the switching elements of the converter, and
connect at least one overvoltage protecting element into a fault current path section stretching in the phase arm between the alternating current terminal and the direct current terminal, the connecting being performed based on the detected fault for limiting the current at the direct current terminal of the converter.

The present invention has a number of advantages. It limits the fault current in a direct current power transmission system, which simplifies the removal of the fault. This allows a simpler and more economical realization of circuit breakers to be made. As the current limitation is made in the voltage source converter, there is no additional current limitation element provided in the direct current power transmission system. This allows current limitation to be provided without significantly limiting the efficiency of the direct current power transmission system in normal operation. This also provides current limiting functionality with a limited number of additional elements.

The control for limiting the fault current may be based on detecting the current at a direct current side of the converter and control switching elements in the fault current path section based on this detected current.

The control may comprise controlling of the current at a direct current side of the converter to a set current limitation value.
According to the invention it is also possible to detect the removal of the fault and return to normal operation based on the detection of the removal of the fault, which may involve the detection of the voltage recovery after the fault. The detection may comprise comparing the voltage at the direct current side with a voltage reference and determining that the fault has been removed in case this voltage rises above the voltage reference.

The control for limiting the fault current may involve a phase angle control. In this control a further switching element-first rectifying element combination can be controlled to provide a zero crossing of the current at the direct current side of the converter. In phase angle control this may be obtained at a phase angle that is approximately ninety degrees. This simplifies the direct current circuit breaker design even more.

The switching elements, rectifying elements and overvoltage protecting elements may be parts of one or more two-level voltage source converter cells.

**BRIEF DESCRIPTION OF THE DRAWINGS**

The present invention will in the following be described with reference being made to the accompanying drawings, where

fig. 1 schematically shows a DC power transmission system being connected to AC power lines via four voltage source converters,
fig. 2 schematically shows a voltage source converter having a number of parallel branches in the form of phase legs each provided with a number of voltage source converter cells,

fig. 3 schematically shows the structure of a first type of ordinary voltage source converter,

fig. 4 schematically shows the structure of a second type of voltage source converter cell according to a first embodiment of the invention,

fig. 5 schematically shows the structure of a third type of voltage source converter cell according to a second embodiment of the invention,

fig. 6 shows a block schematic outlining a phase angle control unit for a converter,

fig. 7 schematically shows a flow chart including a number of method steps in a method for limiting the current in the DC power transmission system and being performed in a voltage source converter,

fig. 8 schematically shows the current and voltage of the first voltage source converter at the DC side in relation to a fault,

fig. 9 shows a fourth type of voltage source converter cell according to a third embodiment of the invention,

fig. 10A shows a fifth type of voltage source converter cell according to a fourth embodiment of the invention,

fig. 10B shows a sixth type of voltage source converter cell according to a fifth embodiment of the invention, and

fig. 11 schematically shows a data carrier carrying program code for implementing the control unit of the present invention.
DETAILED DESCRIPTION OF THE INVENTION

In the following, a detailed description of preferred embodiments of the invention will be given.

Fig. 1 shows a single line diagram of a simplified Direct Current (DC) power transmission system 20 being connected to four different Alternating Current (AC) power lines via voltage source converters 12, 14, 16 and 18. The power transmission system may with advantage be a High Voltage Direct Current (HVDC) system. There is here a first voltage source converter 12 having an AC side connected to a first AC power line 13 and a DC side connected to a first junction 23 between a first DC power line 22 and a second DC power line 24. There is also a second voltage source converter 14 having an AC side connected to a second AC power line 15 and a DC side connected to second junction 25 between the second DC power line 24 and a third DC power line 26. There is also a third voltage source converter 16 having an AC side connected to a third AC power line 17 and a DC side connected to a third junction 27 between the first DC power line 22 and a fourth DC power line 28. There is furthermore a fourth voltage source converter 18 having an AC side connected to a fourth AC power line 19 and a DC side connected to a fourth junction 29 between the third DC power line 26 and the fourth DC power line 28. The AC power lines 13, 15, 17 and 19 may here be provided in different AC power transmission and/or distribution systems. The DC power transmission system 20 may also be termed a DC grid. There is furthermore provided a
first circuit breaker 30 in the first power line 22 at the first junction 23 and a second circuit breaker 32 also in the first power line 22 at the third junction 27 of the DC power transmission system 20. Finally fig. 1 shows that the first voltage source converter 12 supplies a DC current $i_{dc}$ and a DC voltage $u_{dc}$ to the DC power transmission system 20. Here the first and second circuit breakers 30 and 32 together with the first, second, third and fourth DC power lines 22, 24, 26 and 28 together form the DC power transmission system 20, while the voltage source converters 12, 14, 16, and 18 are interfaces between the AC power transmission lines 13, 15, 17, 19 and the DC power transmission system 20.

It should here be realized that the DC power transmission system can be more complex and include several more DC power lines, for instance two connected to each converter for providing a bipole system. It can also include less power lines, for instance one. It should furthermore be realized that there may be several more circuit breakers in the DC system. There are only two in fig. 1 in order to simplify the description of the present invention. There may also be more or fewer voltage source converters interfacing the DC power transmission system.

Fig. 2 shows a block schematic outlining an example of a voltage source converter 12. The voltage source converter 12 is here a cell based voltage source converter and includes a group of branches in the form of phase legs connected in parallel between two DC terminals DC+ and DC- for connection to the DC power transmission system. In the example given here there
are three such branches or phase legs PL1, PL2, PL3 in order to enable connection to a three-phase AC transmission system. It should however be realized that as an alternative there may be for instance only two phase legs. Each phase leg PL1, PL2, PL3 has a first and second end point. In a converter of the type depicted in fig. 2 the first end points of all the phase legs PL1, PL2 and PL3 are connected to a first DC terminal DC+ while the second end points are connected to a second DC terminal DC-. Each phase leg includes a lower and upper phase arm and at the junction where the arms of a leg meet, a three-phase connection point AC1, AC2 and AC3 is provided. Each three-phase connection point AC1, AC2, AC3 is here connected to the corresponding phase leg via a respective inductor LAC1, LAC2, LAC3. The two DC terminals DC+ and DC- here make up the DC side of the voltage source converter 12, while the AC terminals AC1, AC2 and AC3 make up the AC side of the voltage source converter.

Each phase arm furthermore includes a number of switching cells CA1, CA2 and CA3, CA4, CA5 and CA6, CB1, CB2 and CB3, CB4, CB5 and CB6, CC1, CC2 and CC3 and CC4, CC5 and CC6. These cells are all being controlled by a control unit 34.

In the present example there are three cells in each phase arm. Thus the upper phase arm of the first phase leg PL1 includes three cells CA1, CA2 and CA3, while the lower phase arm of the first phase leg PL1 includes three cells CA4, CA5 and CA6. In a similar fashion the upper phase arm of the second phase leg PL2 includes three cells CB1, CB2 and CB3, while the lower phase arm
of the second phase leg PL2 includes three cells CB4, CB5 and CB6. Finally the upper phase arm of the third phase leg PL3 includes three cells CC1, CC2 and CC3, while the lower phase arm of the third phase leg PL3 includes three cells CC4, CC5 and CC6. The numbers are here only chosen for exemplifying the principles of the present invention. It is often preferred to have many more cells in each phase leg, especially in HVDC applications.

The control unit 34 controls the switching elements of the switching arrangements for converting AC power to DC power or vice versa.

The exemplifying converter 12 may here be operated in two power directions. The control typically involves generating control signals by the control unit 34 in known fashion based on PWM modulation, for instance using a triangular saw-tooth wave as a reference signal, and supplying these control signals to the cells. The control unit 34 has further DC fault current limiting functionality, which will be described later on.

Some of the cells of the converter may be a first type of cells that are ordinary cells. The structure of this first type of cell is shown in fig. 3.

Fig. 3 schematically shows the first type of converter cell CCA. The cell CCA is a half-bridge or two-level converter cell and includes an energy storage element, here in the form of a capacitor C, which is connected
in parallel with a first group of switching units. The switching units in the first group are connected in series with each other in a switching unit branch. The first group here includes a first switching unit SU1 and a second switching unit SU2 (shown as dashed boxes), where each switching unit SU1 and SU2 may comprise a switching element that may be an IGBT (Insulated Gate Bipolar Transistor) transistor and an anti-parallel rectifying element, typically a diode. It should here be realized that a switching unit could include several such series connected IGBTs with anti-parallel diodes.

It can be seen that the first and second switching units SU1 and SU2 have the same orientation in the branch. In the specific realization shown here, the second switching element T2 has its collector connected to a first end of the cell capacitor C and its emitter to the collector of the first switching element T1, which in turn has its emitter connected to the second end of the cell capacitor C. The cathodes of the rectifying elements D1 and D2 are connected to the collectors of the corresponding switching elements while the anodes are connected to the emitters.

The cell has a first connection terminal TEIA and a second connection terminal TE2A, each providing a connection for the cell to a phase leg of the voltage source converter. In this first type of cell the first connection terminal TEIA more particularly provides a connection from the phase leg to the junction between the first and the second switching unit SU1 and SU2, while the second connection terminal TE2A provides a
connection from the phase leg to the junction between the first switching unit SU1 and the capacitor C. These connection terminals TEIA and TE2A thus provide points where the cell can be connected to the phase leg. The connection of the first connection terminal TEIA thus joins the phase leg with the connection point or junction between two of the series connected switching units of the first group, here the first and second switching units SU1 and SU2, while the connection of the second connection terminal TE2A joins the phase leg with a connection point between the first group of series connected switching units and the energy storage element, which is here the connection point between the first switching unit SU1 and the capacitor C. The first and second switching units SU1 and SU2 are here provided for normal cell switching in the voltage source converter, i.e. for contributing to the conversion between AC and DC.

In positive valve arms the first connection terminal TEIA is connected towards the positive dc-bus and the second connection terminal TE2A towards the ac bus. In negative valve arms the first connection terminal TEIA is connected towards the ac-bus and the second connection terminal TE2A towards the negative dc bus.

Fig. 4 schematically shows a second type of converter cell CCB that may be used for limiting the fault current according to the principles of the invention. The cell CCB is also a half-bridge or two-level converter cell and includes an energy storage element, here in the form of a capacitor C, which is connected in parallel with a first group of switching units. The
switching units in the first group are connected in series with each other in a switching unit branch. The first group here includes a first switching unit SU1 a second switching unit SU2 and a further switching unit FSU (shown as dashed boxes), where each switching unit SU1, SU2 and FSU may comprise a switching element that may be an IGBT (Insulated Gate Bipolar Transistor) transistor and an anti-parallel rectifying element, typically a diode. It should here be realized that a switching unit could include several such series connected IGBTs with anti-parallel diodes and being operated as one unit.

The first switching unit SU1 is a first type of switching unit placed in the middle of the group and includes a first transistor T1 and here an IGBT with a first rectifying element in the from of a first diode D1. This first type of switching unit is the same type of switching unit that was used in the first type of cell shown in fig. 3. The further switching unit FSU is here a second type of switching unit that is connected below the first switching unit and includes a further switching element FT of the same type as the first switching element with an antiparallel further rectifying element FD of the same type as the first rectifying element in the first switching unit. However, the further switching unit FSU also incudes an overvoltage protecting element in parallel with the further switching element FT and further rectifying element FD. This element is in this example a surge arrester ZA, like a varistor. The second switching unit SU2 is in this first embodiment of the same type as the first switching unit and connected above the first
switching unit SU1. The second switching unit SU2 includes a second switching element T2 of the same type as the first switching element with an antiparallel second rectifying element D2 of the same type as in the first switching unit.

It can be seen that the first and second switching units SU1 and SU2 have the same orientation in the branch, while the further switching unit FSU has an opposite orientation. This means that the first and second switching elements T1 and T2 have one orientation while the further switching element FT has an opposite orientation. In the same way the first and second rectifying elements have the same orientation while the further rectifying element has the opposite orientation in the branch. This here means that the emitter and collector of the first and second switching elements T1 and T2 have the same orientation in the branch, while the emitter and collector of the further switching element FT has the opposite orientation. This furthermore also means that the first and second rectifying elements D1 and D2 conduct current in one direction, while the further rectifying element FD conducts current in the opposite direction. In the specific realization shown here, the second switching element T2 has its collector connected to a first end of the cell capacitor C and its emitter to a following switching element in the branch, that the first switching element T1 has its collector connected closer to the second switching element T2 than the emitter and the emitter closer to the second end of the capacitor than the collector. The further switching element FT does in turn have its emitter connected to the emitter
of another switching element in the branch and the collector closer to the second end of the cell capacitor C than the emitter. Here the collector of the first switching element T1 is connected to the emitter of the second switching element T2 and the emitter of the first switching element T1 is connected to the emitter of the further switching element FT, the collector of which is connected to the second end of the cell capacitor C.

In fig. 4 the rectifying elements D1 and D2 of the first and second switching units SU1 and SU2 are therefore also oriented upwards in the figure, which is towards the capacitor C, and connected in parallel between emitter and collector, of the first transistor T1 and second transistor T2, respectively. Each rectifying elements is thus each connected with its anode to the collector and with its cathode to the emitter and conduct current from the anode to the cathode, which is in a direction that is parallel with the direction from the second to the first end of the cell capacitor C. The further rectifying element FD is oriented downwards for conducting current from the emitter to the collector of the further switching element, i.e. in a direction that is parallel with the direction from the first to the second end of the cell capacitor.

The cell has a first connection terminal TEIB and a second connection terminal TE2B, each providing a connection for the cell to a phase leg of the voltage source converter. In this first type of cell the first connection terminal TEIB more particularly provides a
connection from the phase leg to the junction between the second and the first switching unit SU2 and SU1, while the second connection terminal TE2B provides a connection from the phase leg to the junction between the further switching unit FSU and the capacitor C. These connection terminals TEIB and TE2B thus provide points where the cell can be connected to the phase leg. The connection of the first connection terminal TEIB thus joins the phase leg with the connection point or junction between two of the series connected switching units of the first group, here the second and first switching units SU2 and SU1, while the connection of the second connection terminal TE2B joins the phase leg with a connection point between the first group of series connected switching units and the energy storage element, which is here the connection point between the further switching unit FSU and the capacitor C. The first and second switching units SU1 and SU2 are here provided for normal cell switching in the voltage source converter, i.e. for contributing to the conversion between AC and DC, while the further switching unit FSU is provided for fault current limitation purposes. In positive valve arms the first connection terminal TEIB is connected towards the positive DC bus and the second connection terminal TE2B is connected towards the AC bus. In negative valve arms the first connection terminal TEIB is connected towards the AC-bus and second connection terminal TE2B towards the negative DC bus.

Through connecting a suitable number of such cells in cascade or series with each other in the phase legs a voltage source converter is obtained. A phase leg as
shown in fig. 2 may for instance be obtained through
connecting a first connection terminal of a first cell
to the first DC terminal (positive) via an inductor,
connecting a first connection terminal of a second cell
to the second connection terminal of the first cell,
connecting a first connection terminal of a third cell
to the second connection terminal of the second cell,
connecting a first connection terminal of a fourth cell
to the second connection terminal of the third cell,

5 connecting a first connection terminal of a fifth cell
to the second connection terminal of the fourth cell,
connecting a first connection terminal of a sixth cell
to the second connection terminal of the fifth cell and
connecting the second terminal of the sixth cell to the
second DC terminal via an inductor. It should here be
realized that some of the cells may be provided without
the further switching unit, for instance being provided
in accordance with the first type of switching unit.

Fig. 5 schematically shows a third type of half-bridge
converter cell CCC having the same type of components
as the second type and the same orientation. This cell
is a cell according to a second embodiment of the
invention. Here the further switching unit FSU is

10 provided in the middle of the branch, below the first
switching unit SU1 and above the second switching unit
SU2. There is also in this third type of cell CCC a
connection terminal TE2C, a second connection terminal,
which provides a connection between the branch and the
connection point between two switching units, here
between the further and the second switching units FSU
and SU2 as well as a connection terminal, a first
connection terminal TE1C, which provides a connection
between the branch and the junction between a switching unit and the capacitor C, here at the junction between the first switching unit SU1 and the capacitor C.

5 It can thus be seen that the first and further switching elements T1 and FT with the first and further anti-parallel rectifying elements D1 and FD are in both the second and third types of cells provided between the two connection terminals TE1B and TE2B and TE1C and TE2C, respectively, while second switching element T2 with a second antiparallel rectifying element D2 is provided on one side of both the connection terminals, which in fig. 4 is above both the connection terminals TE1B and TE2B and in fig. 5 below both connection terminals TE1C and TE2C.

10 It should here furthermore be realized that it is possible to connect two voltage source converters, in pairs between a junction in the DC system and the AC system. The first DC terminal of a first converter of such a converter pair would then be connected to a positive DC potential, while the second DC terminal would be connected to ground. The first DC terminal of the second converter of the converter pair would then be connected to ground, while the second DC terminal would be connected to a negative DC potential.

20 According to the principles of the present invention, the voltage source converter is provided with cells of the second or the third type, at least in one of the upper or lower of phase arms and here in the upper phase arms, while any possible remaining cells are ordinary cells, for instance of the first type. It can
here be mentioned that further examples on other types of cells that can be used will be given later. This means that there is a combination of a first type of switching unit with first switching element together with a first anti-parallel rectifying element but without overvoltage protecting element and a second type of switching unit with opposite orientation and with overvoltage protecting element, i.e. a switching element with anti-parallel rectifying element and parallel overvoltage protecting element.

The voltage source converter according to the invention may be provided in relation to high voltage DC applications where large currents and voltages are used. In HVDC systems it is possible that a fault is created in the DC power transmission system, for instance in the first power line in fig. 1. Such DC faults are hard to handle in DC power transmission systems. One reason for them being hard to handle is that the currents may become very high in the case of a fault. Another problem is that the system is a DC power transmission system, where the current is a DC current. This makes the breaking of power lines a rather complex affair.

The present invention is directed towards addressing such issues.

The normal way of providing a voltage source converter is to provide all switching elements as switching elements of the first type CCA lacking an overvoltage protecting element, for instance solely comprising transistor and diode combinations. When this is the
case, the current through the voltage source converter will increase when a DC fault occurs and the transistors will be blocked in order to avoid thermal damage. If the phase legs are solely made up of transistor-diode pairs, the converter will behave as a diode bridge i.e. the fault current is uncontrolled (in an active sense).

The idea behind the present invention is to connect the overvoltage protecting element of a cell into a section of the fault current path, where the fault current path is the path that the fault current will take through the voltage source converter. This section may be a current delivery section of this path through which current is delivered to the DC power transmission system or a return section through which current is returned. It should here be realized that this connection may be performed both in the delivery section and in the return section.

Fig. 6 shows a block schematic of one way of realizing a phase angle control functionality 35 of the control unit for controlling the further switching element of the cells to function as a thyristor together with the first rectifying element of the same cell. In fig. 6 there is a first subtracting unit 36, which receives two signals $i_{d_e}$ and $i_{lim}$ and supplies the result of a subtracting operation to an amplifying unit 38, which amplifies the difference with a gain $k$ and provides a phase angle $\delta$ as output to a switch 40. The switch 40 also receives a zero phase angle $\delta_0$ and is switchable between two positions based on two control signals.
F_DTC representing fault detection and F_RMV representing fault removal. The switch provides as its output a phase angle $\delta$, that is either of the two phase angles $\delta$ or $\delta_0$.

Now the functioning of the present invention according to a first embodiment of the invention as provided in the first converter 12 will be described in more detail with reference being made to fig. 1, 3, and 6 as well as to fig. 7, which schematically shows a flow chart including a number of method steps in a method for limiting the current in the DC power transmission system and being performed in the first voltage source converter 12, and to fig. 8, which schematically shows the current and voltage of the first voltage source converter at the DC side in relation to a fault in the first power line.

In the first embodiment, the voltage source converter is a cell-based voltage source converter including cells of the second type CCB. In this embodiment, the further switching elements are in normal mode, i.e. when there is no fault in the DC system 20, always conducting. This means that the further switching unit has no influence on the functioning of the cell in which it is provided, it is short-circuited. This means that depending on the direction of current either the further switching element FT or the anti-parallel further diode FD of the second type of cell CCB will in normal operation always conduct current. Since this is the case, the surge arrester ZA has consequently no influence on the functioning of the cell in this normal mode. Here the first and second switching elements Tl
and $T_2$ will operate as traditional switching elements for either providing a zero voltage contribution or the voltage contribution of the cell capacitor $C$. As an alternative the further switching element $FT$ may be controlled together with the first rectifying element $D_1$ of the first switching unit $SU_1$ to act as a diode or thyristor with a firing angle equal to zero. This means that the further switching element and first rectifying element combination are controlled by the control unit according to a first control mode so that they will always conduct current as a positive voltage is applied over them. The further switching element may here also be switched off or become non-conducting as the first switching element is switched on and becomes conducting and vice versa. It can also be continuously switched on or start to conduct continuously. This means that the switch $40$ of the phase angle control functionality $35$ of the control unit $34$ in this mode may be set to provide a phase angle $\delta_0$ that is a zero phase angle $\delta_0$ or to function as a diode together with the first rectifying element. As long as the further switching element is turned on and conducting when there is a positive voltage across it, the further switching unit will because of this have no impact on the functioning of the cell.

Normal operation is then provided up till a time at which time a DC fault occurs in the DC grid or DC power transmission system $20$. As an example a pole-to-pole fault occurs in relation to the first power line $22$. Since the AC terminals of the converter experiences AC voltages this means that a fault current path section is formed in an upper phase arm between an AC terminal
and one of the faulty DC poles, where another fault
current path section is formed in the corresponding
lower phase arm between the AC terminal and the other
DC pole. In this way several alternating parallel fault
current paths may be formed through the three phase
legs. At this point in time $t_1$, DC currents start to
increase and DC voltages start to decrease. This means
that also the DC current $i_{DC}$ and the DC voltage $v_{DC}$ at
the DC side of the first converter 12 change in the
same way. A fault current will thus start to run
between the AC terminal and a DC terminal via a phase
arm. This fault current is then detected, step 42. As
the currents rise, the currents running through the
switching elements of the cells may then be higher than
a reference level. Therefore there may be a detection
that the currents through the transistors are higher
than the reference level. This overcurrent detection
may constitute a detection of the fault current. The
detection of the overcurrent in turn, causes the
transistors to be blocked, step 44. The overcurrent
detection and transistor blocking takes place at time
$t_2$. In this embodiment they thus take place
simultaneously. This blocking may be done in order to
protect the transistors from thermal damage. The
control unit 34 may thus determine that the current
through the transistors are jeopardizing them and
therefore block them. It is thus possible that the
fault current is detected through the detection of the
overcurrent causing the switching elements to be
blocked.

This was just one way in which detection of a fault can
be performed. There exist a multitude of other ways. It
may for instance be detected through comparing a characteristic of a power component at the DC side of the voltage source converter with a corresponding power component threshold and to determine that there is a fault in case this characteristic of the power component passes this threshold. In one embodiment of the invention, the power component is a voltage and one characteristic of this voltage is the voltage level that is compared with a fault indicating voltage level threshold. This means that as the voltage level at the DC side of the voltage source converter 12 is decreasing it is possible to detect a fault through detecting that this voltage level, and thus the voltage in the DC system, falls below a voltage threshold.

This means that the detecting of a fault can in this case involve comparing the voltage at the DC side of the converter with a fault indicating voltage reference and determining that there is a fault in dependence of if this voltage falls below the fault indicating voltage reference.

Faults may alternatively be detected through sensing another characteristic, the rate of change of the voltage at the DC side of the voltage source converter, comparing this rate of change with a corresponding rate of change threshold and determining the existence of a fault in case this rate of change is below the rate of change threshold, which rate of change threshold is normally negative. This means that a fault would be detected if the rate of change, which is negative, falls below this negative threshold. This means that the absolute value of this rate of change is higher
than the absolute value of the threshold. In this way it is possible to detect a fast drop of the voltage.

It is also possible to detect a characteristic of another power component, the current, where the characteristic may be the current level. Here it is possible that the current level at the DC side of the voltage source converter is detected, compared with a corresponding current level threshold and the existence of a fault is determined if this current level threshold is exceeded. It is furthermore possible to detect another characteristic of the current at the DC side of the voltage source converter, the rate of change, compare this rate of change with a corresponding rate of change threshold and determine that there is a fault in case this rate of change is above this rate of change threshold, which threshold is normally positive. This means that a fast increase of the current would be detected. It should finally be mentioned that it is also possible with a combination of any of these detection techniques for detecting a fault.

Simultaneously with the detection of the fault, the control unit 34 changes control mode for the further switching element FT of the further switching units in a fault current path from the first normal control mode to a second control mode, a fault current limitation mode. In the fault current limitation mode the surge arrester ZA is connected into the fault current path, step 46. This mode may also involve the control of the further switching element FT to function as a thyristor together with the first rectifying element D1 or in
other words phase angle control of the further
switching element and first rectifying element
combination. However, in contrast to a real thyristor,
the further switching element may turn-off while
cconducting fault current and thereby insert the surge
arrester in the fault circuit. The control unit 34 thus
changes control mode, which involves controlling the
further switching element FT to connect the surge
arrester ZA into the fault current path optionally
combined with switching the control of the further
switching element - first rectifying element
combination from diode to phase angle control. Since
the first switching element Tl is blocked, the further
switching element FT will always be placed in series
with the first rectifying element Dl. This means that
it is possible to emulate a thyristor with this element
combination. The change in mode is performed based on a
fault detecting signal F_DTC, which may thus be
generated internally in the control unit 34 or a signal
received from an entity external to the control unit 34
as a consequence of the detection of a fault in the DC
system. In the phase angle control functionality 35 of
the control unit 34 this signal is supplied to the
switch 40, which then changes from supplying the zero
phase angle $\delta_0$ as output signal $\delta_c$ to providing a phase
angle $\delta_S$ supplied by the amplifying unit 38 as output
signal $\delta_c$. Phase angle control is based on the current
$I_{DC}$ at the DC side of the first converter 12 and more
particularly on the average current on the DC side.
Therefore the current $I_{DC}$ at the DC side of the
converter 12 is detected or measured, step 48. The
control unit 34 then controls the further switching
element based on the detected current. This involves controlling the further switching element / first rectifying element combination for obtaining a set current limitation value $i_{\text{ILM}}$, step 50. This may be done through comparing the average measured current $i_{\text{DC}}$ with the current limitation value $i_{\text{ILM}}$ in the subtracting unit 36 and changing the phase angle based on the difference. It is here for instance possible with P, PI or PID regulation. In fig. 6 proportional regulation is performed using a gain $k$ in the amplifying unit 58 for obtaining a phase angle $\delta$ that is supplied as output phase angle $\delta_3$ for controlling the cells where thyristors are emulated. This means that the emulated thyristors each receive a switching pulse when they are to be turned on or conducting according to the phase angle. This control is continued until the fault has been removed. The current level is thus reduced through the combination of surge arrester, which causes the connection of a voltage between pole and AC terminal counteracting the AC voltage, and phase angle control of the further switching element / first rectifying element combination. This would normally lead to the transistors being de-blocked and starting to operate again. However, as there is still a fault, they have to remain blocked. The control unit 34 therefore continues to block all transistors until the fault has been safely removed. This also means that the current is not used for indicating the fault in this second control mode.

In one embodiment of the invention the further switching elements of all cells in which they are present are controlled in the above described way.
simultaneously. With this control it can be seen that
when the further switching element is switched off, the
fault current will run through the surge arrester,
which due to its high resistance property provides a
significant limitation of the fault current. With a
proper selection of phase angle using phase angle
control of the switch further current limitations are
possible.

The current limit value \( I_{\text{lim}} \) can here be set to zero.
However it may be desirable to continue to feed some
current into the DC power transmission system. It may
for instance be necessary to have some current in the
DC power transmission system in order to perform
selective detection of where in the system the fault is
located in order to find out which parts of the DC
power transmission system that are faulty and need to
be disconnected. It may also be necessary to retain
some currents in order to charge cable capacitances
once the faulty part is disconnected. The fault current
contribution can be substantially lower than the normal
load current, since the indication of fault is obtained
via the DC voltage. If the total fault current allowed
in the DC power transmission system is \( I_{\text{lim}} \), which may
for instance be 4 kA, then the fault current
contribution from the first voltage source converter
may be \( I_{\text{lim}}/m \), where \( m \) is the number of voltage source
converters that are interfacing the DC power
transmission system. The current limit value \( I_{\text{lim}} \) may
thus be set according to: \( I_{\text{lim}} = I_{\text{lim}}/m \). With four
converters the current limit value \( I_{\text{lim}} \) would thus be 1
kA.
Thereafter the fault is removed in the system, which is typically done through the first and second circuit breakers 30 and 32 disconnecting the first DC power line 12 from the DC power transmission system 20. This is done at time \( t_3 \). The removal of the fault may then be detected. This detection may also here be performed in the system outside of the converter or in the converter itself. As the fault is removed the voltage of the DC power transmission system 20 starts to increase. The detection of the removal of the fault may involve detection of voltage recovery. In order to detect this voltage recovery, the control unit 34 may compare the voltage \( u_{\text{DC}} \) at the DC side of the first converter 12 with a voltage reference \( U_{\text{REF}} \), step 52, and if this reference is exceeded, then the control unit 34 determines that the fault has been removed and returns to the first control mode, i.e. to control the further switching element FT to permanently bypass the surge arrester, step 54. This means that currents passing through the cells will no longer pass the surge arrester. This may be combined with controlling the further switching element and first rectifying element combination as diode. It is also possible to keep the further switching element permanently conducting (until another fault occurs). The return to the first control mode is done at time \( t_4 \). The control unit 34 thus resumes control of the controllable rectifying elements in the fault current path according to the first control mode. Then the transistors can also be deblocked and normal operation is thus restored. However if the average voltage did not exceed this reference voltage \( U_{\text{REF}} \), step 52, fault current limitation control is continued, steps 48, 50. A switch
back to the first control mode may be done through generating or receiving a control signal $F_{RMV}$ indicating that the fault has been removed, which signal is supplied to the switch 40, which switches in order to once again supply the zero phase angle $\delta_0$ as output signal for controlling the further switching elements.

Alternative ways of detecting removal of the fault may here be provided. Removal of the fault may for instance be detected through sensing the rate of change of the voltage at the DC side of the voltage source converter, comparing this rate of change with a second rate of change threshold and detecting a removal of the fault in case this rate of change is above this second rate of change threshold, which threshold is normally positive. This means that a fast increase of the voltage would be detected. It should finally be mentioned that it is also possible with a combination of these detection techniques for detecting a removal of the fault.

The fault current in the DC power transmission system is thus limited through the above-described measures, which simplifies the removal of the fault. This allows a simpler and more economical realization of circuit breakers to be made. As the current limitation is made in the rectifying elements of the voltage source converter, there is no additional current limitation element provided in the DC power transmission system. This allows current limitation to be provided without significantly limiting the efficiency of the DC power transmission system in normal operation. This also
provides current limiting functionality without additional elements, but the same voltage source converter elements can be used for voltage conversion and current limitation.

It should here be realized that the time interval $t_3 - t_2$ should be large enough for allowing safe determination of the location of the fault so that wrong disconnections are not made.

According to a variation of the present invention it is possible that the current limitation is set so low that the phase angle will be regulated to approximately ninety degrees and preferably slightly less than ninety degrees. This has the advantage of obtaining a current at the DC side of the converter that has a zero crossing. Because the current at the DC side has a zero-crossing, the circuit breakers in the DC power transmission system can be simplified. Because there are zero-crossings it is possible to use AC circuit breakers that are simpler in structure and often cheaper than regular DC breakers.

There are a number of variations that are possible to make of the present invention.

The use of the further switching element may cause additional losses in normal operation. This can be avoided through the use of the structure shown in fig. 9. Here there is a shown a cell of a fourth type and according to a third embodiment of the invention. This cell is provided according to the principles shown in fig. 4. In this cell a further branch has been placed
in parallel with the surge arrester ZA. This branch includes a mechanical switch MSW, which may be a fast mechanical switch, in series with an electronic switch ESW. The electronic switch ESW can here typically be a MOSFET switch. Both these switches are then conducting in normal operation, taking a majority of the current due to lower on-state resistance as compared to the parallel further switching element FT. As a fault current is detected, and before the further switching element FT is opened for going into a non-conducting state, the electronic switch ESW is first opened and thus becoming non-conducting. This will commutate current to the further switching element FT. As this happens the mechanical switch MSW is opened for becoming non-conducting. After the mechanical switch MSW has been opened the previously described operation is resumed, i.e. the further switching element FT is opened and becomes non-conducting thereby commutating current to the surge arrester ZA.

In the first control strategy described above, the further switching elements in all the cells were switched simultaneously. However, it is possible that they are switched sequentially instead and thereby inserting the surge arresters stepwise. This may be done for making the inserted surge arrester voltage counteract the grid voltage, which has a sinusoidal variation. This means that fault current limitation may be performed without the above-mentioned phase angle control. The objective is that the inserted arrester voltage shall be of the same magnitude as the AC voltage in order to limit the current.
It is furthermore possible to apply PWM control of the further switching elements. This may be done in order to limit ripple in the DC current.

In the method described above the control unit changed from the first normal control mode to the second control mode simultaneously with the blocking of the switching elements, i.e. connected the surge arrester into the fault current path simultaneously with the transistor blocking. The connection of the surge arrester into the fault current path may as alternative be made later than the blocking of switching elements. This may be done through designing the further switching element to be able to withstand a higher current than the other switching elements. This means that the switching elements in the first type of switching units are designed to withstand a lower voltage than the switching elements in the second type of switching units.

Another possible variation is that overvoltage protecting elements are connected in one half of the sinusoidal variation, while cell capacitors are used in the other half, where the first half may be a half when an AC terminal of the converter experiences an AC voltage having one polarity and the other half is when the AC terminal experiences an AC voltage having an opposite polarity. This means that when a phase arm is subject to for instance a positive AC voltage then the further switching elements in this phase arm are switched off for connecting one or more surge arresters into the fault current path while the first and third switching elements are being blocked. When the phase
arm then experiences a negative AC voltages the first switching element is turned off, the further switching element turned on and also the third switching element turned on leading to the cell voltage counteracting the negative AC voltage. This measure assists in the control of the fault current.

Since the further switching element is placed in series with the first rectifying element and the first switching element is placed in series with the further rectifying element, which can be seen from for instance fig. 4, it is readily understood that the diodes used as rectifying elements assist the first and further switching elements to block negative voltages. This means that the transistors used as switching elements will in effect have the ability to withstand a negative voltage applied between collector and emitter because of these diodes.

There are however alternative ways in which this negative voltage blocking ability may be provided. A first way in which this may be done is shown in fig. 10A. This figure shows a fifth type of cell according to a fourth embodiment of the invention, where the first and further transistors T1' and FT' are provided as Reverse Conducting Integrated Gate Bipolar Transistors RC-IGBTs (also called BIGT, Bi-Mode IGBT) , where each transistor here in essence includes an IGBT with anti-parallel diode. In this case the first and further switching units do not include any extra diodes but only these RC IGBTs in series, with their emitters connected to each other. The surge arrester is connected in parallel with the further RC IGBT.
It is also possible to obtain the same result using two antiparallel Reverse Blocking Integrated Gate Bipolar Transistors, RC-IGBTs. Tl'' and FT''. This is shown in fig. 10B, which shows a sixth type of cell according to a fifth embodiment of the invention. The surge arrester is connected in parallel with the further RB IGBT FT''. In this case the first rectifying element of the previously described embodiment can be seen as making up a part of the further transistor FT'', while the further rectifying element can be seen as making up a part of the first transistor Tl''.

When using phase angle control, it is possible to use direct control of the further switching element to obtain a certain current level on the DC side of the converter instead of the above described control loop based on the detected current at the DC side. It is for instance possible to use a predetermined phase angle in a range of for instance 70 – 90 degrees. It is also possible to vary the phase angle according to a predetermined varying scheme, like for instance gradually increasing the phase angle from zero until it reaches a pre-determined end phase-angle for instance in the range of 70 – 90 degrees. It is also possible to provide a controllable rectifying element also in the return path, i.e. in the lower half of a phase leg. In the case of voltage converter cells, it is possible that all switching units of the cell are switching units of the first type. In the method described above the step of blocking switching elements was performed simultaneously with the detection of the fault. However, it should be realized that the fault may as an
alternative be detected before or after the switching elements are blocked.

Another possible variation is to use snubbers in order to limit the rate of change of the voltage at turn off. Such a snubber may for instance be placed in parallel with the further switching element.

The switching units used in the cells have been described as employing transistors. These are with advantage IGBTs. It should be realized that other types of switching elements may be used, such as MOSFET transistors or elements based on thyristors such as GTOs (Gate Turn-Off Thyristor) or IGCTs (Integrated Gate Commuted Thyristor).

The overvoltage protecting element was above described as being a surge arrester in the form of a varistor. However also other types of overvoltage protecting elements may be considered, such as breakover diodes.

The control unit need not be provided as a part of a voltage source converter. It can be provided as a separate device that provides control signals to the voltage source converter. This control unit may be realized in the form of discrete components as indicated in fig. 6. However, it may also be implemented in the form of a processor with accompanying program memory comprising computer program code that performs the desired control functionality when being run on the processor. This computer program product can be provided as a data carrier such as one or more CD ROM discs or one or more memory sticks.
carrying computer program code, which performs the above-described current limitation control functionality when being loaded into a control unit of a voltage source converter. One such data carrier 56 in the form of a CD rom disc carrying such computer program code 58 is schematically shown in fig. 11.

From the foregoing discussion it is evident that the present invention can be varied in a multitude of ways. It shall consequently be realized that the present invention is only to be limited by the following claims.
CLAIMS

1. A method for limiting the current in a direct current power transmission system (20) using a voltage source converter (12) including a phase leg (PL1) with a phase arm stretching between an alternating current terminal (AC1) and a direct current terminal (DC+) of the converter, said phase arm including at least one first switching element (T1) together with an anti-parallel first rectifying element (D1), the method comprising the steps of:

- detecting (42) a fault in the direct current power transmission system,
- blocking (44) the switching elements (T1, FT, T3) of the converter, and
- connecting (46) at least one overvoltage protecting element (ZA) into a fault current path section stretching in the phase arm between said alternating current terminal and said direct current terminal, said step of connecting being performed based on the detected fault for limiting the current at said direct current terminal of the converter.

2. A method according to claim 1, further comprising the step of detecting (52) the removal of the fault and bypassing (54) the overvoltage protecting element based on said detection (F_RMV) of the removal of the fault.

3. A method according to claim 2, wherein the step of detecting a removal of the fault comprises comparing the voltage \( u_{DC} \) at a direct current side of the converter with a voltage reference \( U_{REF} \) and
determining that the fault has been removed in case
this voltage rises above the voltage reference.

4. A method according to any previous claim,

5 further comprising a further switching element (FT)
with a further anti-parallel rectifying element (FD) in
parallel with the overvoltage protecting element and in
series with the first switching element and first
antiparallel rectifying element, where the step of

10 connecting at least one overvoltage protecting element
(ZA) into the fault current path section comprises
controlling the further switching element for
connecting the overvoltage protecting element into the
fault current path section.

15

5. A method according to claim 4, further
comprising the step of detecting (48) the current (i_{DC})
at the direct current terminal of the converter,
wherein the step of connecting at least one overvoltage

20 protecting element (ZA) into the fault current path
section comprises controlling the further switching
element of the fault current path based on this
detected current.

25 6. A method according to claim 5, wherein the step
of controlling the further switching element comprises
controlling the average current (\langle i_{DC} \rangle) at the direct

current terminal of the converter to a set current
limitation value (i_{LIM}).

30

7. A method according to any of claims 4 - 6,
wherein the step of controlling the further switching
element involves controlling the further switching element for providing a zero crossing of the current at the direct current side of the converter.

8. A method according to any of claims 4 - 7, wherein the step of controlling the further switching element comprises controlling the further switching element to act as a thyristor together with the first rectifying element using phase angle control.

9. A method according to any of claims 4 - 8, further comprising a series connection of mechanical switching element (MSW) and electronic switching element (ESW), said series connection being placed in parallel with the overvoltage protecting element, wherein the mechanical and electronic switching elements are conducting in normal operation and non-conducting when inserting the overvoltage protecting element into the fault current path, the method comprising the further steps of turning off the electronic switching element when the further switching element is conducting and thereafter opening the mechanical switching element before the further switching element is controlled to place the overvoltage protecting element in the fault current path.

10. A method according to any of claims 4 - 9, wherein the first and further switching element with first and further anti-parallel rectifying elements are provided in a switching element branch of a two-level converter cell between two connection terminals (TE1A, TE2A; TE1B, TE2B) of the two-level converter cell, said
two-level converter cell having a capacitor \((C)\), being
provided in said phase arm and comprising a second
switching element \((T_2)\) with a second antiparallel
rectifying element \((D_2)\) in the switching element branch
on one side of both the connection terminals.

11. A method according to claim 10, wherein the
step of controlling comprises controlling the further
switching element in all cells in said phase arm being
equipped with said further switching element, to
simultaneously connect an overvoltage protecting
element into said fault current path.

12. A method according to claim 10, wherein the
step of controlling comprises controlling the further
switching element in all cells in said phase arm being
equipped with said further switching element to
sequentially connect an overvoltage protecting element
into said fault current path.

13. A method according to claim 12, wherein the
step of controlling is performed in the cell when an AC
time at the alternating current terminal has a first
polarity and further comprising the step of controlling
the switching elements of the cell for connecting a
capacitor of the cell for controlling the fault current
when the AC voltage at the alternating current terminal
has a second opposite polarity.

14. A voltage source converter \((12)\) for limiting
the current in a direct current power transmission
system \((20)\), being provided with an alternating current
terminal \((AC1)\) and at least one direct current terminal
\((DC+)\) and having a phase leg \((PL1)\) with a phase arm
stretching between said alternating current terminal and said direct current terminal, said phase arm of said voltage source converter comprising:
- a first switching element (T1) together with an anti-parallel first rectifying element (D1),
- a further switching element (FT) together with anti-parallel further rectifying element (FD), and
- an overvoltage protecting element (ZA) in parallel with the further switching element.

15. A voltage source converter according to claim 14, wherein the further switching element and further anti-parallel rectifying element have an opposite orientation in the phase arm compared to the first switching element and first anti-parallel rectifying element.

16. A voltage source converter according to claim 14 or 15, wherein the first and further switching elements are insulated gate bipolar transistors.

17. A voltage source converter according to claim 16, wherein the first switching element and first anti-parallel rectifying element are provided as a first switching unit (T1') that is a reverse conducting insulated gate bipolar transistor unit, the further switching element and further anti-parallel rectifying element are provided as a further switching unit (FT') that is a reverse conducting insulated gate bipolar transistor unit, where these units are provided in series with each other in the phase arm.
18. A voltage source converter according to claim 16, wherein the first switching element and further anti-parallel rectifying element are provided as a first switching unit (T1') that is a reverse blocking insulated gate bipolar transistor unit, the further switching element and first anti-parallel rectifying element are provided as a further switching unit (FT') that is a reverse blocking insulated gate bipolar unit, where these units are provided in parallel with each other in the phase arm.

19. A voltage source converter according to any of claims 14 - 18, further comprising a series connection of mechanical switching element (MSW) and electronic switching element (ESW), said series connection being placed in parallel with the overvoltage protecting element.

20. A voltage source converter according to any of claims 14 - 19, further comprising a control unit (34) configured to, based on a fault being detected (F_DTC) in the direct current power transmission system, control said further switching element to connect the overvoltage protecting element into a fault current path section stretching in the phase arm between said alternating current terminal and direct current terminal, said connecting of the overvoltage protecting element into said fault current path section being performed in order to limit the current at a direct current side of the converter.

21. A voltage source converter (12) according to any of claims 14 - 20, wherein the first and further
switching element with first and further anti-parallel diodes are provided in a switching element branch of a two-level converter cell between two connection terminals (TE1A, TE2A; TE1B, TE2B) of the two-level converter cell, said two-level converter cell being provided in said phase arm, comprising a capacitor (C) and comprising a second switching element (T2) with a second antiparallel rectifying element (D2) in the switching element branch on one side of both the connection terminals.

22. A computer program product for limiting the current in a direct current power transmission system (20) using a voltage source converter (12) including a phase leg having a phase arm stretching between an alternating current terminal and a direct current terminal of the converter, said phase arm including a first switching element (T1) together with an antiparallel first rectifying element (D1), the computer program being loadable into a control unit of the voltage source converter and comprising computer program code provided on a data carrier, which computer program code causes the control unit to, when said program is loaded in said control unit,

- detect a fault in the direct current power transmission system,
- block the switching elements (T1, T2 FT) of the converter, and
- connect at least one overvoltage protecting element (ZA) into a fault current path section stretching in the phase arm between said alternating current terminal and said direct current terminal, said connecting being performed based on the detected
fault for limiting the current at said direct current terminal of the converter.
FIG. 4

FIG. 5
FIG. 7

FIG. 11
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

H02M1/32
H02J3/36 H02M7/49

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H02J 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 practical, 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>
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<tr>
<td>X</td>
<td>wo 2009/149750 AI (ABB TECHNOLOGY AG [CH] ; ASPLUND GUNNAR [SE] ) 17 December 2009 (2009-12-17) figure 2 claims 3, 5, 6 page 1, line 29 - page 2, line 2 page 3 page 4, paragraph 3 - page 5, paragraph 2 ----- -/- -/-</td>
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Further documents are listed in the continuation of Box C.

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Date of the actual completion of the international search

23 November 2011

Date of mailing of the international search report

30/11/2011

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, 340-2041
Fax: (+31-70) 340-3016

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Kai 1, Maximi 1i an

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