



(51) International Patent Classification:

H02M 7/57 (2006.01) *H02J* 3/46 (2006.01)
H02J 3/36 (2006.01)

(21) International Application Number:

PCT/EP2012/068339

(22) International Filing Date:

18 September 2012 (18.09.2012)

(25) Filing Language:

English

(26) Publication Language:

English

(71) Applicant (for all designated States except US): **ABB TECHNOLOGY LTD** [CH/CH]; Affolternstrasse 44, CH-8050 Zürich (CH).

(72) Inventor; and

(71) Applicant (for US only): **FISCHER DE TOLEDO, Paulo** [SE/SE]; Branta Backen 7, S-771 41 Ludvika (SE).

(74) Agent: **AHRENGART, Kenneth**; Ingenjör Bååths gata 11, Mimer T2, Floor E, S-721 83 Västerås (SE).

(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, BN, 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, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, 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, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, 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: METHOD OF CONTROLLING A POWER TRANSMISSION SYSTEM AND CORRESPONDING CONTROL SYSTEM

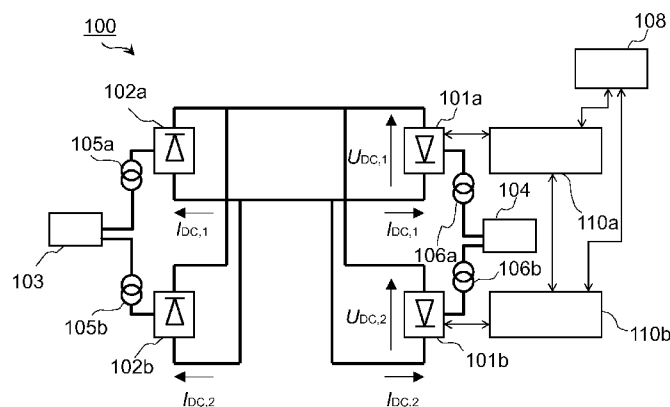


Fig. 2

(57) Abstract: A method of controlling a power transmission system (100) is disclosed. The power transmission system (100) comprises a DC link and at least two inverting converters (101a, 101b) connected in parallel in the DC link. Current reference value or values for the desired current through the respective inverting converters are received or retrieved, e.g. from a controller (108) in the power transmission system. For each of the inverting converters, a current (I_{DC1} , I_{DC2}) through the inverting converter is measured and a first difference value between the measured current and the current reference value is determined. For each of the inverting converters, a second difference value between the first difference value determined for the inverting converter and the first difference value determined for the other inverting converter is determined. For each of the inverting converters, a firing angle offset value is determined based on the second difference value determined for the inverting converter. A firing angle of each inverting converter is adjusted based on the firing angle offset values determined for the respective inverting converters. By adjustment of the firing angle of a inverting converter, an adjustment of the current through the inverting converter may be achieved.

METHOD OF CONTROLLING A POWER TRANSMISSION SYSTEM AND CORRESPONDING CONTROL SYSTEM

Technical field

The present invention generally relates to power systems. In particular, the
5 present invention relates to a method in a power transmission system, a power transmission system and a control system for a power transmission system.

Background

10 In power systems such as power transmission systems, for example so called High Voltage Direct Current (HVDC) power transmission systems, the voltages used in the power transmission are becoming increasingly higher. Voltage levels of about 800 kV are used today, and in some scenarios, voltage levels of up to 1000 kV or even 1200 kV or higher are expected to be
15 used in the future. Converters in HVDC power transmission systems convert between a relatively high alternating current (AC) voltage and such high level direct current (DC) voltages.

In a HVDC power transmission system there can be included a first AC power line and a second AC power line interconnected via a DC link or line.
20 The first AC power line is connected to the DC link at a first end thereof, and the second AC power line is connected to the DC link at a second end thereof. There may be two inverting converters connected in parallel in the DC link between the first AC power line and the second AC power line. Each of the inverting converters is adapted to convert DC power to AC power. The
25 respective outputs from the inverting converters are outcoupled from the DC link at one of the first and second ends thereof. A part of such a power transmission system, specifically a part of the DC link, is schematically depicted in Fig. 1. The DC link includes two inverting converters 101a, 101b connected in parallel and two rectifying converters 102a, 102b connected in
30 parallel as illustrated in Fig. 1. The inverting converter 101b is connected to the line via the inverting converter 101a. The rectifying converter 102b is connected to the line via the rectifying converter 102a.

The rectifying converters 102a, 102b and the inverting converters 101a, 101b are connected to AC lines schematically indicated by reference numerals 103 and 104 via transformers 105a, 105b of the rectifying converters 102a, 102b and via transformers 106a, 106b of the inverting
5 converters 101a, 101b, respectively.

The operation of the inverting converters 101a, 101b is often controlled by having one of the inverting converters 101a, 101b control the DC line voltage, i.e. the DC voltage over the DC link, and the other one of the inverting converters 101a, 101b control the current through it. Furthermore,
10 the rectifying converters 102a, 102b are controlling the currents therethrough, i.e. each of the rectifying converters 102a, 102b is controlling the current through it.

A converter controlling the current therethrough may control the current by varying or adjusting the firing angle of the converter, or the firing angle of
15 converter valves included in the converter, so as to meet the voltage on the DC side of the converter.

Operation of a converter with constant or substantially constant commutation margin angle may be decisive for the operating DC voltage of a converter. Control of the DC voltage can be achieved by varying or adjusting
20 the extinction angle reference value for the converter, which extinction angle reference value for example is supplied from a controller or control unit of the power transmission system, accordingly controlling the DC voltage across the converter. The tap position of a transformer of the converter may be varied or adjusted, thereby controlling the AC voltage across the converter.

25 As known in the art, by firing angle of a converter, it is generally meant the time or angle between the converter valve voltage becoming positive and the instant at which the converter valve is fired. For a converter, the voltage conversion ratio between the DC output and AC input, if acting as a rectifier, or between the AC output and DC input, if acting as an inverter, is a function
30 of the firing angle of the converter. By extinction angle of a converter, it is generally meant the time or angle between when the current in a converter valve ceases and the subsequent positive zero crossing or transition of the anode voltage on that converter valve. By commutation margin angle of the converter, it is generally meant the angle between the end of commutation
35 and the subsequent converter valve voltage positive zero crossing or transition.

However, using a control scheme for operation of the inverting converters 101a, 101b as described above, the inverting converters 101a, 101b may operate at different extinction angles. For example, one of the inverting converters 101a, 101b may operate at a higher extinction angle
5 when controlling the DC current therethrough, which may result in a higher reactive power consumption of the inverting converter 101a, 101b and/or an increased stress on the converter valves of the inverting converter 101a, 101b.

Using a control scheme for operation of the inverting converters 101a,
10 101b as described above, an imbalance between the currents through the respective inverting converters 101a, 101b may occur, in particular following possible disturbances in the power transmission system. During recovery of such disturbances, the inverting converter 101a, 101b that is controlling the DC line voltage may be more prone to accept or take more current compared
15 to the inverting converter 101a, 101b which controls the current through it and may therefore operate with a higher static characteristic than the inverting converter 101a, 101b that is controlling the DC line voltage.

Summary

20 In view of the above discussion, a concern of the present invention is to provide a method in a power transmission system including a DC link in which at least two inverting converters are connected in parallel, which method facilitates or enables the current flow between the inverting converters to become more balanced as compared to using a control scheme for operation
25 of the inverting converters such as described with reference to Fig. 1.

A further concern of the present invention is to provide a method in a power transmission system including a DC link in which at least two inverting converters are connected in parallel, by which method occurrence of imbalance between the currents through the respective inverting converters
30 may be reduced or even eliminated.

To address at least one of these concerns and other concerns, a method, a power transmission system and a control system for a power transmission system in accordance with the independent claims are provided. Preferred embodiments are defined by the dependent claims.

35 According to a first aspect of the present invention, there is provided a method in a power transmission system. The power transmission system comprises a first AC power line and a second AC power line, and at least two

inverting converters connected in parallel in a DC link between the first AC power line and the second AC power line. The first AC power line is connected to the DC link at a first end thereof and the second AC power line is connected to the DC link at a second end thereof. Each of the at least two inverting converters is adapted to convert DC power to AC power. The output from the at least two inverting converters is outcoupled from the DC link at one of the first and second ends thereof. The power transmission system comprises a controller for controlling operation of the DC link. The method comprises receiving current reference value for the desired current through the respective inverting converters from the controller. For each of the inverting converters, a current through the inverting converter is measured, and a first difference value between the measured current and the current reference value is determined. For each of the inverting converters, a second difference value between the first difference value determined for the inverting converter and the first difference value determined for the other inverting converter is determined. For each of the inverting converters, a firing angle offset value is determined based on the second difference value determined for the inverting converter. A firing angle of each inverting converter is adjusted or determined based on the firing angle offset values determined for the respective inverting converters.

For example, adjustment or determination of the firing angle of each of the inverting converters may comprise summing a firing angle reference value for the inverting converter, e.g. received from the controller, and the firing angle offset values determined for the inverting converter, thereby obtaining an adjusted firing angle for the inverting converter.

The current through each of the inverting converters may be adjusted at least in part based on the adjustment of the firing angle of the respective inverting converters. By adjustment of the firing angle of a inverting converter, an adjustment of the current through the inverting converter may be achieved.

By adjustment of the respective firing angles of the inverting converters according to the method in a control loop, which for example may be a proportional type (P-type) of control loop or a proportional-integral type (PI-type) of control loop as will be further described in the following, the current flow between the inverting converters may become more balanced, or the difference between the currents through the inverting converters may become less, as compared to using a control scheme for operation of the inverting converters such as described in the foregoing with reference to Fig. 1. Thus,

by a method according the present invention, occurrence of imbalance between the currents through the respective inverting converters may be reduced or even eliminated.

- The adjustment of the respective firing angles of the inverting converters according to the method in the control loop may be repeatedly carried out until a selected requirement is met and/or a selected criteria for the difference between the currents through the inverting converters is complied with. The selected requirement may for example be expiry of a timer or reaching a certain number of successive executions of the method steps.
- 10 The selected criteria for the difference between the currents through the inverting converters may for example be the difference between the currents through the inverting converters falling below a predefined current difference threshold value.

- The measurement of the currents in the respective inverting converters may be performed at the same time or substantially at the same time, e.g. within a few microseconds.

The firing angle offset values may be determined as a product of the respective second difference values determined for the inverting converters and a proportional gain value.

- 20 The steps of, for each of the inverting converters, (ii) measuring a current through the inverting converter and (iii) determining a first difference value between the measured current and the current reference value, and, for each of the inverting converters, (iv) determining a second difference value between the first difference value determined for the inverting converter and the first difference value determined for the other inverting converter, and, for each of the inverting converters, (v) determining a firing angle offset value is determined based on the second difference value determined for the inverting converter, and (vi) adjusting or determining a firing angle of each inverting converter based on the firing angle offset values determined for the
- 25
- 30 respective inverting converters, may be repeated at least once. The steps (ii)-(vi) may thereby be comprised in a control loop for repeatedly adjusting the respective firing angles of the inverting converters. The control loop may for example be a P-type control loop.

- Alternatively, the control loop may for example be a PI-type control loop, as further described in the following.

By repeating the above-mentioned steps (ii)-(vi) at least one time, a plurality of successive second different values are generated for each

inverting converter. The adjustment of the firing angle of each of the inverting converters may comprise selecting one of the plurality of successive second different values such that there is at least one second different value the determination of which preceded the determination of the selected one of the successive second different values. For each of at least one of the inverting converters, a firing angle offset value may be determined as a sum of a product of the selected one of the successive second different values and a proportional gain value, and a product based on an integral gain value and a sum of the selected one of the successive second different values and preceding one or ones of the successive second different values. A firing angle of the inverting converter may be adjusted based on the firing angle offset value. Thereby, adjustment of the current through the inverting converter may be effected. For each inverting converter or converters other than the above-mentioned at least one of the inverting converters, a firing angle offset value may be determined as a product of the selected one of the successive second different values and a proportional gain value. A firing angle of the inverting converter may be determined based on the firing angle offset value. Thereby, adjustment of the current through the inverting converter may be effected.

Possibly, the receiving of a current reference value for the desired current through the respective inverting converters from the controller may also be repeated at least once and be comprised in the control loop.

The power transmission system may comprise communication means for communication of signals between the at least two inverting converters.

The communication means may be wired and/or wireless. The communication means may for example comprise a wireless communication link of a type as known in the art.

The determination, for each of the inverting converters, of a second difference value between the first difference value determined for the inverting converter and the first difference value determined for the other inverting converter, may be implemented in the respective inverting converters.

To this end, a current reference value for the desired current through the respective inverting converter from the controller may be received at each of the at least two inverting converters at least once. Each of the at least two inverting converters may communicate the value of the measured current through the inverting converter, the current reference value and/or the first

difference value determined for the respective inverting converter to at least one other of the at least two inverting converters at least once.

An extinction angle reference value for the desired extinction angle of the respective inverting converters may be received or retrieved, e.g. from the controller in the power transmission system.

The extinction angle of the respective inverting converters may be determined or measured. On a condition that there is a difference between the extinction angle of the respective inverting converters and the extinction angle reference value, the extinction angle of the respective inverting converters may be adjusted so as decrease the difference between the extinction angle of the respective inverting converters and the extinction angle reference value. Adjusting the extinction angle of the inverting converters may for example comprise adjusting the tap positions of transformers of the respective inverting converters.

At least one of the inverting converters may be configured to control the DC voltage over the DC link.

A DC voltage reference value for the desired DC voltage over the respective inverting converters may be received or retrieved, e.g. from the controller in the power transmission system.

The DC voltage over the at least one of the inverting converters which is configured to control the DC voltage over the DC link may be determined, and on a condition that there is a difference between the DC voltage over the at least one of the inverting converters and the DC voltage reference value, the DC voltage over the at least one of the inverting converters may be adjusted so as decrease the difference between the DC voltage over the at least one of the inverting converters and the DC voltage reference value. The determination and adjustment of the DC voltage over the at least one of the inverting converters may be conditional on that the difference between the extinction angle of the respective inverting converters and the extinction angle reference value is below a predefined extinction angle difference reference value. The adjustment of the DC voltage over the at least one of the inverting converters may for example comprise adjusting the tap positions of a transformer of the at least one of the inverting converters.

According to a second aspect of the present invention, there is provided a power transmission system. The power transmission system comprises a first AC power line and a second AC power line, and a DC link between the first AC power line and the second AC power line. The first AC

power line is connected to the DC link at a first end thereof and the second AC power line is connected to the DC link at a second end thereof. The power transmission system comprises at least two inverting converters connected in parallel in the DC link. Each of the at least two inverting converters is adapted to convert DC power to AC power. The output from the at least two inverting converters is outcoupled from the DC link at one of the first and second ends thereof. The power transmission system comprises a controller for controlling operation of the DC link, and a converter control system. The converter control system is adapted to receive current reference value for the desired current through the respective inverting converters from the controller, and for each of the inverting converters, measure a current through the inverting converter and determine a first difference value between the measured current and the current reference value. The converter control system is adapted to, for each of the inverting converters, determine a second difference value between the first difference value determined for the inverting converter and the first difference value determined for the other inverting converter. The converter control system is adapted to, for each of the inverting converters, determine a firing angle offset value based on the second difference value determined for the inverting converter, and adjust a firing angle of each inverting converter based on the firing angle offsets determined for the respective inverting converters.

By adjustment of the firing angle of each inverting converter, adjustment of the current through the respective inverting converters may be achieved.

According to a third aspect of the present invention, there is provided a converter control system for a power transmission system. The power transmission system comprises a first AC power line and a second AC power line, and a DC link between the first AC power line and the second AC power line. The first AC power line is connected to the DC link at a first end thereof and the second AC power line is connected to the DC link at a second end thereof. The power transmission system comprises at least two inverting converters connected in parallel in the DC link. Each of the at least two inverting converters is adapted to convert DC power to AC power. The output from the at least two inverting converters is outcoupled from the DC link at one of the first and second ends thereof. The power transmission system comprises a controller for controlling operation of the DC link. The converter control system is adapted to receive current reference value for the desired

current through the respective inverting converters from the controller, and for each of the inverting converters, measure a current through the inverting converter and determine a first difference value between the measured current and the current reference value. The converter control system is
5 adapted to, for each of the inverting converters, determine a second difference value between the first difference value determined for the inverting converter and the first difference value determined for the other inverting converter. The converter control system is adapted to, for each of the inverting converters, determine a firing angle offset value based on the
10 second difference value determined for the inverting converter, and adjust a firing angle of each inverting converter based on the firing angle offsets determined for the respective inverting converters.

According to a fourth aspect of the present invention, there is provided a computer program product adapted to be executed in a converter control
15 system in a power transmission system. The computer program product comprises computer-readable means carrying computer program code. The power transmission system comprises a first AC power line and a second AC power line, and a DC link between the first AC power line and the second AC power line. The first AC power line is connected to the DC link at a first end
20 thereof and the second AC power line is connected to the DC link at a second end thereof. The power transmission system comprises at least two inverting converters connected in parallel in the DC link. Each of the at least two inverting converters is adapted to convert DC power to AC power. The output from the at least two inverting converters is outcoupled from the DC link at
25 one of the first and second ends thereof. The power transmission system comprises a controller for controlling operation of the DC link. The computer program code is configured to, when executed in the converter control system, cause the converter control system to:

30 receive current reference value for the desired current through the respective inverting converters from the controller;

for each of the inverting converters, measure a current through the inverting converter and determine a first difference value between the measured current and the current reference value;

35 for each of the inverting converters, determine a second difference value between the first difference value determined for the inverting converter and the first difference value determined for the other inverting converter;

for each of the inverting converters, determine a firing angle offset value based on the second difference value determined for the inverting converter; and

- adjust a firing angle of each inverting converter based on the firing
5 angle offsets determined for the respective inverting converters.

Further objects and advantages of the present invention are described in the following by means of exemplifying embodiments.

- It is noted that the present invention relates to all possible combinations of features recited in the claims. Further features of, and
10 advantages with, the present invention will become apparent when studying the appended claims and the following description. Those skilled in the art realize that different features of the present invention can be combined to create embodiments other than those described in the following.

15 **Brief description of the drawings**

Of the accompanying drawings, Fig. 1, which has already been described in the foregoing, is a schematic view of a DC link in a power transmission system according to an example.

- Exemplifying embodiments of the invention will be described below
20 with reference to the other accompanying drawings, in which:

Fig. 2 is a schematic view of a part of a power transmission system in accordance with an embodiment of the present invention;

Fig. 3 is a schematic view of a part of a power transmission system in accordance with an embodiment of the present invention; and

- 25 Fig. 4 is a schematic flowchart of a method according to an embodiment of the present invention.

In the accompanying drawings, the same reference numerals denote the same or similar elements throughout the views.

30 **Detailed description**

- The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which exemplifying embodiments of the present invention are shown. The present invention may, however, be embodied in many different forms and should not be construed as limited to
35 the embodiments set forth herein; rather, these embodiments are provided by way of example so that this disclosure will convey the scope of the invention to those skilled in the art. Furthermore, like numbers refer to like or similar

elements or components throughout. The steps of any method described herein do not have to be performed in the exact order as described, unless specifically stated.

Referring now to Fig. 2, there is shown a schematic view of a part of a power transmission system 100, to be specific a part of a DC link or line in a power transmission system 100, according to an embodiment of the present invention. The DC link includes two inverting converters 101a, 101b connected in parallel and two rectifying converters 102a, 102b connected in parallel as illustrated in Fig. 2. The inverting converter 101b is connected to the line via the inverting converter 101a. The rectifying converter 102b is connected to the line via the rectifying converter 102a.

It is noted that the power transmission system 100 depicted in Fig. 2 is according to an example embodiment of a power transmission system, including a DC link in which at least two inverting converters or inverters are connected in parallel, and that many variations of the particular arrangement of the other elements in the power transmission system relatively to each other can be contemplated. For example, the DC link may include at least three inverting converters connected in parallel.

The rectifying converters 102a, 102b and the inverting converters 101a, 101b may for example be thyristor-based.

The rectifying converters 102a, 102b and the inverting converters 101a, 101b are connected to first and second AC lines schematically indicated by reference numerals 103 and 104 via transformers 105a, 105b of the rectifying converters 102a, 102b and via transformers 106a, 106b of the inverting converters 101a, 101b, respectively. Thus, the first AC power line 103 is connected to the DC link at a first end thereof, and the second AC power line 104 is connected to the DC link at a second end thereof. Each of the inverting converters 101a, 101b is adapted to convert DC power to AC power. The respective outputs from the inverting converters 101a, 101b are outcoupled from the DC link at the second end thereof.

The power transmission system 100 comprises a controller 108 for controlling operation of the DC link.

The power transmission system 100 comprises converter control units 110a, 110b. According to the embodiment depicted in Fig. 2, the converter control unit 110a is adapted to control operation of the inverting converter 101a, and the converter control unit 110b is adapted to control operation of the inverting converter 101b.

One or both of the inverting converters 101a, 101b may be configured to control the DC line voltage, i.e. the DC voltage over the DC link. This may be achieved for example by means of varying or adjusting the extinction angle reference value for the one or both inverting converters 101a, 101b, which
5 extinction angle reference value for example is supplied from the controller 108, thereby controlling the DC voltage across the inverting converter 101a, 101b, or by means of varying the tap position of the respective transformers 106a, 106b of the inverting converters 101a, 101b.

The rectifying converters 102a, 102b may be configured to control the
10 currents therethrough, i.e. each of the rectifying converters 102a, 102b is controlling the current through it.

Each of the converter control units 110a, 110b is adapted to receive a current reference value, or current order, for the desired current through the inverting converters 101a and 101b, respectively, e.g. from the controller 108
15 as illustrated in Fig. 2.

As illustrated in Fig. 2 by two-way arrows, the converter control units 110a, 110b are coupled with the controller 108 so as to be able to transmit signals to and receive signals from the controller 108. In another embodiment, the converter control units 110a, 110b are coupled with the controller 108 so
20 as to be able to receive signals from the controller 108, but not necessarily so as to be able to transmit signals to the controller 108.

As further illustrated in Fig. 2 by two-way arrows, the converter control units 110a, 110b are coupled with the inverting converters 101a and 101b, respectively, so as to be able to transmit signals to and receive signals from
25 the inverting converters 101a and 101b, respectively. The converter control units 110a, 110b are intercoupled so as to be able to transmit signals therebetween.

Transmission of signals between different elements in the power transmission system 100 as discussed in the foregoing and in the following
30 may be effected by means of communication means which may be wired and/or wireless. For example, transmission of signals between the converter control units 110a, 110b may be effected by means of a wireless communication link as known in the art.

Generally in the drawings, two-ways arrows between two elements
35 indicate two-way communication capability between the respective elements, but do not necessarily imply necessity of two-way communication; one-way communication may be contemplated.

Each of the converter control units 110a, 110b is adapted to cause the inverting converter 101a and 101b, respectively, to measure current $I_{DC,1}$, $I_{DC,2}$ through the respective inverting converter 101a, 101b, and to determine a first difference value between the measured current and the current reference value. Alternatively, the inverting converters 101a, 101b, after having measured the current through the respective inverting converter 101a, 101b, transmits the respective measured current values to the converter control units 110a and 110b, respectively, at which the determination of the first difference value is performed.

Alternatively or optionally, each of the converter control units 110a, 110b may be adapted to cause a current sensor or sensors (not shown in Fig. 2), connected to the converter control units 110a, 110b, to measure currents $I_{DC,1}$, $I_{DC,2}$ through the respective inverting converters 101a, 101b.

According to the embodiment depicted in Fig. 2, the first difference values for the respective inverting converters 101a, 101b are exchanged between the converter control units 110a, 110b.

At the converter control unit 110a, a second difference value between the first difference value determined for the inverting converter 101a and the first difference value determined for the other inverting converter 101b is determined. Alternatively, the converter control unit 110a may be adapted to cause the inverting converter 101a to perform the determination of the second difference value. The converter control unit 110a is adapted to determine a firing angle offset value for the inverting converter 101a, or for converter valves of the inverting converter 101a, based on the second difference value determined for the inverting converter 101a.

At the converter control unit 110b, a second difference value between the first difference value determined for the inverting converter 101b and the first difference value determined for the other inverting converter 101a is determined. Alternatively, the converter control unit 110b may be adapted to cause the inverting converter 101b to perform the determination of the second difference value. The converter control unit 110b is adapted to determine a firing angle offset value for the inverting converter 101b, or for converter valves of the inverting converter 101b, based on the second difference value determined for the inverting converter 101b.

The converter control units 110a, 110b are adapted to adjust or determine a firing angle of the inverting converters 101a, 101b, respectively,

based on the firing angle offset values determined for the respective inverting converters 101a, 101b.

By adjustment of the firing angle of the inverting converters 101a, 101b, adjustment of the current through the respective inverting converters
5 101a, 101b may be achieved.

The measurement of the current through the respective inverting converters 101a, 101b, determination of the first difference values for the respective inverting converters 101a, 101b, determination of the second difference values for the respective inverting converters 101a, 101b,
10 determination of firing angle offset values based on the respective second difference values, and possibly the receipt of current reference values for the desired current through the respective inverting converters 101a, 101b, may be performed repeatedly and hence be part of a control loop, e.g. effected by the controller 108 and/or the converter control units 110a, 110b.

15 The converter control units 110a, 110b may be adapted to measure or determine the DC voltage $U_{DC,1}$, $U_{DC,2}$ over the inverting converter 101a and 101b, respectively.

By adjustment of the respective firing angles of the inverting converters 101a, 101b such as described above with reference to Fig. 2 in a control loop,
20 which for example may be a proportional type (P-type) of control loop or a proportional-integral type (PI-type) of control loop, the current flow between the inverting converters 101a, 101b may become more balanced, or the difference between the currents through the inverting converters 101a, 101b may become less, as compared to using a control scheme for operation of the
25 inverting converters 101a, 101b such as described with reference to Fig. 1. Thus, by adjustment of the respective firing angles of the inverting converters 101a, 101b such as described above with reference to Fig. 2, occurrence of imbalance between the currents through the respective inverting converters 101a, 101b may be reduced or even eliminated.

30 In the control loop, the current error for each inverting converter 101a, 101b, defined as a difference between the current order and momentaneous current through the respective inverting converter 101a, 101b, is monitored over a period. For each inverting converter, a difference between the determined current error for the inverting converter and the current error
35 determined for the other inverting converter is formed. This latter difference for each inverting converter can be multiplied by a proportional gain so as to obtain a contribution to a firing angle of the respective inverting converter or a

firing angle of converter valves of the respective inverting converter. The proportional gain may be time dependent or predefined or constant. The contribution to the firing angle of the respective inverting converter or the firing angle of converter valves of the respective inverting converter can then
 5 be added to a firing angle of the respective inverting converter or a firing angle of converter valves of the respective inverting converter established by or obtained from some other control system, e.g. the controller 108, e.g. a Current Control Amplifier included in a Converter Firing Control functionality.

As indicated in the foregoing, the converter control units 110a, 110b
 10 may be adapted to determine the firing angle offset values as a product of the respective second difference values determined for the respective inverting converters 101a, 101b and a proportional gain value, and possibly some other factor and/or constant. The proportional gain value may be time-dependent or predefined or constant.

15 In a P-type control loop, a transfer function of the control loop may for example be defined by the following equation, for each inverting converter:

$$\alpha_{\text{offset}} = (1/[1+sT]) \cdot [(I_{\text{response, own}} - I_{\text{order, own}}) - (I_{\text{response, other}} - I_{\text{order, other}})] \cdot K_p,$$

20 where:

(1/[1+sT]) represents a relatively small filter time constant, which may reduce the level of possible ripple in case introduced in the control system,

$I_{\text{response, own}}$ is the current response, i.e. the measured current, for the inverting converter, or 'own' inverting converter,

25 $I_{\text{order, own}}$ is the current order, e.g. a current reference value, for the inverting converter,

$I_{\text{response, other}}$ is the current response for the other one of the inverting converters,

30 $I_{\text{order, other}}$ is the current order for the other one of the inverting converters, and

K_p is a proportional gain.

Hence, the control loop can use current order and current response from both inverter converters as input variables. According to an embodiment of the present invention, the current order and current response for the
 35 respective inverting converters are exchanged between between the inverting converters, and/or between the converter control units.

Transmission of signals between different elements in the power transmission system may be associated with some latency in the time from sending of a signal from the source to the destination of the signal receiving the signal.

5 The latency generally depends on the characteristics of the communication means or equipment used for transmission of signals between different elements in the power transmission system. In the context of the present application, latency may be between 4-10 ms or less. Latency may introduce restrictions on gain used in the control loop. Simulations have
10 shown that it may be desired or required to reduce gain when taking into account effects of the latency in the control loop. To this end, a parametric analysis of the gain, including the effect of latency, may be performed.

By a P-type control loop the transfer function of which is defined by the equation above, there might be a risk that a residual imbalance between the
15 inverting converters occur. However, such a risk may be reduced or even eliminated by introducing a integral term in the above equation, i.e. by using a PI-type of control loop instead of a P-type control loop. Such an integral term may be introduced for only one of the inverting converters, or for both inverting converters. According to one example, such an integral term is
20 introduced for the inverting converter or converters configured to control the DC voltage over the DC link, but possibly not for an inverting converter not configured to control the DC voltage over the DC link. According to another example, in case the DC link includes at least three inverting converters connected in parallel, a PI-type of control loop for adjustment of the firing
25 angle is employed for two inverting converters, and a P-type of control loop for adjustment of the firing angle is employed for one inverting converter.

For the DC voltage, U_{DC} , and current, I_{DC} , characteristic for an inverting converter, the inverting converter static U_{DC} - I_{DC} characteristic includes two basic segments: a vertical line representing the condition of the inverting
30 converter controlling the DC current and a horizontal line representing the operation of the inverting converter with constant commutation margin.

The U_{DC} - I_{DC} characteristic for an inverting converter can be described by the relationship:

35
$$-U_{DC} = U_{di0} \cdot \cos \alpha - (d_{xN} - d_{rN}) \cdot (U_{di0N} / I_{DCN}) \cdot I_{DC},$$

where:

U_{di0} is the no-load direct voltage,

U_{di0N} is the no-load direct voltage at nominal converter transformer tap position and nominal AC voltage,

α is the extinction angle for the inverting converter or converter valves
5 of the inverting converter,

d_{xN} is the relative inductive voltage drop at rated direct current and at rated no-load direct voltage,

d_{rN} is the resistive voltage drop at rated operation,

I_{DCN} is the rated current, and

10 I_{DC} is the direct current.

A rectifying converter can be described with a U_{DC} - I_{DC} characteristic similar to that above for an inverting converter.

However, from the U_{DC} - I_{DC} characteristic for an inverting converter above, the operation of the inverting converter with constant commutation
15 margin may in reality not be represented by a horizontal line but by a line having a negative slope, with the converter transformer reactance influencing the slope, assuming the inverting converter is connected to a 'stiff' AC system or line, otherwise the network impedance also influences the slope. Such negative slope characteristics may decrease stability in the operation of the
20 inverting converter. In order to improve the operational stability of the inverting converter the static characteristic of the inverting converter may be changed by introducing a positive slope, which can be achieved by adding an appropriate contribution or offset to the inverting converter firing angle proportional to $(I_{\text{response}} - I_{\text{order}})$, similarly to what has been described in the
25 foregoing with respect to the transfer function. This means that the current balance control described in the foregoing can alternatively be interpreted as introducing an additional α -segment with positive slope in the inverting converter static characteristic. This additional α -segment is affected not only by the current error from the 'own' inverting converter but also from the
30 inverting converter arranged in parallel with the 'own' inverting converter. This positive slope segment may have a stabilization effect in balancing of current flows between the inverting converters.

Referring now to Fig. 3, there is shown a schematic view of a part of a power transmission system 100, to be specific a part of a DC link or line in a
35 power transmission system 100, according to an embodiment of the present invention. The embodiment depicted in Fig. 3 is similar to the embodiment depicted in Fig. 2, with an exception in that the power transmission system

100 in Fig. 3 comprises converter transformer tap changer control units 112a, 112b, as illustrated in Fig. 3.

The converter transformer tap changer control units 112a, 112b are configured to control a tap changer mechanism in the transformers 106a, 106b of the inverting converters 101a, 101b, respectively. The tap changer mechanism can change the position of the transformer tap or tapping connection, which is a connection point along a transformer winding that allows a certain number of turns to be selected, thereby enabling voltage regulation of the outputs of the respective transformers 106a, 106b. The tap changer mechanism may for example comprise on-load tap changers that can be used for changing the position of the tapping connection of energized transformer windings.

The converter transformer tap changer control units 112a, 112b are configured to control the tap changer mechanisms in the transformers 106a, 106b of the inverting converters 101a, 101b, respectively, in order to regulate the extinction angle of one or both inverting converters 101a, 101b so as to keep the extinction angle or angles within a selected angle interval, e.g. $\pm 1^\circ$, about an extinction angle reference value that for example may be received from the controller 108. By allowing a variation of the extinction angle within the selected angle interval, no or less 'hunting' of the tap changer mechanism may occur. The regulation of the extinction angle of one or both inverting converters 101a, 101b may be performed over a time period so as to maintain the extinction angle or angles within the selected angle interval during that time period.

Alternatively or optionally, the tap changer mechanisms in the transformers 106a, 106b of the inverting converters 101a, 101b, respectively, may be manually controlled by an operator.

For example, the extinction angle of the respective inverting converters 101a, 101b may be determined or measured at the inverting converters 101a, 101b, respectively. On a condition that there is a difference between the extinction angle of the respective inverting converters 101a, 101b and the extinction angle reference value, the extinction angles of the respective inverting converters 101a, 101b may be adjusted so as decrease the difference between the extinction angles of the respective inverting converters 101a, 101b and the extinction angle reference value. The adjustment is achieved by means of the converter transformer tap changer control units 112a, 112b controlling the tap changer mechanisms in the transformers 106a,

106b of the inverting converters 101a, 101b, respectively, so as to adjust the tap positions of the transformers 106, 106b of the respective inverting converters 101a, 101b.

A no-load control function, which for example may be implemented in the converter transformer tap changer control units 112a, 112b, may control the tap changer mechanism of the inverting converter transformers 106a, 106b when the inverting converters 101a, 101b are in a blocked state so as to establish the no-load DC voltage U_{di0} level corresponding to the steady state requirement at a minimum current level. Thereby, when the inverting converters 101a, 101b are brought out of the blocked state, no immediate stepping would be required by the tap changer mechanism.

A U_{di0} limitation function, which for example may be implemented in the converter transformer tap changer control units 112a, 112b, may monitor, e.g. repeatedly measure, the voltage in the inverting converters 101a, 101b, and override the tap changer mechanisms in the transformers 106a, 106b of the inverting converters 101a, 101b, respectively, in case a no-load DC voltage level is detected that exceeds a predefined U_{di0} threshold value. The U_{di0} threshold value may for example be received from the controller 108. The U_{di0} limitation function may regulate or step down the voltage and/or inhibit or reduce the tap changer mechanism operability or functionality in case a no-load DC voltage level is detected that exceeds the predefined U_{di0} threshold value. The U_{di0} limitation function may protect the valves of the inverting converters 101a, 101b from excessive voltage stress.

As previously mentioned, at least one of the inverting converters 101a, 101b may be configured to control the DC voltage over the DC link. For example, the inverting converter 101a may be configured to control the DC voltage over the DC link, whereas the inverting converter 101b is not controlling DC voltage over the DC link. The DC voltage control may for example be implemented in the converter transformer tap changer control unit 112a. The DC voltage over the the inverting converter 101a is determined or measured at the inverting converter 101a. On a condition that there is a difference between the DC voltage over the inverting converter 101a and a DC voltage reference value, which for example may be established by the controller 108, the DC voltage over the inverting converter 101a may be adjusted so as decrease the difference between the DC voltage over the inverting converter 101a and the DC voltage reference value. The adjustment of the DC voltage over the inverting converter 101a may for example be

effected by means of adjusting the tap positions of the transformer 106a of the inverting converter 101a, possibly controlled by the converter transformer tap changer control unit 112a.

According to an embodiment of the present invention, the above-mentioned DC voltage control may be conditional on that the difference between the extinction angle of the respective inverting converters 101a, 101b and the extinction angle reference value is below a predefined extinction angle difference reference value. In other words, the above-mentioned DC voltage control may only be carried out if a selected criteria for the extinction angles of the inverting converters 101a, 101b is fulfilled. For example, only if it is established that the inverting converters 101a, 101b are operating at extinction angles sufficiently close to the extinction angle reference value, control of the DC voltage of the DC link by one or both of the inverting converters 101a, 101b may be initiated or activated.

For the case where one of the inverting converters 101a, 101b is controlling the DC voltage over the DC link, such as where the inverting converter 101a is configured to control the DC voltage over the DC link and the inverting converter 101b is not controlling DC voltage over the DC link, the regulation or control of the extinction angle may be performed for both of the inverting converters 101a, 101b while the above-mentioned DC voltage control is performed only for the inverting converter 101a which is configured to control the DC voltage over the DC link.

According to an embodiment of the present invention, the converter transformer tap changer control unit 112a is configured to control the tap changer mechanism in the transformer 106a of the inverting converter 101a in order to regulate the DC voltage over the inverting converter 101a so as to keep the DC voltage over the inverting converter 101a within a selected DC voltage interval about the DC voltage reference value . By allowing a variation of the DC voltage over the inverting converter 101a within the selected DC voltage interval, no or less hunting of the tap changer mechanism in the transformer 106a may occur. The regulation of the DC voltage over the inverting converter 101a may be performed over a time period so as to maintain the DC voltage over the inverting converter 101a within the selected DC voltage interval during that time period.

The rectifying converters 102a, 102b are controlling the currents therethrough, i.e. each of the rectifying converters 102a, 102b is controlling the current through it. By controlling the tap positions of the transformers

105a, 105b of the rectifying converters 102a, 102b, the firing angles of the rectifying converters 102a, 102b, or the converter valves of the rectifying converters 102a, 102b, can be controlled so as to keep the firing angles of the rectifying converters 102a, 102b close to a firing angle reference value, e.g. within a selected angle interval, e.g. $\pm 1^\circ$, about the firing angle reference value. The firing angle reference value for the rectifying converters 102a, 102b may for example be received from the controller 108.

Referring now to Fig. 4, there is shown a schematic flowchart of a method 400 according to an embodiment of the present invention. The method 400 is carried out in a power transmission system comprising a first AC power line and a second AC power line, and at least two inverting converters connected in parallel in a DC link between the first AC power line and the second AC power line. The first AC power line is connected to the DC link at a first end thereof and the second AC power line is connected to the DC link at a second end thereof. Each of the at least two inverting converters is adapted to convert DC power to AC power. The output from the at least two inverting converters is outcoupled from the DC link at one of the first and second ends thereof. The power transmission system may comprise a controller for controlling operation of the DC link.

The method 400 comprises receiving or retrieving a current reference value for the desired current through the respective inverting converters, 401, e.g. from the controller.

For each of the inverting converters, a current through the inverting converter is measured and a first difference value between the measured current and the current reference value is determined, 402.

For each of the inverting converters, a second difference value between the first difference value determined for the inverting converter and the first difference value determined for the other inverting converter is determined, 403.

For each of the inverting converters, a firing angle offset value is determined based on the second difference value determined for the inverting converter, 404.

A firing angle of each inverting converter is adjusted based on the firing angle offset values determined for the respective inverting converters, 405.

By adjustment of the firing angle of the respective inverting converters, adjustment of the current through the inverting converters may be achieved. At step 406, there is determined whether a selected requirement is met or a

selected criteria for the difference between the currents through the inverting converters is complied with. The selected requirement may for example be expiry of a timer or reaching a certain number of successive executions of the method steps. The selected criteria for the difference between the currents
5 through the inverting converters may for example be the difference between the currents through the inverting converters falling below a predefined current difference threshold value. In case the selected requirement is not met and/or the selected criteria for the difference between the currents through the inverting converters is not complied with, the method 400 returns
10 to step 402, or alternatively to step 401 as indicated by the dashed line. In case the selected requirement is met and/or the selected criteria for the difference between the currents through the inverting converters is complied with, the method 400 ends.

In conclusion, a method in a power transmission system is disclosed.
15 The power transmission system comprises a DC link and at least two inverting converters connected in parallel in the DC link. Current reference value or values for the desired current through the respective inverting converters are received or retrieved, e.g. from a controller in the power transmission system. For each of the inverting converters, a current through
20 the inverting converter is measured and a first difference value between the measured current and the current reference value is determined. For each of the inverting converters, a second difference value between the first difference value determined for the inverting converter and the first difference value determined for the other inverting converter is determined. For each of
25 the inverting converters, a firing angle offset value is determined based on the second difference value determined for the inverting converter. A firing angle of each inverting converter is adjusted based on the firing angle offset values determined for the respective inverting converters. By adjustment of the firing angle of a inverting converter, an adjustment of the current through the
30 inverting converter may be achieved.

While the present invention has been illustrated and described in detail in the appended drawings and the foregoing description, such illustration and description are to be considered illustrative or exemplifying and not restrictive; the present invention is not limited to the disclosed embodiments. Other
35 variations to the disclosed embodiments can be understood and effected by those skilled in the art in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. The mere fact that certain

measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

Claims

1. A method in a power transmission system comprising a first alternating current, AC, power line and a second AC power line, and at least two
5 inverting converters connected in parallel in a direct current, DC, link between the first AC power line and the second AC power line, wherein the first AC power line is connected to the DC link at a first end thereof and the second AC power line is connected to the DC link at a second end thereof, each of the at least two inverting converters being adapted to convert DC power to
10 AC power, wherein the output from the at least two inverting converters is out-coupled from the DC link at one of the first and second ends thereof, the power transmission system comprising a controller for controlling operation of the DC link, the method comprising:
- (i) receiving current reference value for the desired current through the
15 respective inverting converters from the controller; and
for each of the inverting converters:
 - (ii) measuring a current through the inverting converter; and
 - (iii) determining a first difference value between the measured current and the current reference value;
 - 20 the method further comprising, for each of the inverting converters:
 - (iv) determining a second difference value between the first difference value determined for the inverting converter and the first difference value determined for the other inverting converter; and
 - the method further comprising, for each of the inverting converters:
25
 - (v) determining a firing angle offset value based on the second difference value determined for the inverting converter; and
 - (vi) adjusting a firing angle of each inverting converter based on the firing angle offset values determined for the respective inverting
30 converters.
2. A method according to claim 1, further comprising:
adjusting the current through each of the inverting converters at least in part based on the adjustment of the firing angle of the respective inverting
35 converters.

3. A method according to claim 1 or 2, wherein the firing angle offset values are determined as a product of the respective second difference values determined for the inverting converters and a proportional gain value.
- 5 4. A method according to any one of claims 1-3, further comprising:
repeating at least steps (ii)-(vi) at least one time, wherein at least steps (ii)-(vi) are comprised in a control loop for repeatedly adjusting the firing angle of each of the inverting converters.
- 10 5. A method according to claim 1, further comprising:
repeating at least steps (ii)-(vi) at least one time, whereby a plurality of successive second different values are generated for each inverting converter;
wherein the adjustment of the firing angle of each of the inverting
15 converters comprises:
selecting one of the plurality of successive second different values such that there is at least one second different value the determination of which preceded the determination of the selected one of the successive second different values;
20 for each of at least one of the inverting converters:
determining a firing angle offset value as a sum of:
a product of the selected one of the successive second different values and a proportional gain value;
and
25 a product based on an integral gain value and a sum of the selected one of the successive second different values and preceding one or ones of the successive second different values; and
adjusting a firing angle of the inverting converter based
30 on the firing angle offset value; and
for each inverting converter or converters other than said at least one of the inverting converters:
determining a firing angle offset value as a product of the selected one of the successive second different values and a
35 proportional gain value; and
adjusting a firing angle of the inverting converter based on the firing angle offset value.

6. A method according to any one of claims 1-5, further comprising:
receiving an extinction angle reference value for the desired extinction
angle of the respective inverting converters from the controller;
5 determining the extinction angle of the respective inverting converters;
and
on a condition that there is a difference between the extinction angle of
the respective inverting converters and the extinction angle reference value,
adjusting the extinction angle of the respective inverting converters so as
10 decrease the difference between the extinction angle of the respective
inverting converters and the extinction angle reference value.
7. A method according to claim 6, wherein adjusting the extinction angle
of the inverting converters comprises adjusting the tap positions of trans-
15 formers of the respective inverting converters.
8. A method according to any one of claims 1-7, wherein at least one of
the inverting converters is configured to control the DC voltage over the DC
link, the method further comprising:
20 receiving a DC voltage reference value for the desired DC voltage over
the respective inverting converters from the controller; and
determining the DC voltage over the at least one of the inverting
converters being configured to control the DC voltage over the DC link; and
on a condition that there is a difference between the DC voltage over
25 the at least one of the inverting converters and the DC voltage reference
value, adjusting the DC voltage over the at least one of the inverting
converters so as decrease the difference between the DC voltage over the at
least one of the inverting converters and the DC voltage reference value.
- 30 9. A method according to claim 6 or 7, wherein at least one of the
inverting converters is configured to control the DC voltage over the DC link,
the method further comprising:
on a condition that the difference between the extinction angle of the
respective inverting converters and the extinction angle reference value is
35 below a predefined extinction angle difference reference value:
receiving a DC voltage reference value for the desired DC
voltage over the respective inverting converters from the controller; and

determining the DC voltage over the at least one of the inverting converters being configured to control the DC voltage over the DC link; and

5 on a condition that there is a difference between the DC voltage over the at least one of the inverting converters and the DC voltage reference value, adjusting the DC voltage over the at least one of the inverting converters so as decrease the difference between the DC voltage over the at least one of the inverting converters and the DC voltage reference value.

10

10. A method according to claim 8 or 9, wherein adjusting the DC voltage over the at least one of the inverting converters comprises adjusting the tap positions of a transformer of the at least one of the inverting converters.

15

11. A power transmission system comprising:

a first alternating current, AC, power line and a second AC power line;
a direct current, DC, link between the first AC power line and the second AC power line, wherein the first AC power line is connected to the DC link at a first end thereof and the second AC power line is connected to the DC link at a second end thereof;

20

at least two inverting converters connected in parallel in the DC link, each of the at least two inverting converters being adapted to convert DC power to AC power, wherein the output from the at least two inverting converters is outcoupled from the DC link at one of the first and second ends thereof;

25

a controller for controlling operation of the DC link; and
a converter control system adapted to:

receive current reference value for the desired current through the respective inverting converters from the controller;

30

for each of the inverting converters, measure a current through the inverting converter and determine a first difference value between the measured current and the current reference value;

for each of the inverting converters, determine a second difference value between the first difference value determined for the inverting converter and the first difference value determined for the other inverting converter;

35

for each of the inverting converters, determine a firing angle offset value based on the second difference value determined for the inverting converter; and

5 adjust a firing angle of each inverting converter based on the firing angle offsets determined for the respective inverting converters.

12. A converter control system for a power transmission system, the power transmission system comprising:

10 a first alternating current, AC, power line and a second AC power line;
a direct current, DC, link between the first AC power line and the second AC power line, wherein the first AC power line is connected to the DC link at a first end thereof and the second AC power line is connected to the DC link at a second end thereof;

15 at least two inverting converters connected in parallel in the DC link,
each of the at least two inverting converters being adapted to convert DC power to AC power, wherein the output from the at least two inverting converters is outcoupled from the DC link at one of the first and second ends thereof; and

20 a controller for controlling operation of the DC link;
the converter control system being adapted to:
receive current reference value for the desired current through the respective inverting converters from the controller;

25 for each of the inverting converters, measure a current through the inverting converter and determine a first difference value between the measured current and the current reference value;

for each of the inverting converters, determine a second difference value between the first difference value determined for the inverting converter and the first difference value determined for the other inverting converter;

30 for each of the inverting converters, determine a firing angle offset value based on the second difference value determined for the inverting converter; and

adjust a firing angle of each inverting converter based on the firing angle offsets determined for the respective inverting converters.

35

13. A computer program product adapted to be executed in a converter control system in a power transmission system, the computer program

product comprising computer-readable means carrying computer program code, the power transmission system comprising:

a first alternating current, AC, power line and a second AC power line;

a direct current, DC, link between the first AC power line and the

5 second AC power line, wherein the first AC power line is connected to the DC link at a first end thereof and the second AC power line is connected to the DC link at a second end thereof;

at least two inverting converters connected in parallel in the DC link, each of the at least two inverting converters being adapted to convert DC

10 power to AC power, wherein the output from the at least two inverting converters is outcoupled from the DC link at one of the first and second ends thereof; and

a controller for controlling operation of the DC link;

the computer program code being configured to, when executed in the
15 converter control system, cause the converter control system to:

receive current reference value for the desired current through the respective inverting converters from the controller;

for each of the inverting converters, measure a current through the inverting converter and determine a first difference value between
20 the measured current and the current reference value;

for each of the inverting converters, determine a second difference value between the first difference value determined for the inverting converter and the first difference value determined for the other inverting converter;

25 for each of the inverting converters, determine a firing angle offset value based on the second difference value determined for the inverting converter; and

adjust a firing angle of each inverting converter based on the firing angle offsets determined for the respective inverting converters.

30

1/4

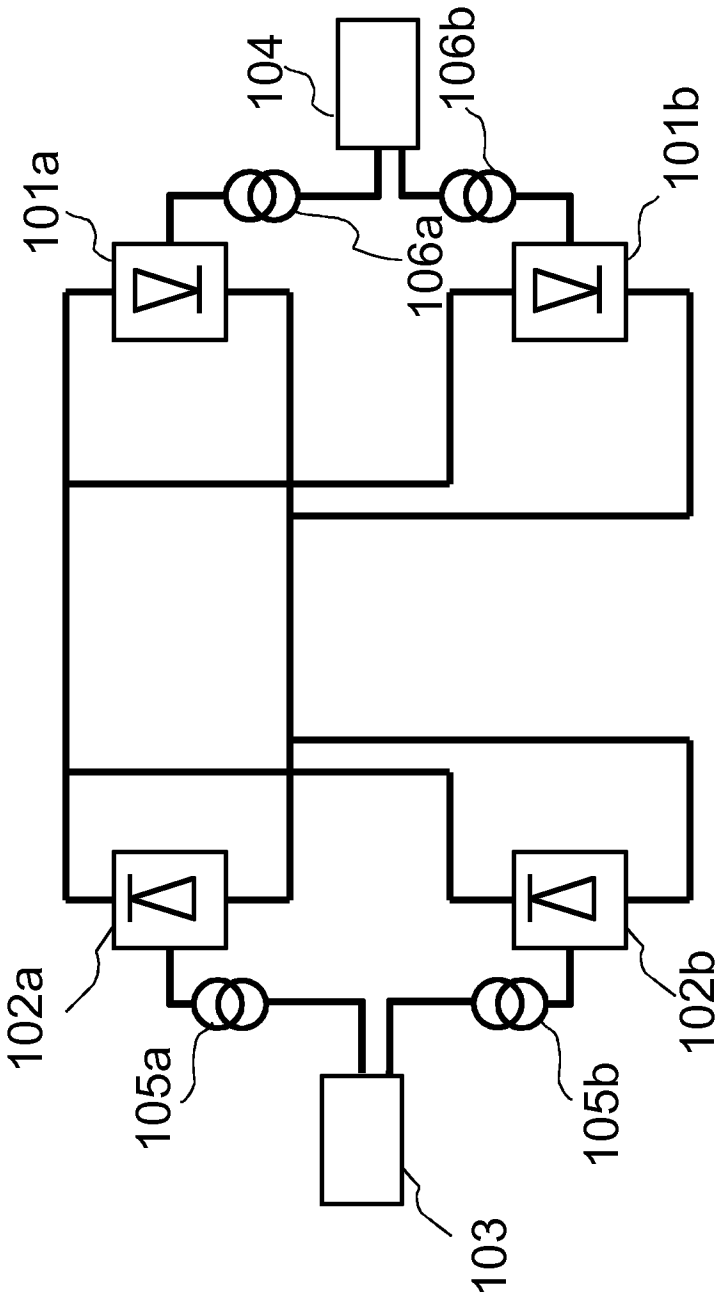


Fig. 1

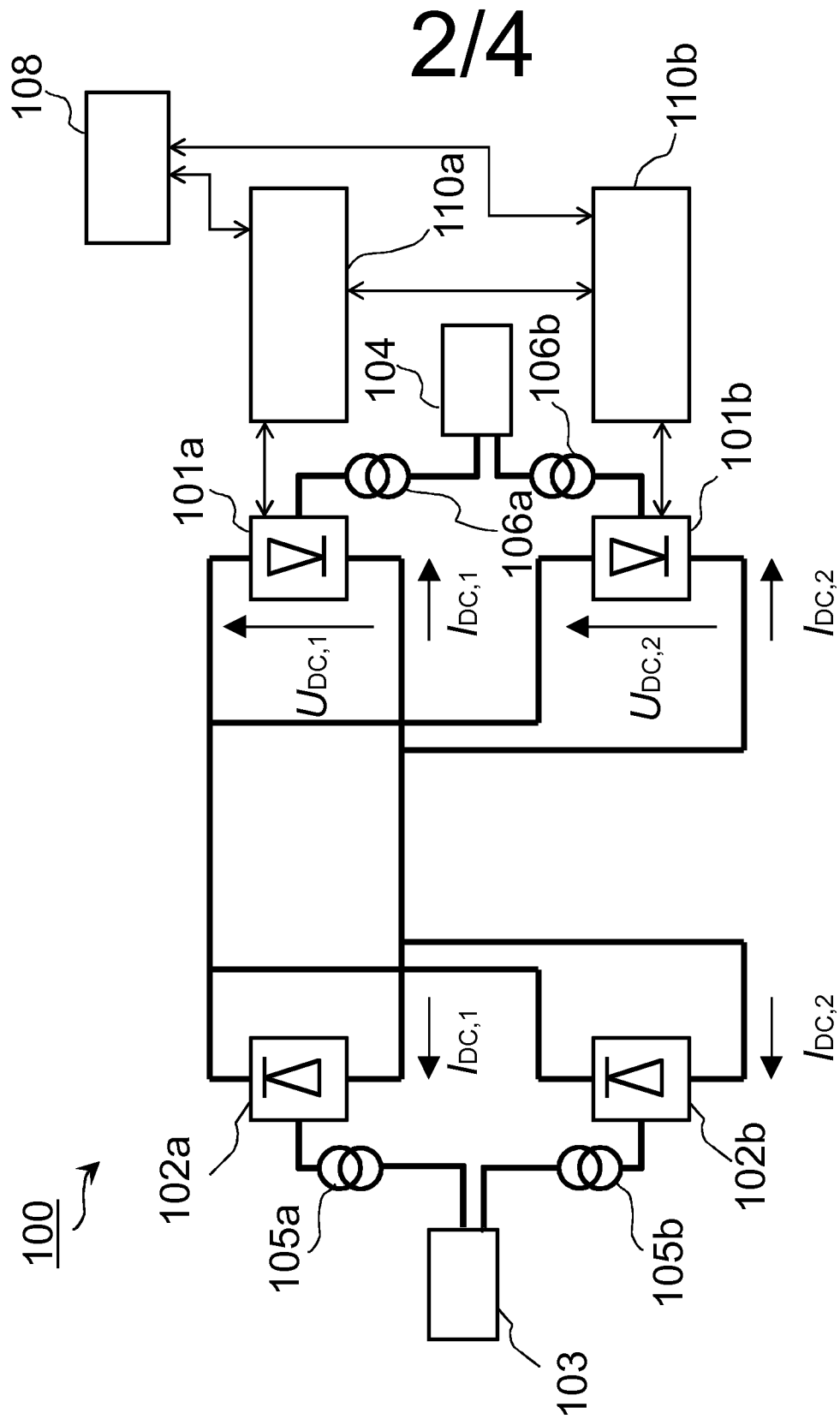


Fig. 2

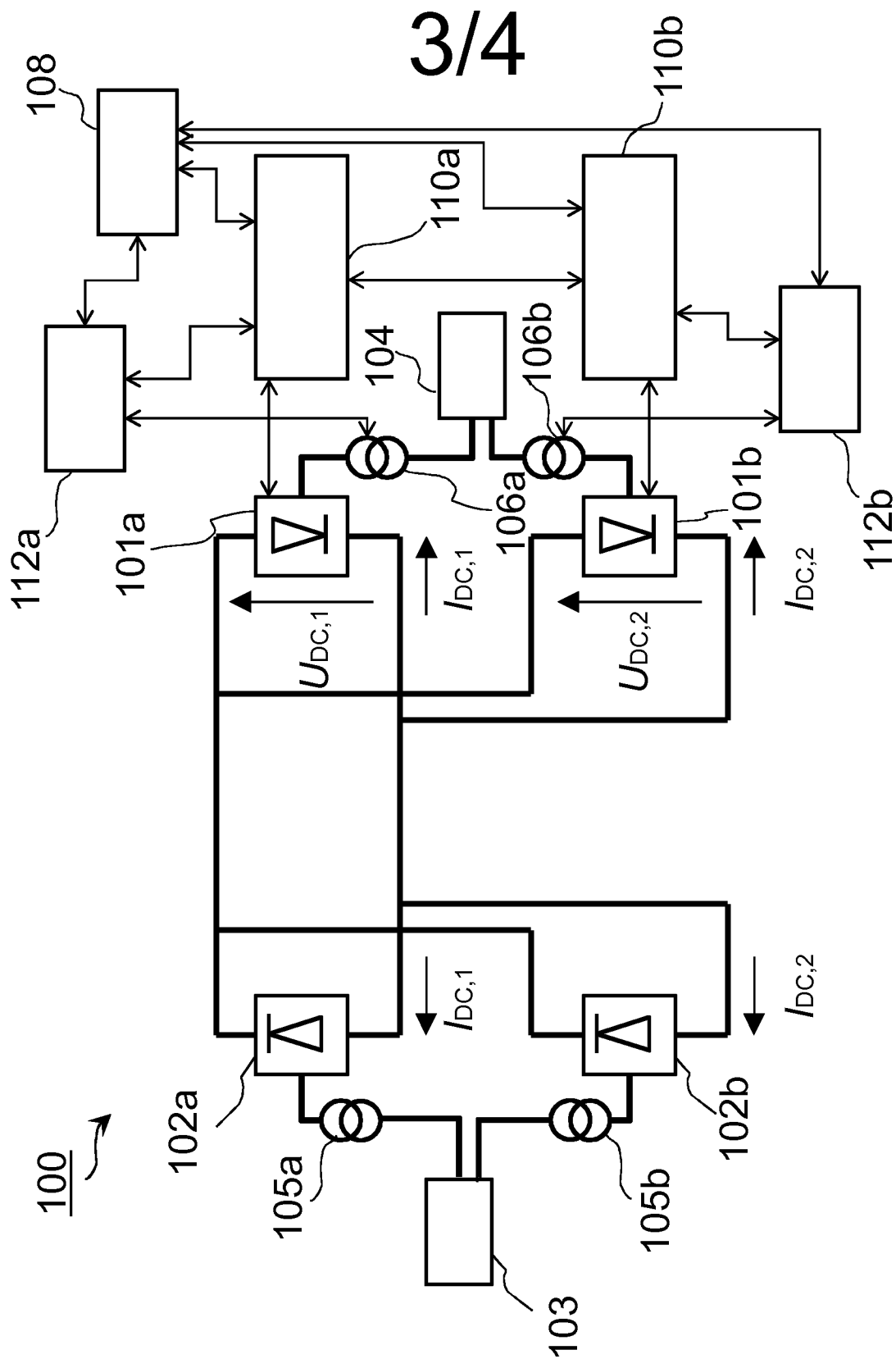
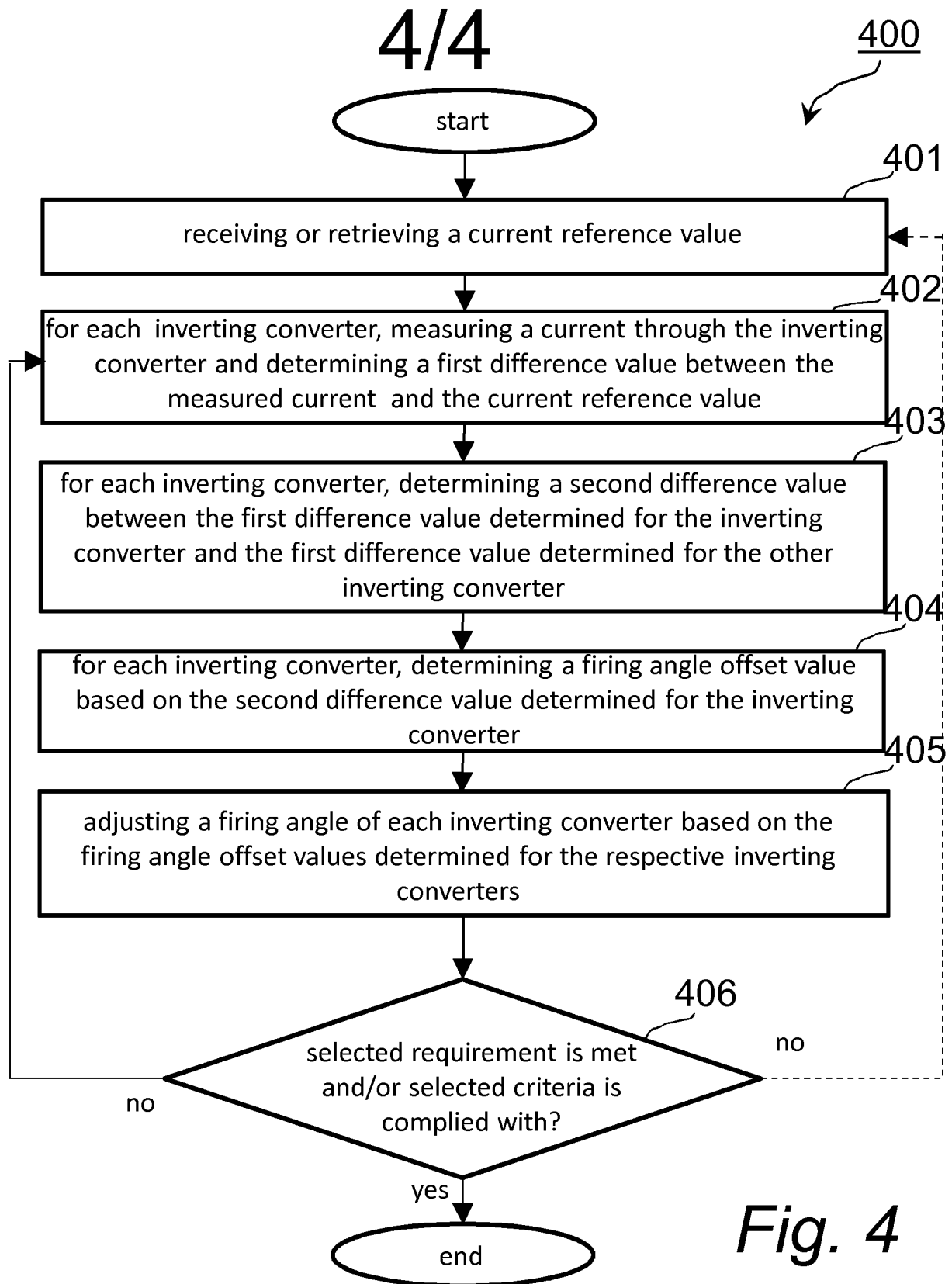


Fig. 3



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/068339

A. CLASSIFICATION OF SUBJECT MATTER

INV. H02M7/757 H02J3/36 H02J3/46
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)

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 practicable, search terms used)

EPO-Internal, COMPENDEX, INSPEC, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2008/036009 A1 (ABB TECHNOLOGY LTD [CH]; HOLMGREN TOMMY [SE]; HYTTINEN MATS [SE]) 27 March 2008 (2008-03-27) abstract; figures 1,7 page 7, line 2 - line 8 -----	1-13
Y	US 5 627 734 A (KARLECIK-MAIER FRANZ [DE]) 6 May 1997 (1997-05-06) column 3, line 22 - column 4, line 48; figures 1,5,6 -----	1-13
Y	WO 2008/110211 A1 (ABB TECHNOLOGY AG [CH]; RADBRANDT ULF [SE]) 18 September 2008 (2008-09-18) page 8, line 6 - line 21; figures 1,2 -----	7,9,10



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

9 April 2013

Date of mailing of the international search report

17/04/2013

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

Braccini, Roberto

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2012/068339

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2008036009	A1	27-03-2008	NONE

US 5627734	A	06-05-1997	CA 2158374 A1 29-09-1994
			DE 4308362 C1 03-11-1994
			EP 0689732 A1 03-01-1996
			JP H08507673 A 13-08-1996
			US 5627734 A 06-05-1997
			WO 9422211 A1 29-09-1994

WO 2008110211	A1	18-09-2008	AT 507606 T 15-05-2011
			CN 101647188 A 10-02-2010
			EP 2122819 A1 25-11-2009
			US 2010091528 A1 15-04-2010
			WO 2008110211 A1 18-09-2008
