



(51) International Patent Classification:

H02M 7/483 (2007.01) *H02M* 1/36 (2007.01)
H02H 9/02 (2006.01)

(21) International Application Number:

PCT/EP2011/058480

(22) International Filing Date:

24 May 2011 (24.05.2011)

(25) Filing Language:

English

(26) Publication Language:

English

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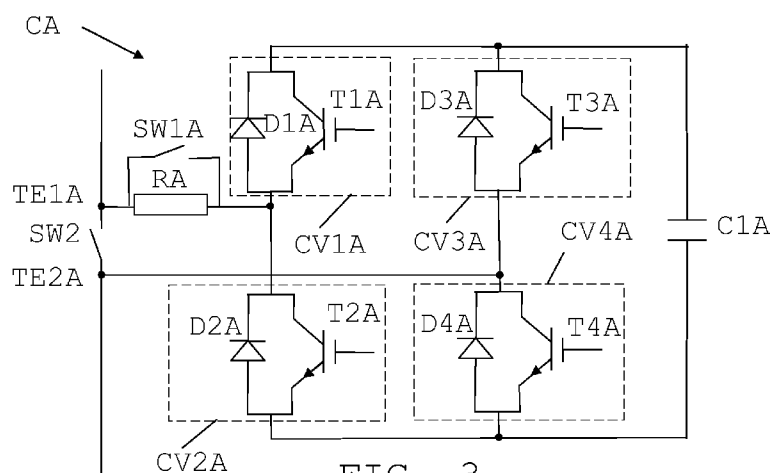
(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: INRUSH CURRENT CONTROL IN A CELL-BASED VOLTAGE SOURCE CONVERTER



(57) Abstract: The invention concerns a voltage source converter comprising a number of voltage source converter cells and a method of controlling start up of a cell-based voltage source converter. The voltage source converter comprises a number of voltage source converter cells (CA) connected in cascade in at least two branches, where each voltage source converter cell comprises: a first and a second connection terminal (TE1A, TE2A) each providing a connection to a corresponding branch of the voltage source converter, a number of valve elements (CV1A, CV2A, CV3A, CV4A), an energy storage element (C1A) and a parallel circuit comprising a resistive element (RA) in parallel with a first switching element (SW1A) in order to limit the current running through the voltage source converter branch at start up.

INRUSH CURRENT CONTROL IN A CELL-BASED VOLTAGE SOURCE
CONVERTER

FIELD OF INVENTION

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The present invention generally relates to voltage source converters. More particularly the present invention relates to a voltage source converter comprising a number of voltage source converter cells and to a method of controlling start up of a cell-based voltage source converter.

BACKGROUND

15 There have recently evolved voltage source converts (VSCs) that are based on cascaded voltage source converter cells provided in branches. Each cell is in one type of cell structure made up of a DC energy storage element in parallel with a first group of valve elements as well as with a second group of valve elements. A valve element is here typically made up of semiconductor elements like transistors with anti-parallel diodes. The cell is also equipped with two connection terminals, where one is provided between two valve elements of the first group and the other between two valve elements in the second group. These types of cells may be used in Static Var Compensators (STATCOMs or SVCs).

30 It is also known to provide another cell structure. In this other type of cell a DC energy storage element, typically a capacitor, is connected in parallel with only a first group of valve elements for forming a

half-bridge converter cell. The cell is also connected to a voltage source converter branch using two connection terminals, one between two valve elements in the first group and the other between the first or last
5 valve element in the group and the energy storage element. Such a cell structure can be used in inverters and in rectifiers.

During the energization of a voltage source converter,
10 i.e. during the charging of DC capacitors, the semiconductors of the cells may face a large inrush current since these capacitors may, most probably, be completely discharged. The VSC structure then acts as a rectifier and the full inrush current will pass through
15 the diodes. Therefore, in order to limit the stress on the semiconductors in terms of maximum current and maximum energy, a current limiter circuit is sometimes needed.

20 This is typically solved through providing a current limitation circuit outside of the VSC structure, i.e. outside of the cells.

Such a situation is for instance disclosed in WO
25 2010/097122, where a current limiting resistance in parallel with a switch is placed in the AC phases leading to a VSC.

However, there is still room for improvement in
30 relation to the limitation of inrush currents.

SUMMARY OF THE INVENTION

One object of the present invention is to provide a voltage source converter that is improved in relation to inrush current limitation.

This object is according to a first aspect of the present invention solved through a voltage source converter comprising a number of voltage source converter cells, connected in cascade in at least two branches where each voltage source converter cell comprises:

- a first and a second connection terminal, each providing a connection to a corresponding branch of the voltage source converter,
- a number of valve elements,
- an energy storage element, and
- a parallel circuit comprising a resistive element in parallel with a first switching element in order to limit the current running through the voltage source converter branch at start up.

Another object of the present invention is to provide a method of controlling start up of a cell-based voltage source converter that is improved in relation to inrush current limitation.

This object is according to a second aspect of the present invention solved through a method of controlling start up of a cell-based voltage source converter comprising a number of cells, where each cell comprises an energy storage element and a parallel circuit comprising a resistive element in parallel with

a first switching element, the method comprising the steps of:

opening all switching elements in each cell of the voltage source converter,

- 5 charging the energy storage elements of the cells via the resistive elements,
determining for each cell if the corresponding energy storage element is sufficiently charged, and
closing the switching elements of the cells that are
10 sufficiently charged.

The present invention has a number of advantages. It is economical since the components of the parallel circuit may be designed for low voltage levels. The technical
15 requirements on the first switching element are furthermore low since no fast operation is required. The parallel circuit realization has an automatic scalability to the DC capacitance to be charged, which allows a standard design to be used for parallel
20 circuit. The charging time constant is preserved independently of how many cells are connected in series.

BRIEF DESCRIPTION OF THE DRAWINGS

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

- 30 fig. 1 schematically shows a first type of voltage source converter having a number of delta connected phase branches each being provided with a number of voltage source converter cells,

fig. 2 schematically shows a second type of 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,

5 fig. 3 schematically shows the structure of a first type of cell used in the first type of voltage source converter,

fig. 4 schematically shows the structure of a second type of cell used in the second type of voltage source

10 converter,

fig. 5 schematically shows the structure of a third type of cell also used in the second type of voltage source converter,

15 fig. 6 shows a first variation of the second type of cell,

fig. 7 shows a second variation of the second type of cell,

fig. 8 shows a flow chart of a method of controlling start up of a cell-based voltage source converter,

20 fig. 9 schematically shows a third type of voltage source converter having branches with voltage source converter cells,

fig. 10 schematically shows a fourth type of voltage source converter having branches with voltage source

25 converter cells, and

fig. 11 schematically shows a variation of the fourth type of voltage source converter, where half the converter is provided with voltage source converter cells.

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DETAILED DESCRIPTION OF THE INVENTION

In the following, a detailed description of preferred embodiments of voltage source converter cells and voltage source converters including voltage source converter cells will be given.

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Voltage source converters can be used in many types of electrical power systems, such as high-voltage power transmission systems. Examples on systems are direct current power transmission systems like HVDC (High
10 Voltage Direct Current), HVDC back-to-back systems and FACTS (Flexible Alternating Current Transmission System). In such systems voltage source converters are used as for instance rectifiers, inverters, DC/DC converter, AC/AC converters and Static VAR compensators
15 (SVCs or STATCOMs).

Fig. 1 shows a block schematic outlining an example of a first type of voltage source converter 10.

20 In this first type of voltage source converter 10 there are three branches, also denoted phase branches, PB1, PB2, PB3 connected to each other in series and forming a closed loop. This type of connection is also termed a delta connection. The phase branches are here indicated
25 through being marked by dashed ellipses. A first phase branch PB1 here has a first and a second end point, where the first end point is connected to a first Alternating Current (AC) terminal AC1 and to a first end point of a second phase branch PB2, while the
30 second end point of the first phase branch PB1 is connected to a second AC terminal AC2 and a first end point of a third phase branch PB3. A second end point of the second phase branch PB2 is finally connected to

a second end point of the third phase branch PB3 as well as to a third AC terminal AC3. The AC terminals may here be connected to a three-phase AC transmission system. Each phase branch here includes a current
5 limiting inductor LPB1, LPB2 and LPB3 and a number of cells CA. In this example each branch comprises three cells. It should however be realized that a branch may include more or fewer cells. The number of cells is furthermore typically the same in all the branches.

10

The cells used in this first type of voltage source converter are here a first type of cells that are full-bridge cells. All the cells CA are being controlled by a control unit 11. This control is indicated with two-
15 way arrows between the control unit 11 and the cells CA.

The converter in fig. 1 is a STATCOM that is provided for reactive power compensation in the AC system. It
20 should here be realized that this converter may be connected in a wye-connection instead of a delta-connection.

Fig. 2 shows a second type of voltage source converter
25 12. This second type of converter 12 includes a group of branches in the form of phase legs connected in parallel between two DC terminals DC+ and DC- for connection to a DC transmission system. In the example given here there are three such branches or phase legs
30 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 PL3 are connected to a first DC terminal DC+ while the second end points are connected
5 to a second DC terminal DC-.

Each phase leg PL1, PL2, PL3 of this second type of voltage source converter 12 further includes a lower and upper phase leg half and at the junction where the
10 halves of a leg meet, there is provided an AC terminal. In the exemplifying voltage source converter 12 there is here a first phase leg PL1 having an upper half and a lower half, a second phase leg PL2 having an upper half and a lower half and a third phase leg PL3 having
15 an upper half and a lower half. At the junction between the upper and lower halves of the first phase leg PL1 there is provided a first AC terminal AC1', at the junction between the upper and lower halves of the second phase leg PL2 there is provided a second AC
20 terminal AC2' and at the junction between the upper and lower halves of the third phase leg PL3 there is provided a third AC terminal AC3'. Each AC terminal AC1', AC2', AC3' is here connected to the corresponding phase leg via a respective inductor LAC1, LAC2, LAC3.
25 Here each half furthermore includes one current limiting inductor Lu1, Lu2, Lu3, Ll1, Ll2, and Ll3 connected to the corresponding DC terminal DC+ and DC-. Each half furthermore includes a number of cells CB. These cells are here half-bridge cells of a second type
30 and thus different from the cells in the first type of converter. There is furthermore normally a control unit connected to the cells (not shown). In the present example there are three cells in each phase leg half.

Thus the upper half of the first phase leg PL1 includes three cells CB, while the lower half of the first phase leg PL1 also includes three cells CB. In a similar fashion the upper half of the second phase leg PL2 includes three cells CB, while the lower half of the second phase leg PL2 includes three cells CB. Finally the upper half of the third phase leg PL3 includes three cells CB, while the lower half of the third phase leg PL3 includes three cells CB. It should here be realized that the number of cells shown are only provided as an example. The number of cells may be varied in a multitude of ways. Typically there may be more cells than what is needed for normal operation. There may thus exist redundant cells. There may in fact be redundant cells in all voltage source converters being described in this document.

Fig. 3 schematically shows a first type of converter cell CA, which may be used in the first type of voltage source converter.

The cell CA is a full-bridge converter cell and includes an energy storage element, here in the form of a capacitor C1A, which is connected in parallel with a first group of valve elements. The valve elements in the first group are connected in series with each other. The first group here includes two valve elements CV1A and CV2A (shown as dashed boxes), where each valve element CV1A, CV2A may be realized in the form of a switch that may be a transistor like an Insulated Gate Bipolar Transistor (IGBT) together with an anti-parallel diode. In fig. 3 there is therefore a first valve element CV1A having a first transistor T1A with a

first diode D1A having an anode connected to an emitter of the first transistor T1A and a cathode connected to a collector of the first transistor T1A. The collector of the first transistor T1A is here furthermore
5 connected to a first end of the capacitor C1A. There is also a second valve element CV2A connected in series with the first valve element CV1A and having a second diode D2A connected between emitter and collector of a second transistor T2A in the same way as the first
10 valve element CV1A. The emitter of the second transistor T2A is here furthermore connected to a second end of the capacitor C1A. In this example the emitter of the first transistor T1A is connected to the collector of the second transistor T2A. The first and
15 second valve elements CV1A and CV2A are thus connected in series with each other in a first string, which first string is connected in parallel with the capacitor C1A.

20 In this first type of cell there is also a second group of valve elements connected in series with each other. This second group of valve elements are here connected in parallel with the first group as well as with the energy storage element C1A. The second group here
25 includes a third and a fourth valve element CV3A and CV4A, provided through a third transistor T3A with anti-parallel third diode D3A and through a fourth transistor T4A with anti-parallel fourth diode D4A connected in the same way as the first and second valve
30 elements CV1A and CV2A. This second group is thus provided in a second string in parallel with the capacitor C1A.

The cell CA has a first connection terminal TE1A and a second connection terminal TE2A, each providing a connection for the cell to a branch of the voltage source converter. In this first type of cell the first
5 connection terminal TE1A more particularly provides a connection from the VSC branch to a connection point between two of the valve elements in the first group of valve elements. In this example the VSC branch is connected to the junction between the first and the
10 second valve element CV1A and CV2A. In a similar manner the second connection terminal TE2A provides a connection from the branch to a connection point between two of the series connected valve elements in the second group, and here this connection is provided
15 to the junction between the third and fourth valve elements CV3A and CV4A.

These connection terminals TE1A and TE1B thus provide points where the cell can be connected to a branch,
20 where the branch may be a phase branch of a voltage source converter of the first type. The connection of the first connection terminal TE1A thus joins the branch with the connection point or junction between two of the series connected valve elements of the first
25 group, here the first and second valve elements CV1A and CV2A, while the connection of the second connection terminal TE2A joins the branch with a connection point between two of the series connected valve elements of the second group, here the third and fourth valve
30 elements CV3A and CV4A.

In this first type of cell there is according to the invention also provided a parallel circuit. This

parallel circuit is made up of a resistor RA in parallel with a first switching element SW1A. The switching element may be a bistable switch and with advantage a bistable mechanical bypass switch. The
5 parallel circuit, which is provided for current limitation purposes at start up of the VSC, which is when the cell capacitors are being charged, is more particularly connected in a start up current charging path of the converter, which is a path that runs
10 through the cells of a voltage source converter branch or branch half when the capacitors are being charged to their operating voltages. Such a path will then run through all the cells of a branch or branch half.

15 In the first type of cell CA in fig. 3 the parallel circuit is more particularly connected in series with a connection terminal of the cell and in this example in series with the first connection terminal TE1A. It is here more particularly connected between the junction
20 between the first and second valve elements CV1A and CV22A and the first connection terminal TE1A.

There is also a second switching element SW2 placed between the first and the second connection terminals
25 TE1A and TE2A. This second switching element SW2 has the function to disconnect the cell from the VSC branch.

Fig. 4 schematically shows a second type of cell CB
30 that may be used in a converter of the second type. This type of cell is a half-bridge cell that may be connected in a phase leg of a converter of the second type. This cell is in many ways similar to the first

type of cell. There is here a first group of series connected valve elements CV1B and CV2B. There is thus here a first group of valve elements including a first valve element CV1B (shown as a dashed box) having a first transistor T1B and a first anti-parallel diode D1B in series with a second valve element CV2B (also shown as a dashed box) having a second transistor T2B with a second anti-parallel diode D2B. In parallel with this first group of valve elements there is a first energy storage element, also here in the form of a capacitor C1B, where the first and second valve elements CV1B and CV2B of this type of cell CB are connected in the same way as the first and second valve elements of the first type of cell.

15

There is also a first connection terminal TE1B provided in the same way as in the first type of cell. In the cell shown in fig. 4 also the parallel circuit of first switching element SW1B and resistor RB has the same placing between the first connection terminal TE1B and the junction between the first and second valve elements CV1B and CV2B. The second switching element SW2 also has the same position between the first and second connection terminal TE1B and TE2B as in the first type of cell.

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However, here there is no second group of valve elements. Furthermore also the second connection terminal TE2B is placed in a different way. In this second type of cell the second connection terminal TE2B connects the VSC branch to the connection between the first group of series connected valve elements and the energy storage element, which is here the connection

30

point between the second valve element CV2B and the capacitor C1B. This connection point is more particularly the junction between the emitter of the second transistor T2C and the second end of the cell
5 capacitor C1B.

Fig. 5 shows a third type of cell CC, which is also a half-bridge cell. This type of cell may also be used in the second type of voltage source converter. There is
10 also here a first group of valve elements including a first valve element CV1C (shown as a dashed box) having a first transistor T1C and a first anti-parallel diode D1C in series with a second valve element CV2C (also shown as a dashed box) having a second transistor T2C
15 with a second anti-parallel diode D2C, both connected in the same way as in the first and second types of cells. In parallel with this first group of valve elements there is a first energy storage element, also here in the form of a capacitor C1C. There is also here
20 a first connection terminal TE1C providing a connection between the branch and the connection point between the first and the second valve elements CV1C and CV2C. There is also here a second switching element SW2 placed between the first and the second connection
25 terminals TE1B and TE2B.

However as opposed to the second type of cell the second connection terminal TE2B here provides a connection between the VSC branch and the junction
30 between the first valve element CV1C and the first end of the capacitor C1C. Furthermore in the example given here the parallel circuit of first switching element SW1C and resistor RC is also connected between this

second connection terminal TE2C and the above-mentioned junction between the first valve element CV1C and the first end of the capacitor C1C.

5 It should be realized that the parallel circuit may have a number of alternative placements, of which two are shown in fig. 6 and 7, where fig. 6 shows a first variation CB' of the second type of cell and fig. 7 shows a second variation CB'' of the second type of
10 cell. These figures only differ from fig. 4 through the placement of the parallel circuit.

In the first variation CB' of the second type of cell, the parallel circuit is connected between the first
15 valve element CV1B and the cell capacitor C1B, and more particularly between the collector of the first transistor T1B and the first end of the cell capacitor C1B, while in the second variation CB'' the parallel circuit is connected between the second switching
20 element and the cell capacitor C1B and more particularly between the emitter of the second transistor T2B and the second end of the cell capacitor C1B. It can thus be seen that the parallel circuit need not be connected at the cell interface to the VSC
25 branch, but may be connected in the interior of the cell.

One possible way to operate the cells of the invention at start of a VSC will now be described with reference
30 being made to fig. 1, 3 and 8, which latter figure shows a flow chart of a number of method steps being carried out in the VSC under the control of the control unit 11.

Each cell described above typically has the function of providing two or three DC voltage contributions that are given to the branch in which the cell is connected.

- 5 The contributions that are possible to make by the first type of cell are here typically a positive voltage across the capacitor, a zero voltage and a negative voltage across the cell capacitor. In the second and third types of cells there are only two
- 10 possible voltage contributions either a zero voltage contribution and a positive voltage contribution or a zero voltage contribution and a negative voltage contribution.
- 15 The voltage source converter that is obtained through a suitable combination of voltage source converter cells may be provided in high voltage applications, where large currents and voltages are used. Before the voltage source converter is put into operation the cell
- 20 capacitors are normally discharged, which means that they have no charge. They are empty and cannot therefore provide any voltage contributions. Because of this, it is necessary to charge the cell capacitors before a VSC is put into operation. Because of the
- 25 applications in which the VSC is used, there will then be very high currents needed for charging the cell capacitors and these currents may be harmful to the electronics in the cells. They may typically destroy the valve elements like transistors or diodes.

30

There is therefore a need for limiting the current at startup of a voltage source converter. The purpose of

the parallel circuit is to take care of this current limitation during charging.

5 The traditional way to limit the current is to use external charging transformers, i.e. transformers outside the VSC system, external power electronic units or external current limiter resistors. The external current limiter resistors must then be by-passed for the normal operation.

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The present invention instead proposes a distributed current limitation concept which can be applied to multilevel converters and which leads to a modular and auto-scalable solution with lower system cost, embedded
15 redundancy for higher reliability and which avoids the need of additional external components.

The inrush current control of the voltage source converter is here provided through the control
20 performed by the control unit 11. At start up of the converter 10 the control unit 11 first of all makes sure that all the first switching elements SW1A in the parallel circuits of the cells are open. It therefore opens all these switching elements SW1A, step 14, which
25 may be done through sending appropriate control signals to these switching elements. Then all the cell capacitors C1A are charged, step 16, which may be done through connecting each branch to an appropriate voltage source, for instance a DC voltage source. This
30 may also be done through closing a pair of circuit breakers connecting a branch to this voltage source. The branches of the converter may here be simultaneously connected in parallel or in series to

the voltage source. As an alternative they may be connected in sequence, i.e. sequentially one after the other after having been charged.

5 When a branch is connected to the voltage source for being charged in the above-described way, the current delivered by the voltage source will pass through the resistors RA of the parallel circuits in the cells CA. The reason for this is that since the parallel circuits
10 are placed in the start up current charging path of the cells and the first switches SW1A are open, this charging current will have to pass the resistors RA and thereby the current is limited so that electronic equipment like transistors and diodes are not
15 destroyed.

As this is done the control unit 11 makes sure that the cell capacitors are getting charged. In doing this it may start a counter N that is initially set to a value
20 such as one, step 18. The control unit then investigates if the cell capacitor CA of the investigated cell is sufficiently charged. This may be done through investigating that the voltage across the capacitor CA has the operating voltage, i.e. the
25 voltage at which it is to operate. It may also involve investigating if there is any current running through the cell. If there is no current, then the cell capacitor may be deemed to be sufficiently charged.

30 In case the cell capacitor is sufficiently charged, step 20, then the method continues to investigate if the cell was the last, step 28. However, in case the cell is not sufficiently charged, step 20, then the

control unit 11 performs an investigation if the cell is faulty or not. This investigation may be performed based on the time of the charging process. In case the cell capacitor has not been sufficiently charged within
5 a specified time limit, then the cell may be deemed to be faulty. If the cell is not deemed to be faulty, step 24, then a new investigation of if the cell is sufficiently charged may be performed, step 20. If however the cell is deemed faulty, step 24, then the
10 cell is bypassed, step 26, which may be done through the control unit 11 closing the second switching element SW2 of the investigated cell.

If the cell is deemed to be faulty it is thus necessary
15 to disconnect the cell from the branch, which can be done through interconnecting the two connection terminals of the cell using the second switching element SW2. In case of failure the cell is thus short-circuited, or by-passed, whereby it is excluded from
20 the series chain of voltage source converter cells. In this way it is possible for the voltage source converter to operate despite one or a few cells being faulty.

25 After the cell has been investigated this way, either through the cell capacitor being sufficiently charged, whereby the cell is found to be operational or through the cell capacitor not being sufficiently charged, whereby the cell is deemed faulty and therefore
30 bypassed, the control unit 11 investigates if the cell was the last cell of the branch and if it was not, step 28, the next cell is investigated, which may be selected through changing the value N, for instance

through incrementing N, step 30, whereupon the next cell is investigated in the same way.

If however the investigated cell was the last cell,
5 step 28, then the switching elements SW1A of the all the cells that are sufficiently charged, i.e. of all the cells that have been found to be functional, are closed, step 30. Thereafter the number of non-faulty cells is compared with a reliable operation threshold
10 TH, step 32, which may be a threshold indicating the minimum number of cells needed for operating the converter.

This may be done through providing a further counter,
15 the value of which is changed each time a cell is being found to be operational or sufficiently charged. If the number of operational cells were above this threshold, step 34, then the control unit 11 will start to operate the VSC, step 36, which may involve connecting the AC
20 terminals of the converter 10 to an AC system, for instance through controlling circuit breakers provided between the AC terminals and the phases of such an AC system. Since the first switches SW1A are now closed, no current will pass through the resistors and thus no
25 power will be dissipated through the resistors RA.

If however the number was below the threshold, step 34, then the VSC is tripped, step 38. The control unit 11 may then abort connection of the VSC to any power
30 system. The control unit 11 may furthermore disconnect the converter from the voltage source used for charging. It may here also generate an alarm indicating that the voltage source converter is faulty.

In the above-described way a cell based voltage source converter was started up. It should be realized that it may also be shut down in a similar way. It may thus be
5 shut down through opening the first switching elements in order to connect the resistive element into a capacitor current discharging path and grounding the branch.

10 According to the invention a standard high impedance component (i.e. resistor) is at start up connected in series with the cell and limits the inrush current across the diodes during the energization of the DC capacitors. The bi-stable mechanical contact assures
15 the by-pass of the resistive element once the energization is completed.

The bi-stable switching element is only operated at the energization process, i.e. going from being closed to
20 being open and at the system shut-off, i.e. going from being closed to being open. In case the cell or the parallel circuit fails during operation, the second switching element will short-circuit the connection terminals of the converter cell.

25 The impedance (i.e. resistance) value of the resistive element may be chosen such as the maximum inrush current does not damage or over-stress the cell diodes. The highest value may typically depend on the allowable
30 time constant for the energization process.

The present invention has several advantages. It is economical since the components of the parallel circuit

may be designed for low voltage levels. The technical requirements on the first bi-stable mechanical switching element are low since no fast operation is required. The parallel circuit realization has an automatic scalability to the DC capacitance to be charged, which allows a standard design to be used for the parallel circuit. The charging time constant is furthermore preserved independently of how many cells are series connected (standard design of the energization circuit and start-up sequence). The second switching element furthermore presents an embedded redundancy against the malfunctioning of the first switching element of the parallel circuit, i.e. the converter cell is bypassed without the need of tripping the system. There is no need for external equipment (designed for medium voltage) in order to reduce the footprint of the system and the complexity of MV connections to an AC grid.

Although the method was above described in relation to the first type of converter and first type of cell, it should be realized that it may also be performed in the second type of converter and the second or third type of cell. Furthermore, the cells were also described as being investigated sequentially. It should here be realized that they may be investigated in parallel. The control unit 11 may thus perform several investigations simultaneously. It should also be realized that the comparison of the number of non-faulty cells with a reliable operation threshold may be made in relation to a phase leg half instead of a whole phase leg. In the case of discharging capacitors, this type of reliable operation comparison may also be omitted.

The first type of cell may be placed in a different type of converter than the one shown in fig. 1. It may for instance be placed in a converter of the type shown in fig. 9. This converter 40 is also provided for reactive power compensation and comprises cells CA of the first type in branches interconnecting the phases of two AC systems. Here there is a branch for every combination of AC phase interconnection. Every phase of one of the systems is here connected to every phase of the other system via a corresponding branch with converter cells. The converter 40 thus comprises a matrix of branches providing an interconnection between every phase of the two AC systems.

15

Another type of converter in which the second type of cell may be used is an AC/AC converter having an intermediate DC conversion. Such a converter is shown in fig. 10.

20

This converter, which is a back-to-back converter, includes cells CB of the second type. It here includes six phase legs, a first three-some with their AC terminals connected to the phases of a first AC system and a second three-some with their AC terminals connected to the phases of a second AC system. The DC terminals of the first three-some are then connected to the DC terminals of the second three-some. Here all the cells are of the second or the third type. This type of converter is thus a converter made up of two converters of the second type.

25
30

A further back-to-back converter variation is shown in fig. 11. This converter 44 differs from the converter in fig. 10 through one three-some of phase legs, i.e. through one converter of the second type, having been
5 replaced by another converter 46. This other converter 46 may here be a two- or three-level voltage source converter. It may also be a current source converter employing thyristors instead of transistors with anti-parallel diodes.

10

There are countless ways in which the second switching element may be implemented. It may be implemented as a magnetic contactor, a spring loaded contact, series connected thyristors and anti-parallel silicon
15 controlled rectifiers.

The valve elements used in the cells have been described as employing IGBTs. It should be realized that other types of valve elements may be used, such as
20 elements based on thyristors, MOSFET transistors, GTOs (Gate Turn-Off Thyristor), IGCTs (Integrated Gate Commuted Thyristor) and mercury arc valves.

The control unit need not be provided as a part of a
25 voltage source converter. It can be provided as a separate device that provides control signals to the cells. This control unit may furthermore be realized in the form of a processor with accompanying program memory comprising computer program code that performs
30 the desired control functionality when being run on the processor.

From the foregoing discussion it is evident that the present invention can be varied in a multitude of ways. The voltage source converter is for instance not limited to power transmission systems. It may for instance also be used in motor drives. It shall consequently be realized that the present invention is only to be limited by the following claims.

CLAIMS

1. A voltage source converter (10; 12; 40; 42; 44) comprising a number of voltage source converter cells
5 (CA; CB; CC; CB'; CB'') connected in cascade in at least two branches (PB1, PB2, PB3; PL1, PL2, PL3), where each voltage source converter cell comprises:
- a first and a second connection terminal (TE1A, TE2A; TE1B, TE2B; TE1C, TE2C) each providing a
10 connection to a corresponding branch of the voltage source converter,
 - a number of valve elements (CV1A, CV2A, CV3A, CV4A; CV1B, CV2B; CV1C, CV2C),
 - an energy storage element (C1A; C1B; C1C), and
 - 15 - a parallel circuit comprising a resistive element (RA; RB; RC) in parallel with a first switching element (SW1A; SW1B, SW1C) in order to limit the current running through the voltage source converter branch at start up.
- 20
2. The voltage source converter according to claim 1, wherein the parallel circuit is connected in a start up current charging path of the cell.
- 25
3. The voltage source converter according to claim 1 or 2, wherein the parallel circuit is connected in series with one of the connection terminals (TE1A; TE1B; TE2B; TE2C).
- 30
4. The voltage source converter according to any previous claim, wherein the parallel circuit is

connected between one valve element (CV1B; CV2B) and the energy storage element (C1B).

5. The voltage source converter according to any
5 previous claim, wherein there is a first group of valve elements (CV1A, CV2A; CV1B, CV2B; CV1C, CV2C) connected in series in a cell, said first group being connected in parallel with the energy storage element (C1A; C1B; C1C).

10

6. The voltage source converter according to claim 5, wherein one connection terminal (TE1A; TE1B; TE1C) provides a connection to the junction between two of the valve elements (CV1A, CV2A; CV1B, CV2B; CV1C, CV2C)
15 of the first group.

7. The voltage source converter cell (10; 12) according to claim 6, wherein the other connection terminal (TE2B; TE2C) provides a connection to a
20 connection point between the first group of valve elements and the energy storage element.

8. The voltage source converter (10; 40) according to claim 5 or 6, where each cell comprises a second
25 group of valve elements (CV3A, CV4A) connected in series with each other, said second group being connected in parallel with the energy storage element (C1A) and with the first group.

30 9. The voltage source converter according to claim 8, wherein the other connection terminal (TE2A) provides a connection to the junction between two of

the series connected valve elements of the second group.

10. The voltage source converter according to any
5 previous claim, wherein a valve element (CV1A, CV2A, CV3A, CV4A; CV1B, CV2B; CV1C, CV2C) comprises a switch (T1A, T2A, T3A, T4A; T1B, T2B; T1C, T2C) together with an anti-parallel diode (D1A, D2A, D3A, D4A; D1B, D2B; D1C, D2C).

10

11. The voltage source converter (10; 14) according to any previous claim, wherein the first switching element (SW1A; SW1B; SW1C) of the parallel circuit is a bi-stable mechanical by-pass switch.

15

12. The voltage source converter according to any previous claim, wherein the resistive element (RA; RB; RC) has a value that depends on the allowable time constant for energizing the cell capacitor.

20

13. The voltage source converter according to any previous claim, wherein each cell comprises a second bypass switching element (SW2) connected between the connection terminals of the cell.

25

14. A voltage source converter (10) according to any previous claim, wherein there are at least three branches (PB1, PB2, PB3) connected to each other in a loop and alternating current terminals (AC1, AC2, AC3)
30 are provided at connection points between the branches.

15. The voltage source converter (12) according to any of claims 1 - 13, wherein the branches are phase legs (PL1, PL2, PL3) being connected in parallel

between two direct current poles (DC+, DC-) of the converter and each phase leg includes a lower and an upper phase leg half.

5 16. The voltage source converter (10) according to claim 15, wherein an alternating current terminal (AC1', AC2', AC3') is connected to a respective phase leg branch in a junction between the lower and upper phase leg half.

10

17. The voltage source converter (42; 44) according to claim 15 or 16, in which it is a back-to-back converter.

15 18. The voltage source converter (40) according to any of claims 1 - 13, wherein the converter comprises a matrix of branches, where one branch interconnects a phase of a first AC system with a phase of a second AC system and the matrix provides an interconnection
20 between every phase of the two systems.

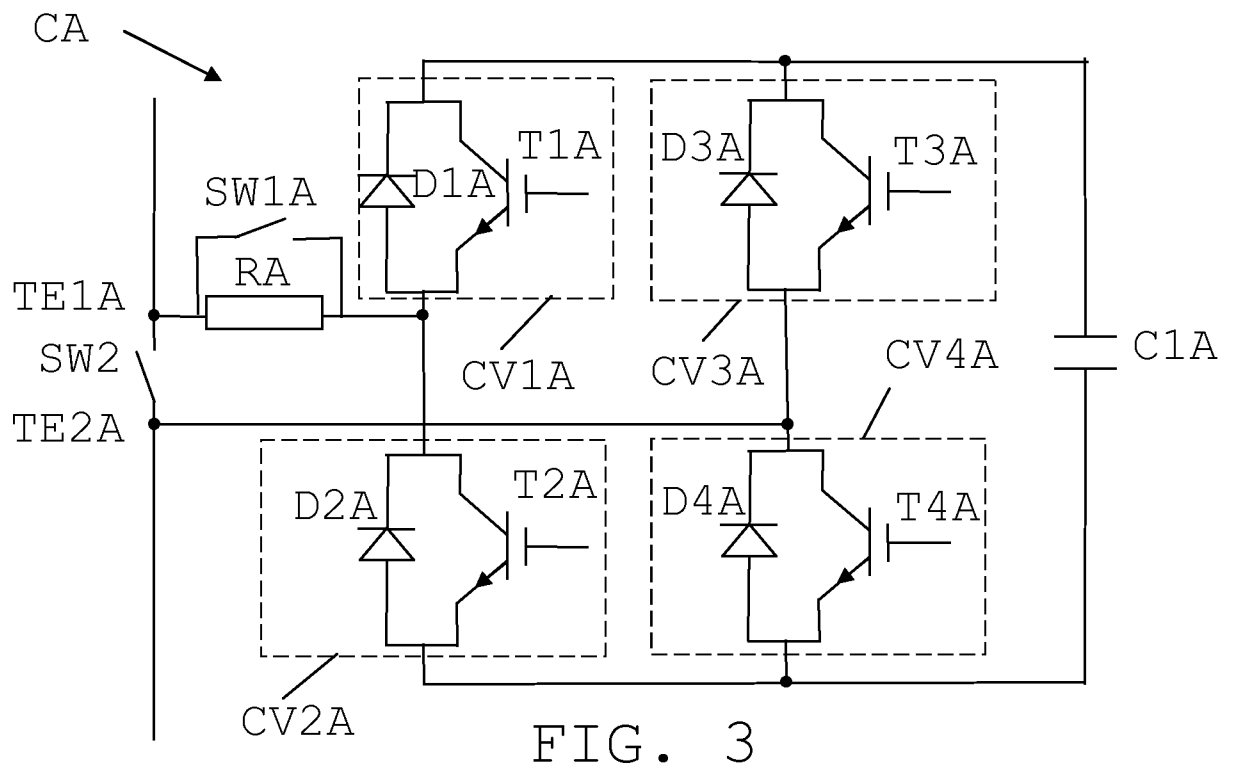
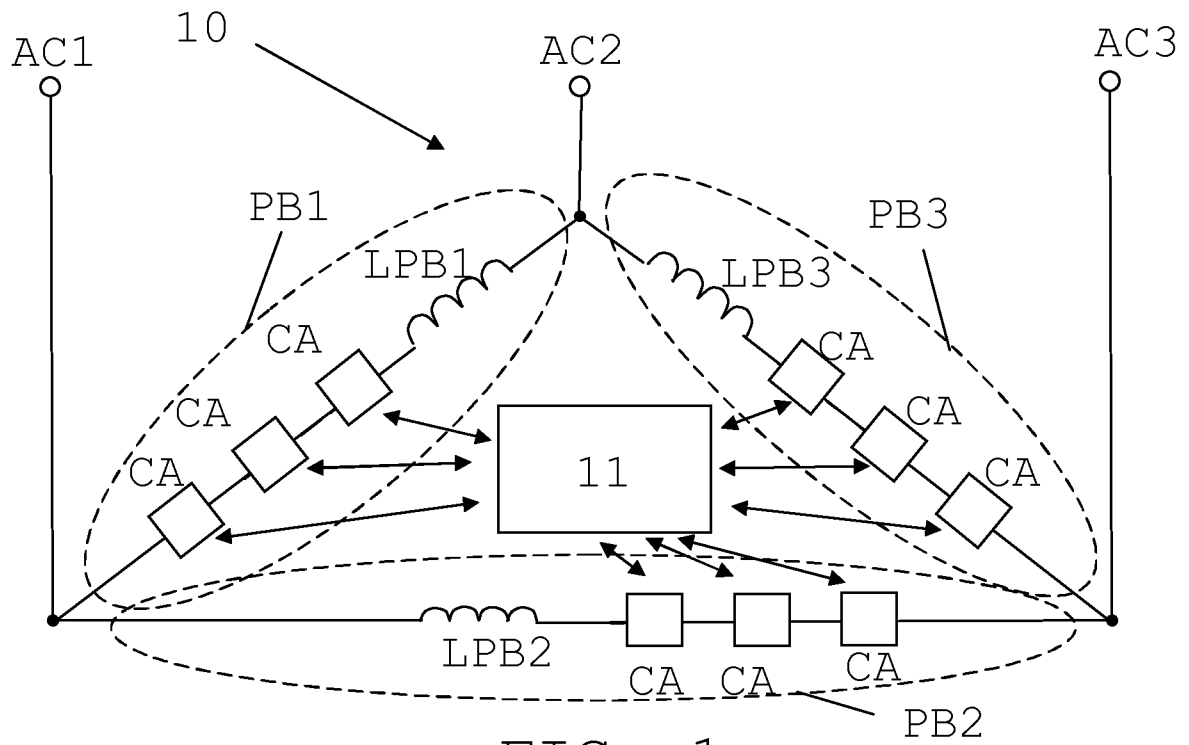
19. A voltage source converter according to any previous claim, further comprising a control unit (11)
25 configured to, at start up of the voltage source converter,
open all switching elements in each cell for charging the energy storage elements of the cells via the resistive elements,
30 determine if the energy storage element of a cell is sufficiently charged, and
close the corresponding switching element if it is.

20. A method of controlling start up of a cell-based voltage source converter comprising a number of cells (CA; CB; CC; CB'; CB''), where each cell comprises an energy storage element (C1A; C1B; C1C) and
5 a parallel circuit comprising a resistive element (RA; RB; RC) in parallel with a first switching element (SW1A; SW1B, SW1C), the method comprising the steps of: opening (14) all switching elements in each cell of the voltage source converter,
10 charging (16) the energy storage elements of the cells via the resistive elements,
determining (20) for each cell if the corresponding energy storage element is sufficiently charged, and
closing (30) the switching elements of the cells that
15 are sufficiently charged.

21. The method according to claim 20, wherein each cell furthermore comprises a second bypass switching element (SW2), and further comprising the steps of
20 investigating (24) if a cell where the energy storage element has not been sufficiently charged is faulty and
controlling (26) the second bypass switching element to bypass the cell if it is.

22. The method according to claim 21, further comprising comparing (32) the number of cells for which the corresponding energy storage elements have been determined to be sufficiently charged with a
25 reliability operations threshold, and tripping (38) the voltage source converter if the number is below the
30 reliable operations threshold.

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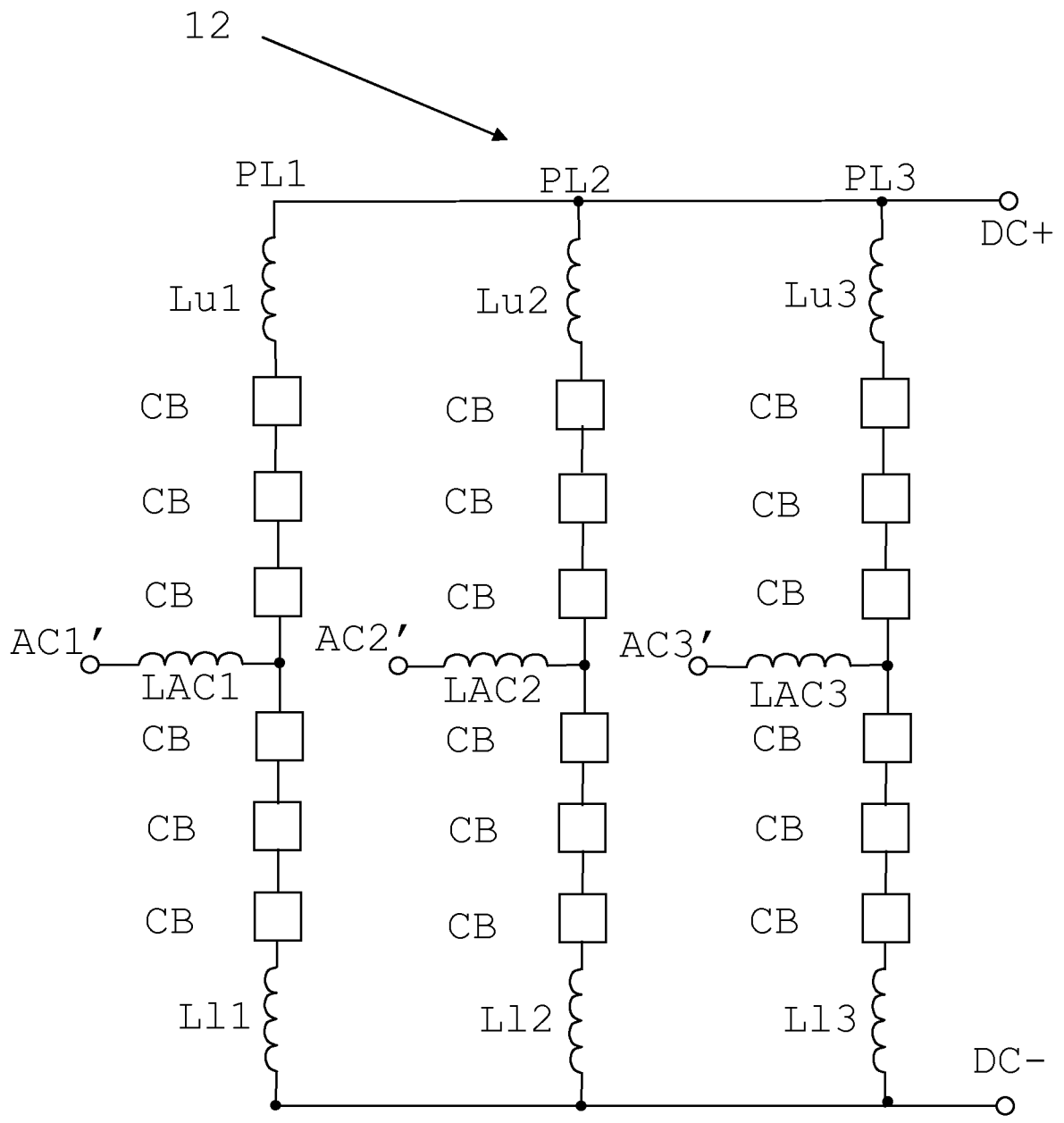


FIG. 2

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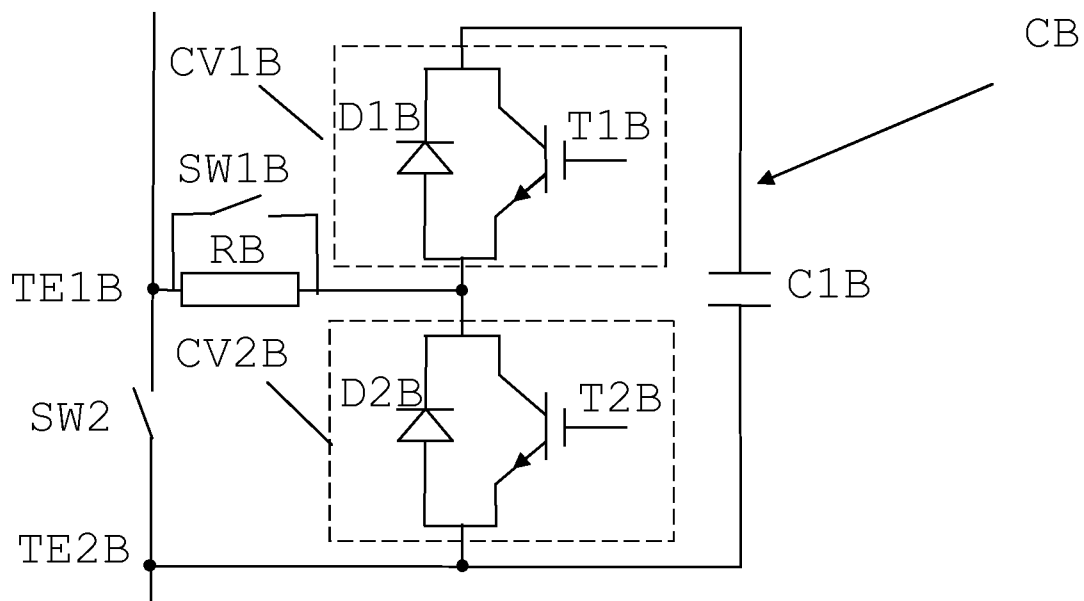


FIG. 4

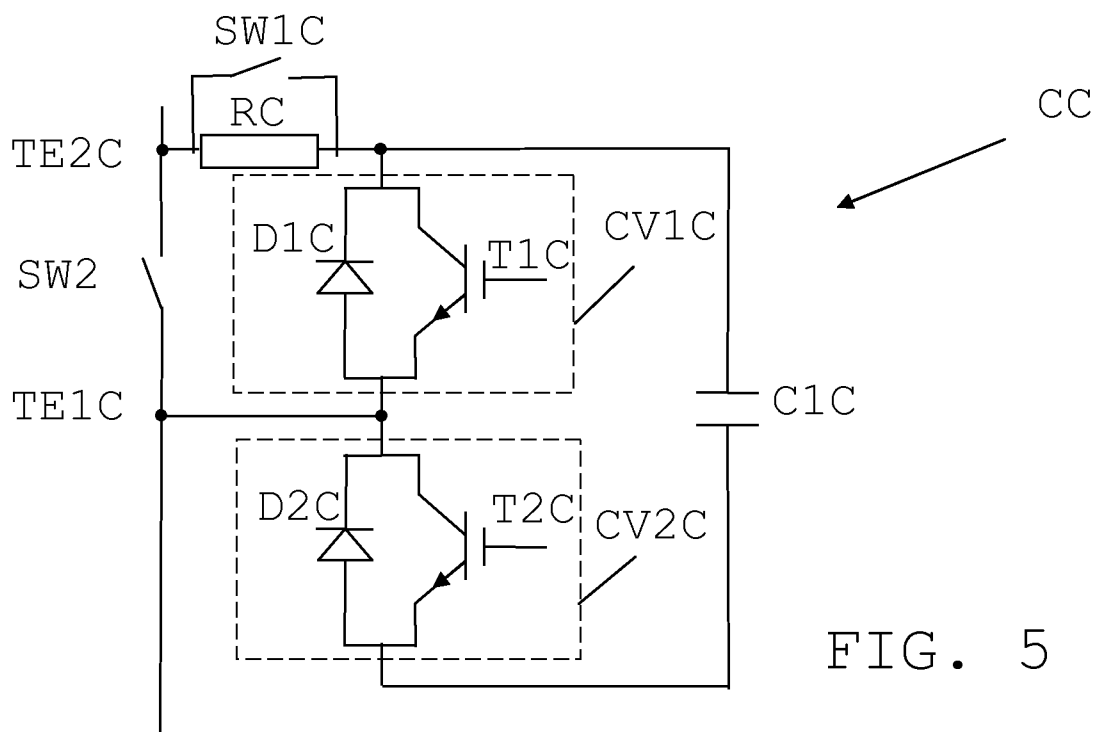


FIG. 5

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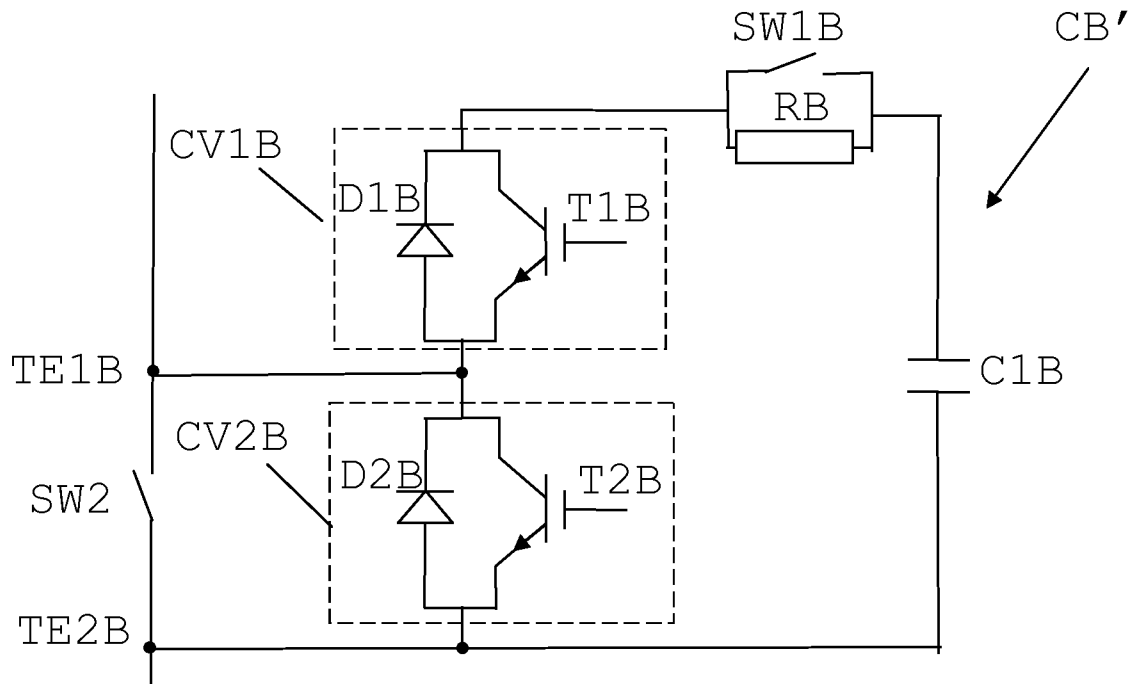


FIG. 6

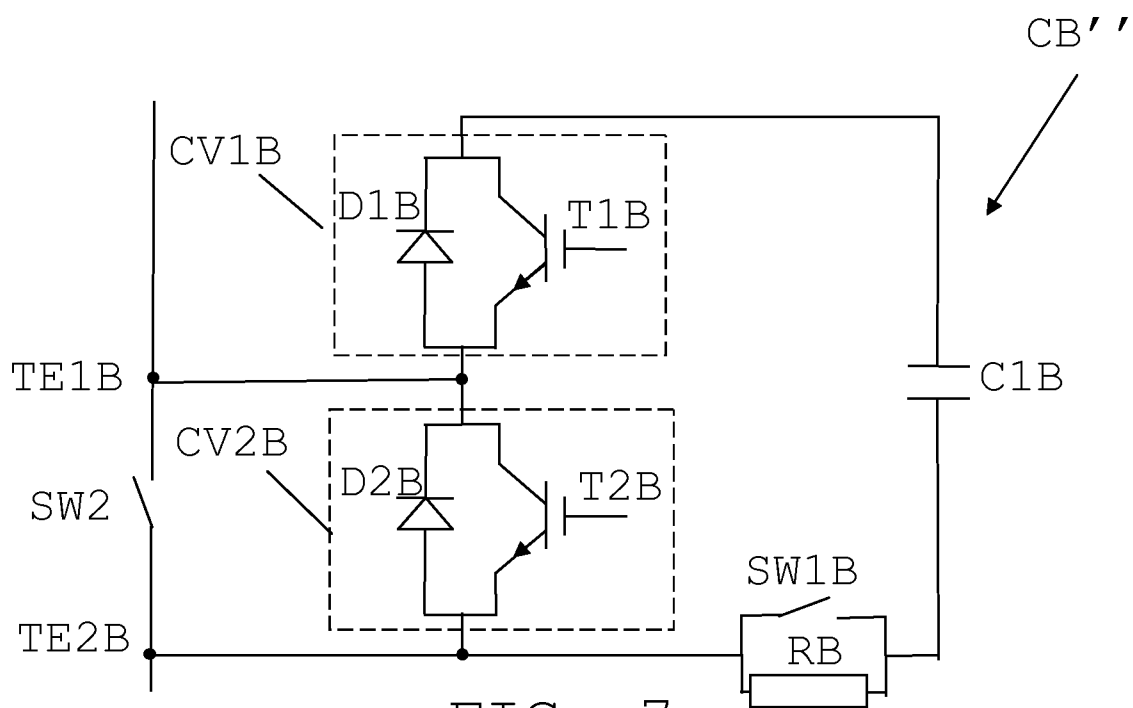


FIG. 7

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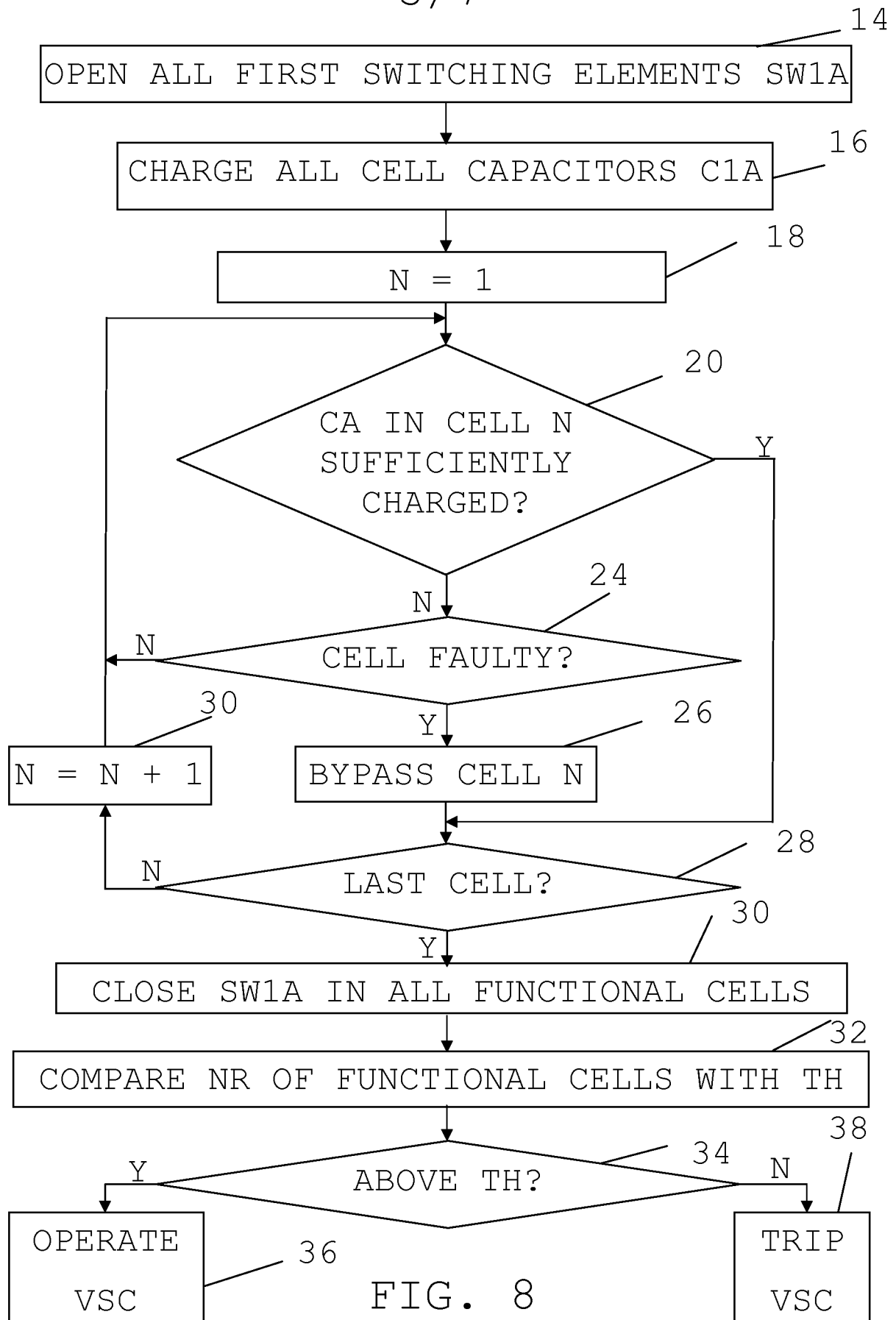


FIG. 8

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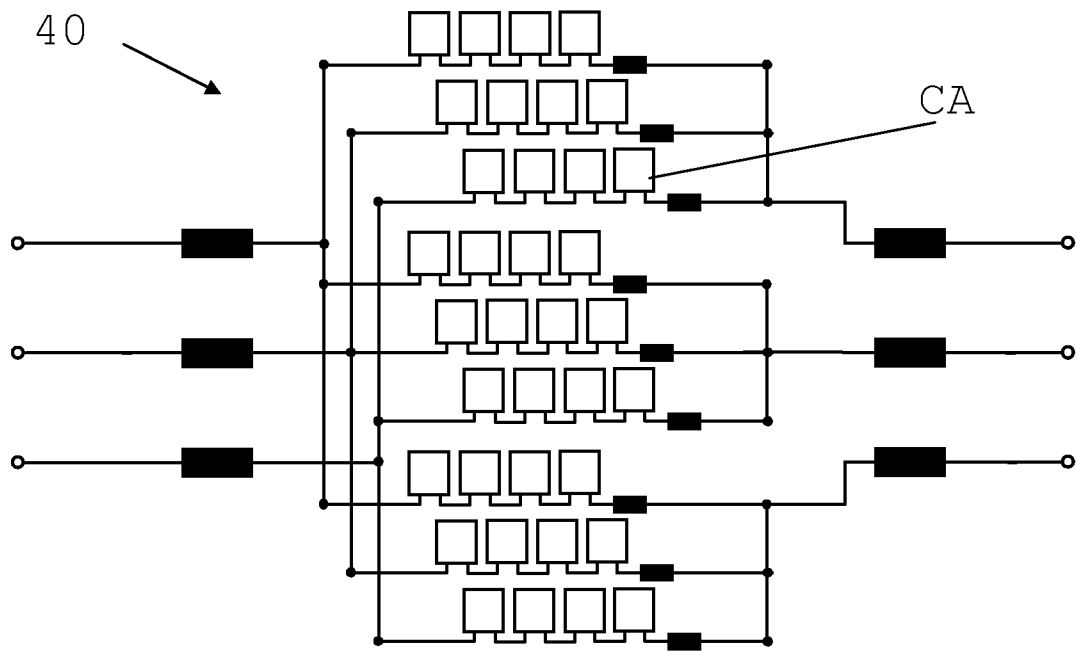


FIG. 9

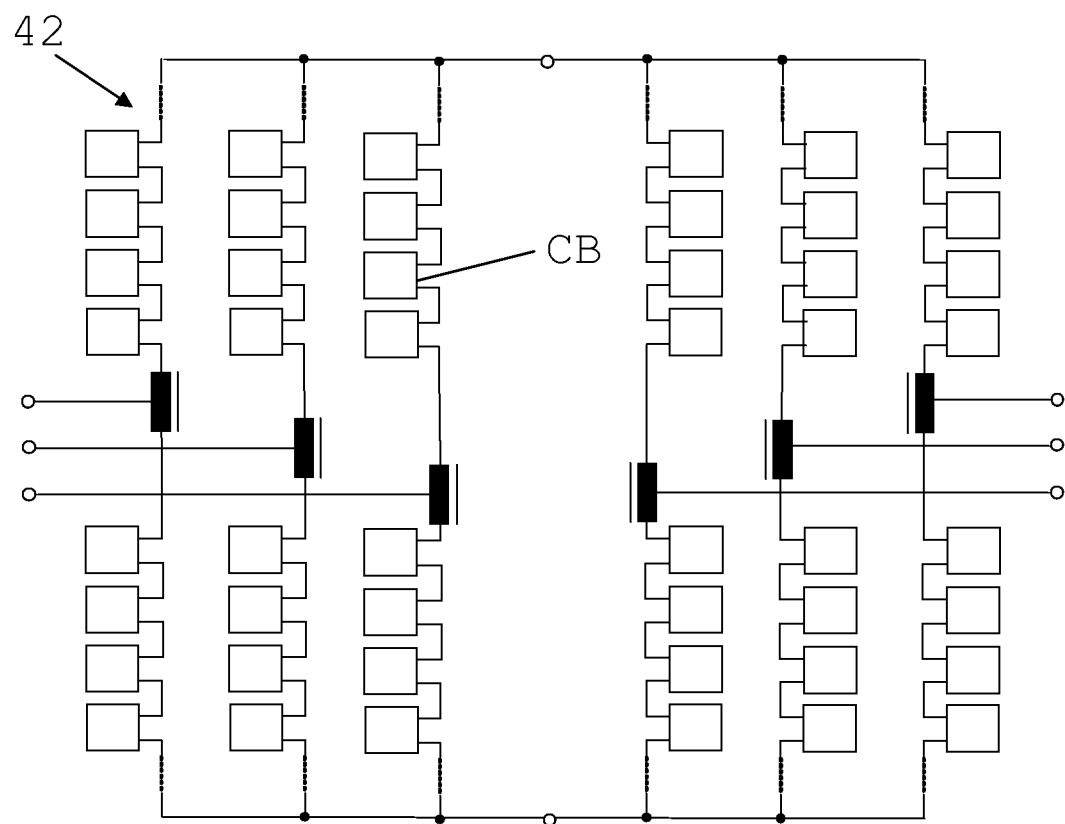


FIG. 10

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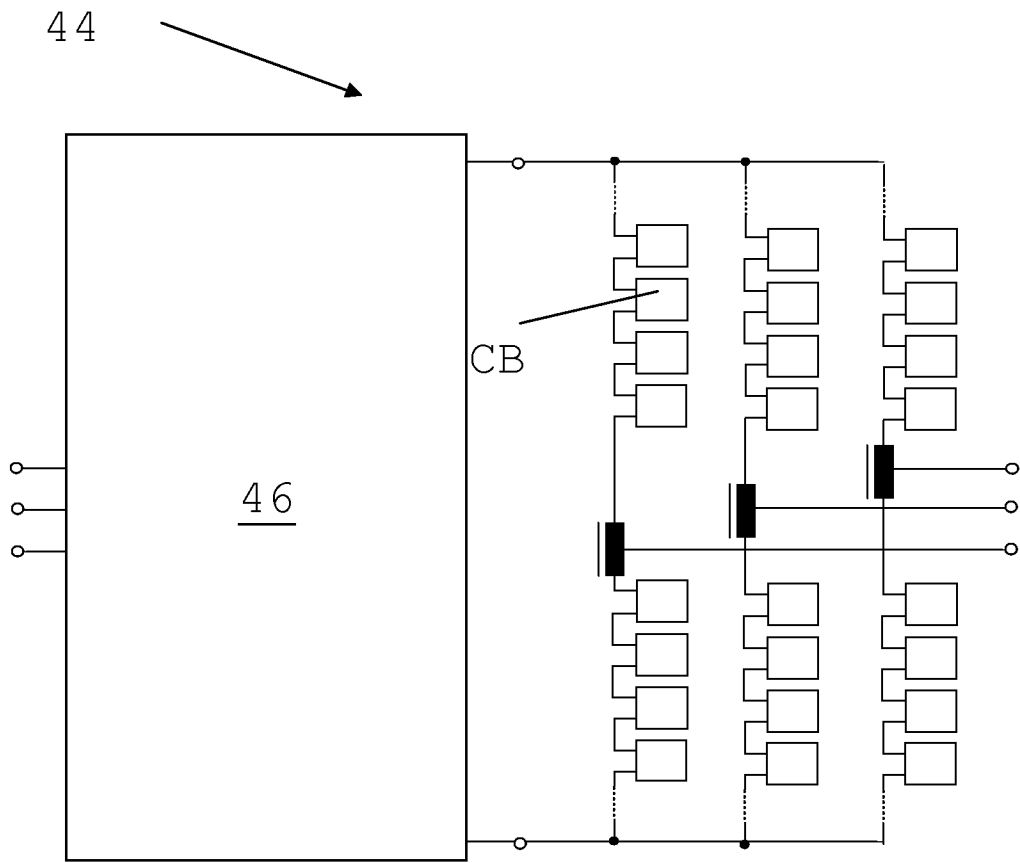


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2011/058480

A. CLASSIFICATION OF SUBJECT MATTER INV. H02M7/483 H02H9/02 H02M1/36 ADD.		
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 H02H		
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		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2010/097122 A1 (ABB TECHNOLOGY LTD [CH]; HASLER JEAN-PHILIPPE [SE]; HOSINI FALAH [SE];) 2 September 2010 (2010-09-02) figures 1-4	1-22
Y	US 6 163 469 A (YUKI HITOSHI [JP]) 19 December 2000 (2000-12-19) column 1, lines 19,20,39-50; figures 1,3,6,10,11	1-22
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☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
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Date of the actual completion of the international search 27 February 2012		Date of mailing of the international search report 08/03/2012
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Hanisch, Thomas

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2011/058480

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Information on patent family members

International application No

PCT/EP2011/058480

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