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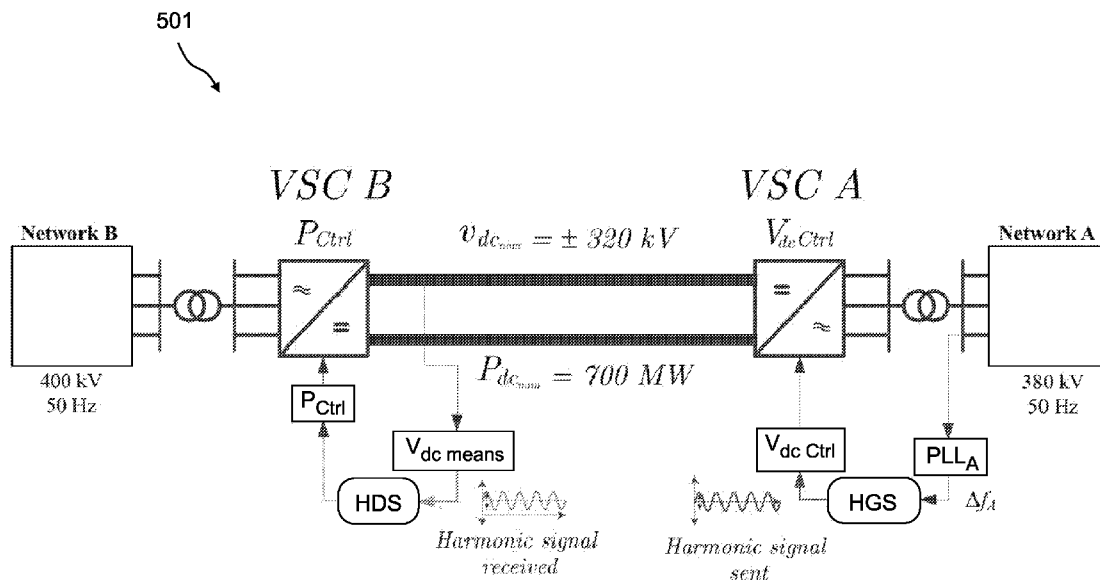


Fig. 6

(57) Abstract: A transmitting control unit arranged for controlling a Voltage Source Converter, VSC, of a VSC-High Voltage Direct Current, HVDC, network, said transmitting control unit comprising a frequency detection unit arranged for determining a frequency offset of a frequency of an output of said AC network with a predetermined reference frequency, a communication signal generation unit arranged for generating said communication signal, and a control block arranged for inserting said communication signal into HVDC cables by controlling said VSC based on said generated communication signal.

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Title

Control units for controlling Voltage Source Converters, VSC, of a VSC-High Voltage Direct Current, HVDC, network, as well as corresponding methods.

5

Technical field

The present disclosure is directed to field of High Voltage Direct Current, HVDC, networks and, more specifically, to communication between Voltage Source Converters, VSCs of said HVDC over HVDC cables.

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Background

The development of Voltage Source Converter based High Voltage DC links, known as VSC-HVDC links, in close proximity is leading to the idea of connecting them together to form a meshed VSC-HVDC network. However, ensuring the interoperability of such a network is a difficult task that requires a technical approach. To address this issue, a power line communication concept has been proposed for AC/DC/AC power management using point-to-point VSC-HVDC links to support active power balance regulation that is reflected in the dynamic performance of frequency stability.

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Previous methods have relied on the active power regulation capabilities of VSC-HVDC links to support primary active power - frequency response, but their reliability is dependent on conventional communication methods such as fiber optics. New frequency control strategies have been developed that focus on DC voltage regulation and enable alternative communication methods using power-line communication principles. These emerging methods can be classified into two strategies: non-periodic controlled signals, NPCS, and periodic controlled signals, PCS.

25

NPCS aims to adjust the DC voltage level of the VSC-HVDC link in proportion to frequency deviations in the affected power system. PCS strategies involve adding small amplitude voltage waveforms with variable frequency to the DC voltage reference.

30

However, introducing such frequency-modulated AC voltage waveforms within the HVDC cable can cause resonance within the VSC-HVDC link, potentially affecting the stability of the HVDC/HVAC power transmission process.

5

Summary

Following the above, it would be advantageous to achieve control units that are able to transmit, and receive, communication signals over the HVDC cables without affecting the stability of the HVDC/HVAC power transmission process.

10

In a first aspect of the present disclosure, there is provided a transmitting control unit arranged for controlling a Voltage Source Converter, VSC, of a VSC-High Voltage Direct Current, HVDC, network, such that said VSC induces a communication signal into HVDC cables comprised by said HVDC network for transporting DC power, said communication signal being representative for power imbalance at an Alternating

15 Current, AC, network arranged to be connected to said VSC, said transmitting control unit comprising:

20

- a frequency detection unit, for example a dynamic frequency behaviour tracking unit, arranged for determining a frequency offset of a frequency of an output of said AC network with a predetermined reference frequency;

25

- a communication signal generation unit arranged for generating said communication signal, wherein said communication signal generation unit is arranged for:

- generating said communication signal as a harmonic oscillatory signal having a first frequency in case said determined frequency offset is

25 positive;

- generating said communication signal as a harmonic oscillatory signal having a second frequency in case said determined frequency offset is negative;

30

- wherein said first frequency differs from said second frequency;
- a control block arranged for inserting said communication signal into said HVDC cables by controlling said VSC based on said generated communication signal.

The inventors have found a beneficial way to communicate from one VSC to another without utilizing dedicated communication cables. The communication may be performed over the HVDC cable in such a way that the system stays stable.

5 The above is especially applicable for communicating information with respect to power imbalance, between the VSCs.

In an AC network, the frequency of the electrical signal represents the rate at which the current changes direction. Typically, the frequency of an AC network is fixed at a certain value, such as 50 or 60 Hz, and power generation is adjusted to maintain this frequency.

10 If there is too much power being generated in the AC network, the load on the system may not be able to consume all the generated power. This can lead to an imbalance between the power generated and consumed, which can cause the frequency of the network to increase.

15 The reason for this is that the frequency of the network is directly proportional to the balance between the generated and consumed power. When the generated power exceeds the consumed power, the frequency increases, and when the consumed power exceeds the generated power, the frequency decreases.

20 Therefore, to maintain a stable AC network, it may be important to balance the generated power with the consumed power and adjust power generation accordingly.

The power balance information may then be communicated from one VSC to another, such that the another VSC may be able to take appropriate actions.

25 According to the present disclosure, a harmonic oscillatory signal is generated, wherein the harmonic oscillatory signal may have a first or a second frequency, depending on the frequency offset.

30 The frequency offset is the difference between the actual frequency of the AC network and the "fixed" frequency of the AC network. As mentioned above, a higher actual frequency of the AC network may represent an over-generation of power, i.e. a surplus of power. A lower actual frequency of the AC network may represent an under-generation of power, i.e. a deficit of power.

If the determined frequency offset is positive, a first, relatively high, frequency may be used for the harmonic oscillatory signal. This may be indicative for an over-generation of power at the AC network. If the determined frequency offset is

negative, a second, relatively low, frequency may be used for the harmonic oscillatory signal. This may be indicated for an under-generation of power at the AC network.

In accordance with the present disclosure, the control block is arranged for inserting the communication signal into said HVDC cables by controlling the VSC
5 based on the generated communication signal.

The control block may be a V_{DCctrl} block comprised by an outer control block that provide reference values to an inner control block. This is elucidated in more detail with respect to the figures.

10 In an example, the communication signal generation unit is further arranged for modulating an amplitude of said harmonic oscillatory signal based on a magnitude of said frequency offset.

In an example, the communication signal generation unit is arranged to multiple said harmonic oscillatory signal with said determined frequency offset and with a gain factor k .

15 The gain factor may amplify the determined frequency offset, making it more suitable to be transmitted over the HVDC cables. The amplified signal has a higher amplitude such that a receiving VSC is better able to actually receive and interpret the signal. The amplified signal is also less prone to all kinds of external disturbances that may occur during transport of the harmonic signal over the HVDC
20 cables from one VSC to another.

In a further example, the communication signal generation unit comprises a deadband block, wherein said determined frequency offset is provided to said deadband block as an input, and wherein an output of said deadband block provides for a frequency offset with a deadband in which deadband a band of input
25 values translate to zero in an output of said deadband block.

Specifically, a deadband block may be considered a device that introduces a range of values in which no control signal changes are allowed. For example, if a control signal is operating within a specific range of values, say between 40% and 60%, the deadband block will prevent any changes to the control signal until
30 it moves outside that range.

Deadband blocks may be used in the present disclosure, to avoid rapid or unnecessary switching of control signals, which can lead to instability or damage to

the system. By limiting the range of values in which control signals can operate, deadband blocks can help maintain the stability and reliability of the control.

In a further example, the communication signal generation unit is arranged to generate said communication signal by:

5
$$V = K \Delta f(t) \sin(2\pi HOVt),$$

Wherein V is said communication signal, K is said gain factor, $\Delta f(t)$ is said determined frequency offset, t is time and HOV is said harmonic oscillator signal.

The communication signal V may then be used in the control block for controlling the DC voltage of the HVDC cables thereby effectively imposing the communication signal on the HVDC cables.

As mentioned above, the frequency of the HOV may be the first or second frequency, depending on the sign of the frequency offset. That is, a positive frequency offset may result in a first frequency and a negative frequency offset may result in a second frequency.

15 In a second aspect of the present disclosure, there is provided a receiving control unit arranged for controlling a Voltage Source Converter, VSC, of a VSC-High Voltage Direct Current, HVDC, network, such that said VSC is able to receive a communication signal induced on HVDC cables comprised by said HVDC network for transporting DC power, said communication signal being representative for power imbalance at an Alternating Current, AC, network arranged to be connected to a further VSC of said HVDC network, said receiving control unit comprising:

- a voltage measurement unit arranged for measuring a voltage on said HVDC cables;
- a detection system arranged for detecting said communication
- 25 signal being a harmonic oscillatory signal present in said measured voltage
- a control block arranged for controlling said VSC based on said detected communication signal.

It is noted that the advantages as explained with respect to the first aspect of the present disclosure, being the transmitting control unit, are also applicable to the second aspect of the present disclosure, being the receiving control unit.

In an example, the detection system further comprises:

- a filter for filtering said measured voltage on said HVDC cables.

In a further example, the detection system further comprises:

- a rectifier block for rectifying said measured voltage.

In yet another example, an amplitude of said harmonic oscillatory signal is representative for a magnitude of said power imbalance at said AC network, wherein said detection system is further arranged for determining said magnitude of said harmonic oscillatory signal, and wherein said control block is further arranged for controlling said VSC based on said determined magnitude of said harmonic oscillatory signal.

In a further example, the harmonic oscillatory signal may have a first frequency representative for over-generation of power at said AC network and may have a second frequency, different to said first frequency, representative for under-generation of power at said AC network, wherein said detection system is arranged for detecting a frequency of said harmonic oscillatory signal, being said first or said second frequency, and wherein said control block is arranged for controlling said VSC based on said detected frequency, being said first or said second frequency.

In a third aspect of the present disclosure, there is provided a method of operating a transmitting control unit in accordance with any of the previous examples, wherein said method comprises the steps of:

- determining, by said frequency detection unit, said frequency offset of said frequency of said output of said AC network with said predetermined reference frequency;

- generating, by said communication signal generation unit, said communication signal by:

- generating said communication signal as a harmonic oscillatory signal having a first frequency in case said determined frequency offset is positive;

- generating said communication signal as a harmonic oscillatory signal having a second frequency in case said determined frequency offset is negative;

wherein said first frequency differs from said second frequency;

- inserting, by said control block, said communication signal into said HVDC cables by controlling said VSC based on said generated communication signal.

In an example, the method comprises the step of:

- modulating, by said communication signal generation unit, an amplitude of said harmonic oscillatory signal based on a magnitude of said frequency offset.

In a further example, the method comprises the step of:

- 5 - multiply, by said communication signal generation unit, said harmonic oscillatory signal with said determined frequency offset and with a gain factor k.

In yet another example, the method comprises the steps of:

- 10 - measuring, by said voltage measurement unit, said voltage on said HVDC cables;
- detecting, by said detection system, said communication signal being a harmonic oscillatory signal present in said measured voltage;
- controlling, by said control block, said VSC based on said detected communication signal.

15 In an example, an amplitude of said harmonic oscillatory signal is representative for a magnitude of said power imbalance at said AC network, wherein said method further comprises the step of:

- determining, by said detection system, said magnitude of said harmonic oscillatory signal, and
- 20 - controlling, by said control block, said VSC based on said determined magnitude of said harmonic oscillatory signal.

 In a further example, the harmonic oscillatory signal may have a first frequency representative for over-generation of power at said AC network and may have a second frequency, different to said first frequency, representative for under-

25 generation of power at said AC network, wherein said method comprises the steps of:

- detecting, by said detection system, a frequency of said harmonic oscillatory signal, being said first or said second frequency, and
- controlling, by said control block, said VSC based on said detected frequency, being said first or said second frequency.

30 In another aspect of the present disclosure, there is provided a High Voltage Direct Current, HVDC, network comprising two Voltage Source Converters, VSCs, and HVDC cabled connecting those two VSCs to one another, wherein said HVDC comprises:

- a transmitting control unit in accordance with any of the examples provided above and arranged for controlling a first of said two VSCs;
- a receiving control unit in accordance with any of the examples provided above and arranged for controlling a second of said two VSCs.

5 In yet another aspect of the present disclosure, there is provided a computer program product comprising a computer readable medium having instructions stored thereon which, when executed by a control unit, cause said control unit to implement a method in accordance with any of the examples provided above.

10 The present disclosure is described in conjunction with the appended figures. It is emphasized that, in accordance with the standard practice in the industry, various features are not drawn to scale. In fact, the dimensions of the various features may be arbitrarily increased or reduced for clarity of discussion.

15 In the appended figures, similar components and/or features may have the same reference label. Further, various components of the same type may be distinguished by following the reference label by a dash and a second label that distinguishes among the similar components. If only the first reference label is used in the specification, the description is applicable to any one of the similar components having the same first reference label irrespective of the second reference label.

20 The above and other aspects of the disclosure will be apparent from and elucidated with reference to the examples described hereinafter.

Brief description of the drawings

- 25 Fig. 1 discloses examples of HVDC links based on VSC units;
- Fig. 2 discloses a general description of an modular Multi-level Converter unit;
- Fig. 3 discloses a general description of the control layers of an VSC/MMC unit;
- 30 Fig. 4 discloses a generation structure of an inner control block as shown in figure 3;
- Fig. 5 disclose basic examples of control modes conforming the outer control block;

Fig. 6 discloses an HVDC link comprising a communication topology in accordance with the present disclosure;

Fig. 7 discloses an example of a Harmonic Generation System in accordance with the present disclosure;

5 Fig. 8 discloses an example of a Harmonic Detection System in accordance with the present disclosure;

Fig. 9 discloses another example in accordance with the present disclosure

10 Detailed Description

It is noted that in the description of the figures, same reference numerals refer to the same or similar components performing a same or essentially similar function.

15 A more detailed description is made with reference to particular examples, some of which are illustrated in the appended drawings, such that the manner in which the features of the present disclosure may be understood in more detail. It is noted that the drawings only illustrate typical examples and are therefore not to be considered to limit the scope of the subject matter of the claims. The drawings
20 are incorporated for facilitating an understanding of the disclosure and are thus not necessarily drawn to scale. Advantages of the subject matter as claimed will become apparent to those skilled in the art upon reading the description in conjunction with the accompanying drawings.

The ensuing description above provides preferred exemplary
25 embodiment(s) only, and is not intended to limit the scope, applicability or configuration of the disclosure. Rather, the ensuing description of the preferred exemplary embodiment(s) will provide those skilled in the art with an enabling description for implementing a preferred exemplary embodiment of the disclosure, it being understood that various changes may be made in the function and arrangement
30 of elements, including combinations of features from different embodiments, without departing from the scope of the disclosure.

Unless the context clearly requires otherwise, throughout the description and the claims, the words "comprise," "comprising," and the like are to be

construed in an inclusive sense, as opposed to an exclusive or exhaustive sense; that is to say, in the sense of "including, but not limited to." As used herein, the terms "connected," "coupled," or any variant thereof means any connection or coupling, either direct or indirect, between two or more elements; the coupling or connection
5 between the elements can be physical, logical, electromagnetic, or a combination thereof. Additionally, the words "herein," "above," "below," and words of similar import, when used in this application, refer to this application as a whole and not to any particular portions of this application. Where the context permits, words in the Detailed Description using the singular or plural number may also include the plural or singular
10 number respectively. The word "or," in reference to a list of two or more items, covers all of the following interpretations of the word: any of the items in the list, all of the items in the list, and any combination of the items in the list.

These and other changes can be made to the technology in light of the following detailed description. While the description describes certain examples of the
15 technology, and describes the best mode contemplated, no matter how detailed the description appears, the technology can be practiced in many ways. Details of the system may vary considerably in its specific implementation, while still being encompassed by the technology disclosed herein. As noted above, particular terminology used when describing certain features or aspects of the technology should
20 not be taken to imply that the terminology is being redefined herein to be restricted to any specific characteristics, features, or aspects of the technology with which that terminology is associated. In general, the terms used in the following claims should not be construed to limit the technology to the specific examples disclosed in the specification, unless the Detailed Description section explicitly defines such terms.
25 Accordingly, the actual scope of the technology encompasses not only the disclosed examples, but also all equivalent ways of practicing or implementing the technology under the claims.

Fig. 1 discloses examples of HVDC links based on VSC units.

A High Voltage DC link based on Voltage Source Converter technology,
30 i.e. a VSC-HVDC link, may be considered an electrical system in which and AC/DC and DC/AC energy conversion process is developed. Moreover, the VSC-HVDC link is comprised by DC cables, transformers, and VSC units which are utilized for interconnecting synchronous or asynchronous transmission networks. Furthermore, a

VSC-HVDC link can be classified from an AC side point of view, as a non-embedded, i.e. AC networks synchronously decoupled, or as an embedded, i.e. AC networks synchronously coupled, interconnector.

On the other hand, from a DC side point of view, VSC-HVDC links 1 can be classified as a point-to-point, PtP, or a multi-terminal, MT, DC network. These two types of DC side classifications can be further extended based on the possible configurations existing for VSC-HVDC links as for example.

A PtP DC network is shown in figure 1, the top side. The AC network A is indicated with reference numeral 2. The AC network B is indicated with reference numeral 3. Two VSCs are deployed, as indicated with reference numerals 4 and 5. The VSCs are connected to one another via HVDC cables 6.

An MT DC network is shown in figure 1, bottom side. The AC network is indicated with reference numeral 8. The AC network B is indicated with reference numeral 7. Four VSCs are deployed, as indicated with reference numerals 9, 10, 11 and 12. The VSCs are connected to one another via HVDC cables 13.

Independently of the classification utilized, the DC/AC or AC/DC energy conversion process in a HVDC link is basically carried out by the VSC units which have the role of generating the necessary DC and AC voltage waveforms in the corresponding DC or AC networks.

The generation of these DC and AC voltage waveforms in a VSC unit may be established by means of several control systems which are designed to regulate the power flow between the electrical networks, i.e. coupled by the HVDC link using cables, during energization, normal, and fault conditions.

The design and the adjustment of such control systems may be influenced by the electrical properties of the HVDC link and by the AC network characteristics of the coupled power systems. These characteristics and properties may usually be represented in a phasor's based or a differential-equations' based simulation environment, for example a phasor, also known as root-mean square -RMS- simplified representation of a detailed differential-algebraic equation based representation, or an instantaneous Waveform, also known as electromagnetic transient -EMT- representation of a detailed differential-algebraic equation based representation. Thus, the analysis of the energy conversion process may require the implementation of EMT or RMS models capable of expressing the interplay between

the AC and DC networks, from a dynamic response and a steady-state operational point of view.

The implementation of an EMT or RMS model of a VSC-HVDC link may represent the process of describing the mathematical relationships that govern the dynamic response of the currents and voltages defining the power transfer between the AC and DC networks.

Fig. 2 discloses a general description of an modular Multi-level Converter unit.

The basic elements that may constitute a VSC are mainly based on Modular Multi-level Converter, MMC technology.

As seen in figure 2, a VSC unit based on MMC technology may be formed by several reactors, for example six reactors, *LMMC*, and several structures, for example six structures, called valves which may be comprised of tens or hundreds of sub-modules. Within each of these sub-modules, an arrangement of semiconductors, typically IGBTs, may be managed in order to control the moment in which the sub-module's capacitor C is excluded or inserted into the corresponding, internal, current loop, i.e. i_{up} or i_{low} .

It may be pointed out that the i_{up} or i_{low} currents are comprised by DC and AC components which simultaneously flow within the VSC/MMC unit, i.e. DC and AC currents simultaneously flow through the inserted capacitors within the valves.

In essence, the insertions or the exclusions of the capacitors within a single valve may be a consequence of two regulation processes. The first, i.e. outer, regulation process may define the number of capacitors that may need to be inserted in order to produce the desired voltage waveform across the corresponding valve, e.g. $v (+)_{valvex}$. The first regulation process may be developed by considering that the second, i.e. inner, regulation process, referred to as capacitor voltage balancing is properly executed.

The second, i.e. inner, regulation process may determine and define which of the capacitors are to be inserted/excluded in order to maintain the same voltage level across all the capacitors within the same valve, at all times.

The successful development of the capacitor voltage balancing, i.e. the second regulation process, allows managing the VSC/MMC unit as a power electronic

device where a series of identical time-variant voltage sources, located within each valve, are inserted between the DC and AC networks.

Fig. 3 discloses a general description 201 of the control layers of an VSC/MMC unit.

5 The control system's modelling of a MMC unit can be divided in two main sections, i.e. control layers, which are presented in Figure 3. Each of these two sections, i.e. upper 202 and the lower-level control layers 203, may be formed by several control blocks having specific regulation targets.

10 For instance, the lower-level control layer 203 may generate the IGBT switching pulses for directly inserting/excluding the submodules' 206 capacitors based on the capacitor voltage balancing described above.

15 Furthermore, the upper-level control layer 202 may be divided in two parts, the non-island control block 204, and the island control block 205. The island control block 205 is typically utilized when an HVDC converter should self-generate the three-phase AC voltage waveform serving as the voltage reference for those networks mainly consisting of power electronic interfaced generation units, for example an offshore wind farm.

20 On the other hand, the non-island control block 204 may be used in those HVDC converters which are connected to power systems where, the three-phase AC voltage waveform, for example voltage reference, is already established. Thus, in the non-island control block 204, a current-based power control method may be utilized by the VSC/MMC unit, considering several mathematical formulations which give a geometrical perspective to the energy conversion process.

25 Fig. 4 discloses a generation structure 301 of an inner control block as shown in figure 3.

 The structure of the such an inner control block may be based on PI regulators which are calibrated to define the currents' time responses, for i_D and i_Q , considering a short millisecond time-frame, for example around 20ms.

30 The calibration of the PI regulators of the current controllers is referred to the adjustment of their control gains, i.e. K_{PD} , T_{ID} , K_{PQ} , and T_{IQ} . This is not further elucidated in detail in this particular disclosure.

 Fig. 5 disclose basic examples 401 of control modes conforming the outer control block.

The current controllers for i_D and i_Q belong to the Inner Control block which receives the corresponding current references values, that is $i * gDOuter$ and $i * gQOuter$, from the Outer Control block presented in Figure 4. As shown in Figure 5, the Outer Control block may be composed, in a VSC unit operating within a PtP-HVDC link, by four control modes which are responsible of managing the AC voltage level, i.e. $UACCtrl$, the DC voltage level, i.e. $VdcCtrl$, the reactive power level, i.e. $QCtrl$, and the active power level, i.e. $PCtrl$, provided by the converter, i.e. VSC unit.

Similarly to Inner Control block as described above, the control modes within the Outer Control block may utilize dedicated PI regulators which are meant to establish the dynamic responses of the corresponding variables, e.g. ug , Vdc , q , or p , based on AC network requirements and the physical characteristics of the DC network.

Fig. 6 discloses an HVDC link 501 comprising a communication topology in accordance with the present disclosure.

The HVDC link 501 comprises "Network A", "Network B", "VSC A", "VSC B" and the HVDC cables connecting "VSC A" to "VSC B".

The circulating currents i_{circx} of a converter unit, VSC, may be described as the electrical currents that are flowing at each branch of the DC circuit shown associated with the VSC/MMC shown in figure 2. Additionally, i_{circx} is formed by the combination of a third of the DC current, i.e. i_{dc} , i.e. three branches, and a harmonic, balanced, current, i.e. i_{hbalx} , as shown in the equation provided above. The additional term i_{HAMx} provided below represents a harmonic amplitude modulated current, i.e. i_{HAMx} , which is not cancelled at the DC buses, i.e. DC side black dots.

$$i_{ccx} = \frac{i_{dc}}{3} + i_{hbalx} + \frac{i_{HAMx}}{3}$$

This means that the first and the third terms presented in the right side of the above provided equation are introduced within the DC cables of the non-embedded HVDC link shown in figure 6. The introduction of a Harmonic-Amplitude Modulation, HAM, current is developed as a way of transmitting a signal, through the HVDC cables, carrying out the necessary data suitable for adjusting the active power reference of the HVDC link.

This adjustment is designed to be executed when a power unbalance event jeopardize the frequency profile in Network A shown in figure 6. Furthermore,

the signal transmission process is developed under the assumption that a dedicated communication channel, e.g. fiber optic cable, is not available at the HVDC link shown in figure 6.

The present disclosure describes the introduction of harmonic currents within HVDC cables enabling the transmission process of data between HVDC converter stations, VSCs, based on modular multi-level technology by means of two control systems.

These two control systems are in charge of detecting / receiving and generating / sending the harmonic signal having the adjustment of the active power reference of the HVDC link. Consequently, the details of the control structures regarding the harmonic generation system, HGS, and the harmonic detection system, HDS, shown in figure 6 are further elaborated here below.

Fig. 7 discloses an example of a Harmonic Generation System 601 in accordance with the present disclosure.

The generation of the harmonic signal into the HVDC cables may be developed by the HGS block 601. In short, a PLL system of VSC A, i.e. the rectifier VSC station, may be utilized for providing the input signal, i.e. the measured electrical frequency of the Network A, for the HGS block.

The input signal may be related to the frequency offset of the power signal in Network A. That is, the actual frequency of the power signal in Network A minus the set reference of the frequency of the power signal in Network A.

The electrical frequency Δf_A signal may then be passed through a deadband block and a proportional gain K which amplifies such a Network A signal. The amplified Δf_A signal is sent to detector blocks that may be used to identify if the nature of the frequency disturbance corresponds to an over-frequency or an under-frequency issue.

The identification process in the detectors blocks is carried out by determining the properties, i.e. positive or negative sign, of the amplified Δf_A signal. If the Δf_A signal is positive, the output of the Under-frequency Detector block will be automatically set to zero and the output of the Over-frequency Detector block will be equal to the amplified Δf_A signal. On the other hand, if the Δf_A signal is negative the output of the Over-frequency Detector block will be automatically set to zero and the

output of the Under-frequency Detector block will be equal to the amplified Δf_A signal. Thus, the signal V_{dcHAM} may be represented by:

$$v_{dcHAM} = K\Delta f_A(t)\sin(2\pi HOVt)$$

5 The V_{dcHAM} signal depends on the harmonic oscillatory values, HOV_{under} or HOV_{over} , generated by the oscillatory blocks shown in figure 7, which means that the nature of the frequency disturbance occurring at Network A is directly reflected in the harmonic frequency of V_{dcHAM} .

On the other hand, the amplitude of the harmonic V_{dcHAM} signal is defined
10 by the amplification factor K and the severity of the power unbalance affecting Δf_A . Thus, it is shown that the generated V_{dcHAM} signal simultaneously contains the information regarding the level of frequency deviation, i.e. amplitude of V_{dcHAM} , and the over or under-frequency nature, HOV of V_{dcHAM} , of the disturbance occurring at Network A.

15 It is noted that Δf_A essentially modulates the amplitude of the harmonic V_{dcHAM} signal as well as the K proportional factor. However, the selection of the K value may need to be considered to prevent unwanted instabilities across the HVDC network.

20 These instabilities can be prevented by adjusting the HGS' parameters based on a frequency domain, i.e. harmonic stability or selective modal, analysis or a time domain-based sensitivity study to ensure a stable response of the HVDC network.

The selection of the HOVs utilized by V_{dcHAM} is another aspect that may need to be considered to prevent a detrimental of the efficiency and/or the power balance of the modular multilevel based VSC unit.

25 The efficiency, for example internal losses, of a MMC based VSC unit may be regulated through the utilization of a double frequency park's transformation for reducing the double frequency (harmonic) component in icc .

Consequently, the HOVs utilized for the i_{HAMx} current within $iccx$ may be considerably lower, for example at least five times, than the double frequency
30 component associated to $ihbalx$.

This HOV consideration may be needed in order to reduce the influence of the introduction of the harmonic i_{HAM} current over the CCSC performance in the VSC unit avoiding in that way the efficiency detrimental of the VSC unit. Thus, the K

and HOV parameters utilized to the HGS block may be defined as presented below. Finally, once the harmonic V_{dcHAM} signal is generated, it's transmitted to the $DCCtrl$ to influence the DC voltage profile at the rectifier station, i.e. VSC A unit shown in Figure 6.

Parameters	Units
K	1,25 pu
HOV_{under}	5 Hz
HOV_{over}	20 Hz

Once the harmonic $iHAM$ current flows through the HVDC cables of Figure 6, the modification of the active power reference at the inverter, $PCtrl$ mode, VSC unit may be carried out in two steps. The first step represents the detection, i.e. amplification, at the inverter unit of the introduced harmonic signal, and the second step is referred to the processing of the information contained within the harmonic signal.

Fig. 8 discloses an example 701 of a Harmonic Detection System in accordance with the present disclosure.

In the first step of the HDS 701, the methodology for detecting the harmonic signal within the HVDC cable may be based on a control system specifically designed to amplify those harmonic signals generated by HGS.

As shown in the upper side of figure 8, the first section of the amplification loop of HDS may be referred to the measurement of the DC voltage level, i.e. V_{dcmeas} , at the inverter, $PCtrl$ mode, VSC unit. Next, a high pass filter may be utilized, i.e. $G_{dc}(s)$, to get rid of the constant component, associated to the DC voltage measurement, keeping in that way the harmonic content presents in the measured signal. The structure of the $G_{dc}(s)$ block may be based on a filter differentiator as presented here below and defined by the parameters K_{dc} and T_{dc} .

$$G_{dc}(s) = \frac{K_{dc}s}{1 + T_{dc}s}$$

Furthermore, the harmonic content, previously filtered by $G_{dc}(s)$, may then pass through a deadband block to reduce the undesired harmonic components present in the harmonic signal measured.

This reduction may be based on the assumption than the harmonic i_{HAM} current generates the highest harmonic voltage component measured by V_{dcmeas} in figure 8.

Later, an additional block, i.e. $GSORC$, may be utilized to filter out the signal sent by the deadband block. Basically, the $GSORC$ block may contain two inverse notch filters working as second order resonant controllers which are setup to exclusively and individually amplify the $HOVs$ generated by HGS. This means that the output of the $GSORC$ block represents a signals' vector having an individual loop (path) for each harmonic signal, i.e. one loop for the HOV_{under} signal and another loop for the HOV_{over} signal.

The AC networks can be connected through embedded or non-embedded PtP-VSC-HVDC links. Synchronously coupled AC networks can sometimes suffer an extreme power unbalance producing a network split event, i.e. permanent loss of their synchronous coupling. In this connection, this section develops a frequency support strategy for embedded PtP-VSC-HVDC links operating within AC networks having a network split, i.e. synchronous decoupling, event.

The strategy for developing the network support during frequency splits events is based on the addition of two control blocks named Generic Frequency Control, GFC, and a synchronous Coupling Detector, SCD. This is shown by the example 801 provided in figure 9.

The frequency measurement of Network B, i.e. Δf_B , may be developed by PLL_B and given to the GFC block which is based on the generic frequency control scheme, for PtP-VSC-HVDC links.. In short, the GFC may generate the adjustment of the active power level transmitted by the PtP-VSC-HVDC link based on Δf_B signal's value.

In an embedded PtP-VSC-HVDC link, Δf_A and Δf_B in Figure 9 may be identical, i.e. during normal operation conditions, because of the synchronous coupling existing between Network A and Network B. However, during an AC Network split event, it may be expected that Δf_A and Δf_B are fundamentally different.

Consequently, during an AC Network split event, the GFC block and the HDS block may simultaneously produce the corresponding signals for adjusting of the active power level of the PtP-VSC-HVDC link.

Therefore, the Synchronous Coupling Detector, SCD, block presented in figure 9 is introduced to generate the active power modification of the PtP-VSC-HVDC link based on the output signals provided by generic frequency control, GFC, block and the harmonic detection system, HDS, block.

Basically, the SCD develops a comparative process between the output signals provided by the GFC and HDS blocks where all the possible states of Δf_A and Δf_B are shown in the table provided below. This table is developed under the assumption that the DC power in the PtP-VSC-HVDC link, shown in figure 9, flows from the rectifier station, *VdcCtrl*, to the inverter station, *PCtrl*.

Variables & Cases	Possible States of Δf_A and Δf_B							
	A	B	C	D	E	F	G	H
Δf_A (HDS)	+	+	-	-	0	0	+	-
Δf_B (GFC)	+	-	+	-	+	-	0	0
ΔP	0	↑	↓	0	↓	↑	↑	↓

To reduce the number of claims, certain aspects of the technology are presented below in certain claim forms, but the applicant contemplates the various aspects of the technology in any number of claim forms. For example, while some aspect of the technology may be recited as a computer-readable medium claim, other aspects may likewise be embodied as a computer-readable medium claim, or in other forms, such as being embodied in a means-plus-function claim.

In the description above, for the purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of implementations of the disclosed technology. It will be apparent, however, to one skilled in the art that embodiments of the disclosed technology may be practiced without some of these specific details.

Other 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. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or

“an” does not exclude a plurality. 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. Any reference signs in the claims should not be construed as limiting the scope thereof

CLAIMS

1. A transmitting control unit arranged for controlling a Voltage Source Converter, VSC, of a VSC-High Voltage Direct Current, HVDC, network, such that said VSC induces a communication signal into HVDC cables comprised by said HVDC network for transporting DC power, said communication signal being representative for power imbalance at an Alternating Current, AC, network arranged to be connected to said VSC, said transmitting control unit comprising:

- a frequency detection unit arranged for determining a frequency offset of a frequency of an output of said AC network with a predetermined reference frequency;

- a communication signal generation unit arranged for generating said communication signal, wherein said communication signal generation unit is arranged for:

- generating said communication signal as a harmonic oscillatory signal having a first frequency in case said determined frequency offset is positive;

- generating said communication signal as a harmonic oscillatory signal having a second frequency in case said determined frequency offset is negative;

wherein said first frequency differs from said second frequency;

- a control block arranged for inserting said communication signal into said HVDC cables by controlling said VSC based on said generated communication signal.

2. A transmitting control unit in accordance with claim 1, wherein said communication signal generation unit is further arranged for modulating an amplitude of said harmonic oscillatory signal based on a magnitude of said frequency offset.

3. A transmitting control unit in accordance with claim 2, wherein said communication signal generation unit is arranged to multiple said harmonic oscillatory signal with said determined frequency offset and with a gain factor k .

4. A transmitting control unit in accordance with any of the previous claims, wherein said communication signal generation unit comprises a deadband block, wherein said determined frequency offset is provided to said deadband block as an input, and wherein an output of said deadband block provides for a frequency offset
5 with a deadband in which deadband a band of input values translate to zero in an output of said deadband block.

5. A transmitting control unit in accordance with any of the previous claims, and at least comprising claim 3, wherein said communication signal generation unit is
10 arranged to generate said communication signal by:

$$V = K \Delta f(t) \sin(2\pi HOVt),$$

Wherein V is said communication signal, K is said gain factor, $\Delta f(t)$ is said determined frequency offset, t is time and HOV is said harmonic oscillator signal.

6. A receiving control unit arranged for controlling a Voltage Source Converter, VSC, of a VSC-High Voltage Direct Current, HVDC, network, such that said VSC is able to receive a communication signal induced on HVDC cables comprised by said HVDC network for transporting DC power, said communication signal being representative for power imbalance at an Alternating Current, AC, network arranged
20 to be connected to a further VSC of said HVDC network, said receiving control unit comprising:

- a voltage measurement unit arranged for measuring a voltage on said HVDC cables;
- a detection system arranged for detecting said communication
25 signal being a harmonic oscillatory signal present in said measured voltage
- a control block arranged for controlling said VSC based on said detected communication signal,

wherein said harmonic oscillatory signal may have a first frequency representative for over-generation of power at said AC network and may have a
30 second frequency, different to said first frequency, representative for under-generation of power at said AC network, wherein said detection system is arranged for detecting a frequency of said harmonic oscillatory signal, being said first or said second

frequency, and wherein said control block is arranged for controlling said VSC based on said detected frequency, being said first or said second frequency.

7. A receiving control unit in accordance with claim 6, wherein said detection system further comprises:

- a filter for filtering said measured voltage on said HVDC cables.

8. A receiving control unit in accordance with any of the claims 6 – 7, wherein said detection system further comprises:

- a rectifier block for rectifying said measured voltage.

9. A receiving control unit in accordance with any of the claims 6 - 8, wherein an amplitude of said harmonic oscillatory signal is representative for a magnitude of said power imbalance at said AC network, wherein said detection system is further arranged for determining said magnitude of said harmonic oscillatory signal, and wherein said control block is further arranged for controlling said VSC based on said determined magnitude of said harmonic oscillatory signal.

10. A method of operating a transmitting control unit in accordance with any of the claims 1 – 5, wherein said method comprises the steps of:

- determining, by said frequency detection unit, said frequency offset of said frequency of said output of said AC network with said predetermined reference frequency;

- generating, by said communication signal generation unit, said communication signal by:

- generating said communication signal as a harmonic oscillatory signal having a first frequency in case said determined frequency offset is positive;

- generating said communication signal as a harmonic oscillatory signal having a second frequency in case said determined frequency offset is negative;

wherein said first frequency differs from said second frequency;

- inserting, by said control block, said communication signal into said HVDC cables by controlling said VSC based on said generated communication signal.

5 11. A method in accordance with claim 10, wherein said method comprises the step of:

- modulating, by said communication signal generation unit, an amplitude of said harmonic oscillatory signal based on a magnitude of said frequency offset.

10

12. A method in accordance with claim 11, wherein said method comprises the step of:

- multiply, by said communication signal generation unit, said harmonic oscillatory signal with said determined frequency offset and with a gain factor k.

15

13. A method of operating a receiving control unit in accordance with any of the claims 6 – 9, wherein said method comprises the steps of:

20 - measuring, by said voltage measurement unit, said voltage on said HVDC cables;

- detecting, by said detection system, said communication signal being a harmonic oscillatory signal present in said measured voltage;

- controlling, by said control block, said VSC based on said detected communication signal,

25 wherein said harmonic oscillatory signal may have a first frequency representative for over-generation of power at said AC network and may have a second frequency, different to said first frequency, representative for under-generation of power at said AC network, wherein said method comprises the steps of:

30 - detecting, by said detection system, a frequency of said harmonic oscillatory signal, being said first or said second frequency, and

- controlling, by said control block, said VSC based on said detected frequency, being said first or said second frequency.

14. A method in accordance with claim 13, wherein an amplitude of said harmonic oscillatory signal is representative for a magnitude of said power imbalance at said AC network, wherein said method further comprises the step of:

- determining, by said detection system, said magnitude of said harmonic oscillatory signal, and
- controlling, by said control block, said VSC based on said determined magnitude of said harmonic oscillatory signal.

15. A High Voltage Direct Current, HVDC, network comprising two Voltage Source Converters, VSCs, and HVDC cabled connecting those two VSCs to one another, wherein said HVDC comprises:

- a transmitting control unit in accordance with any of the claims 1-5 and arranged for controlling a first of said two VSCs;
- a receiving control unit in accordance with any of the claims 6 – 9 and arranged for controlling a second of said two VSCs.

16. A computer program product comprising a computer readable medium having instructions stored thereon which, when executed by a control unit, cause said control unit to implement a method in accordance with any of the claims 10 – 14.

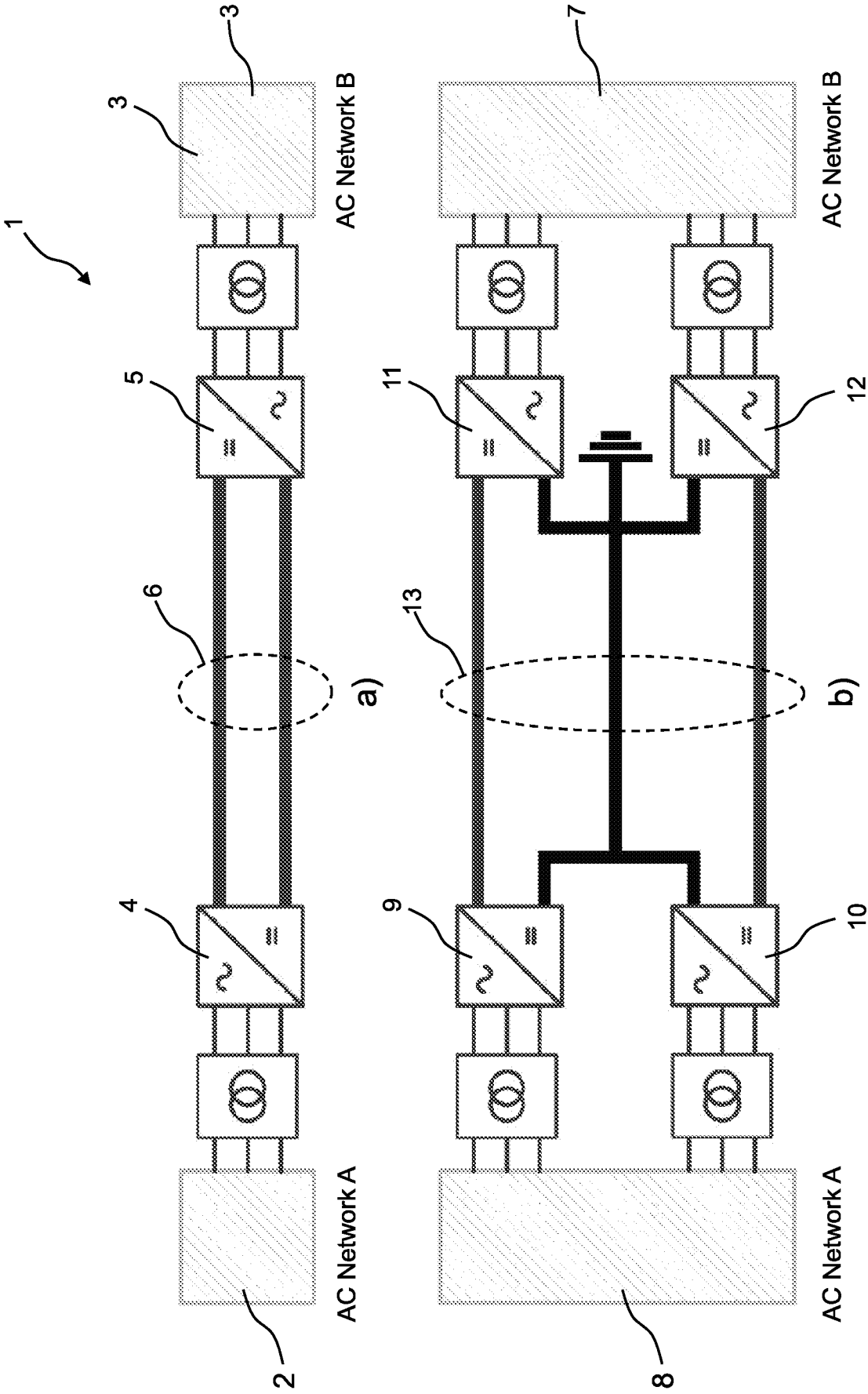


Fig. 1

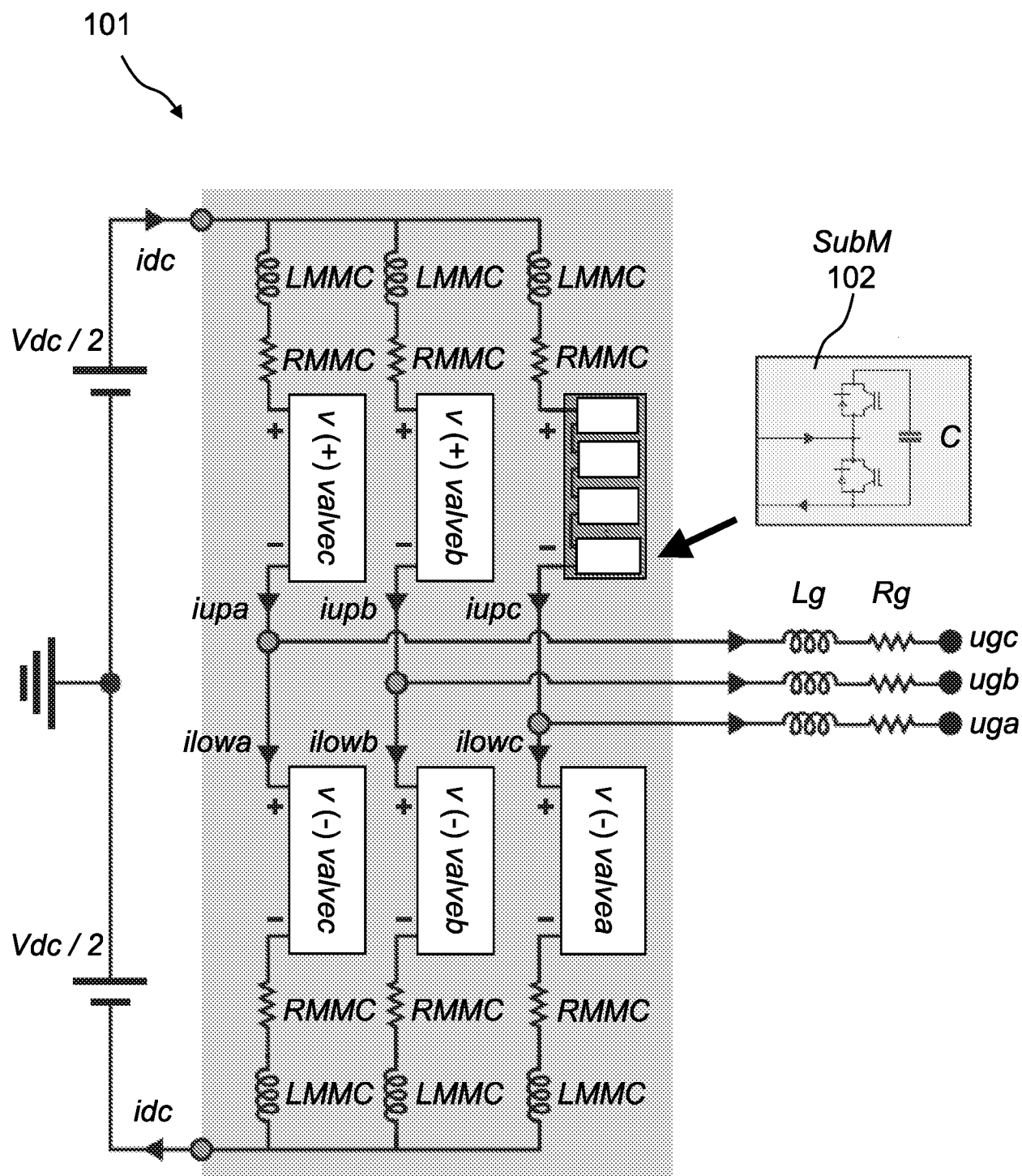


Fig. 2

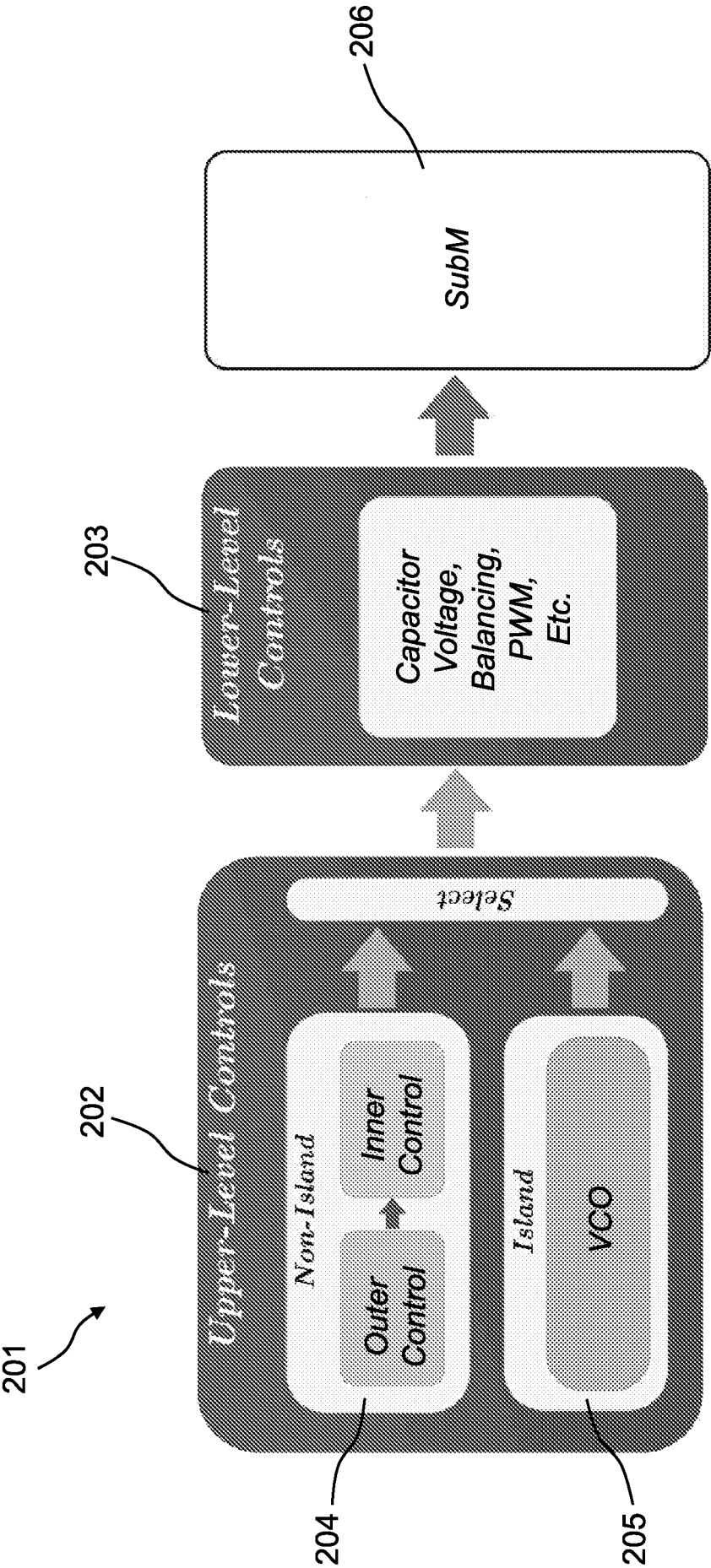


Fig. 3

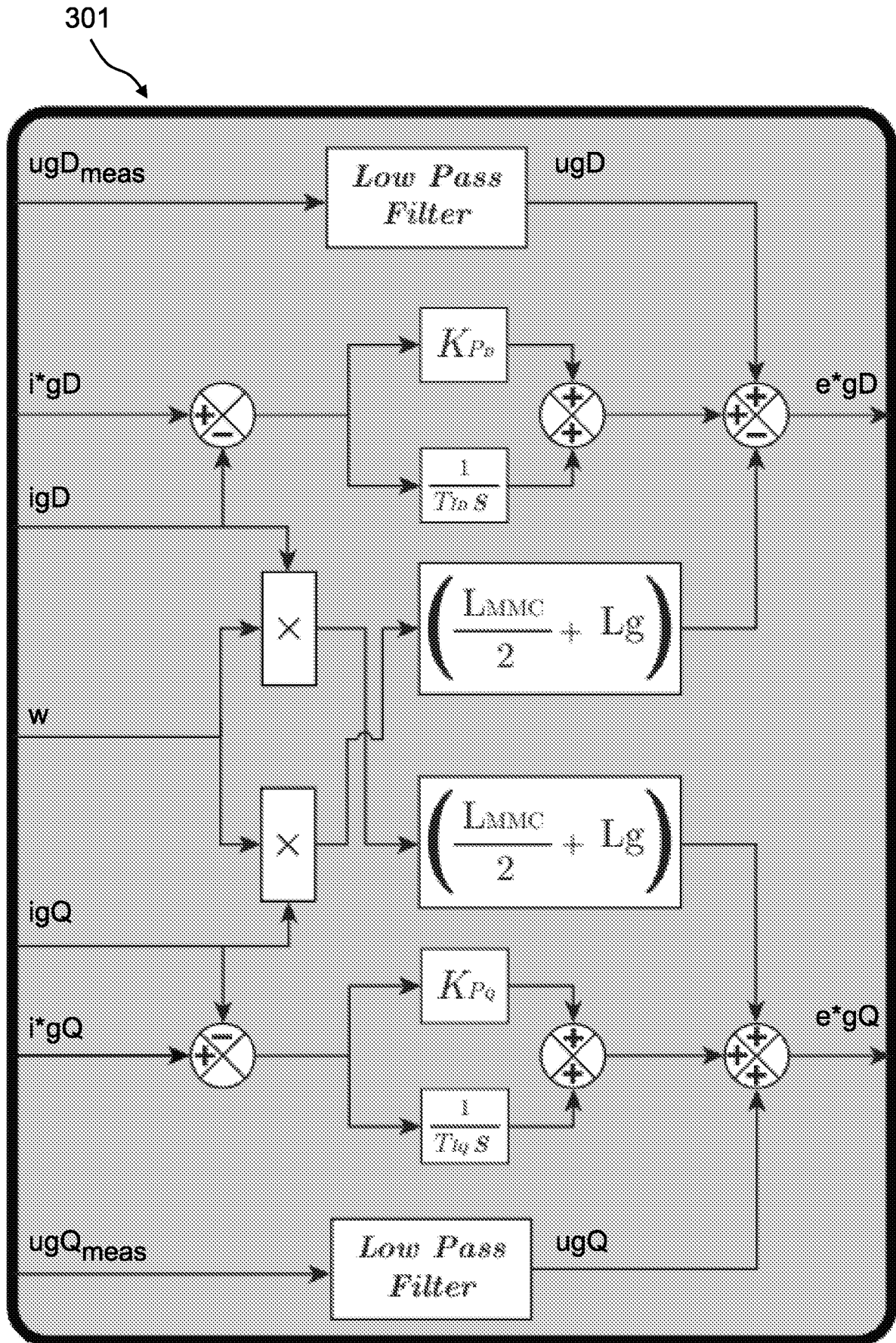


Fig. 4

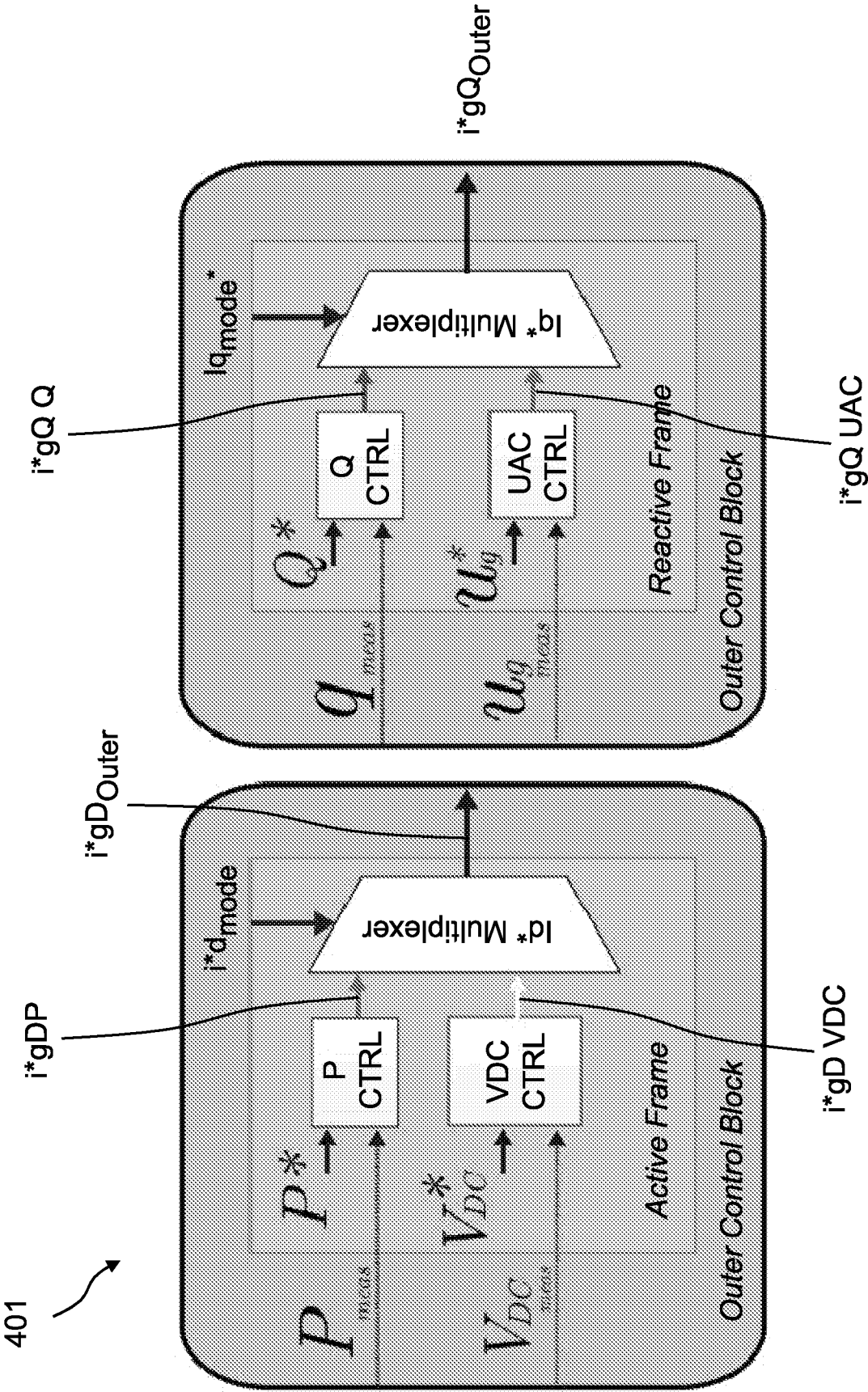


Fig. 5

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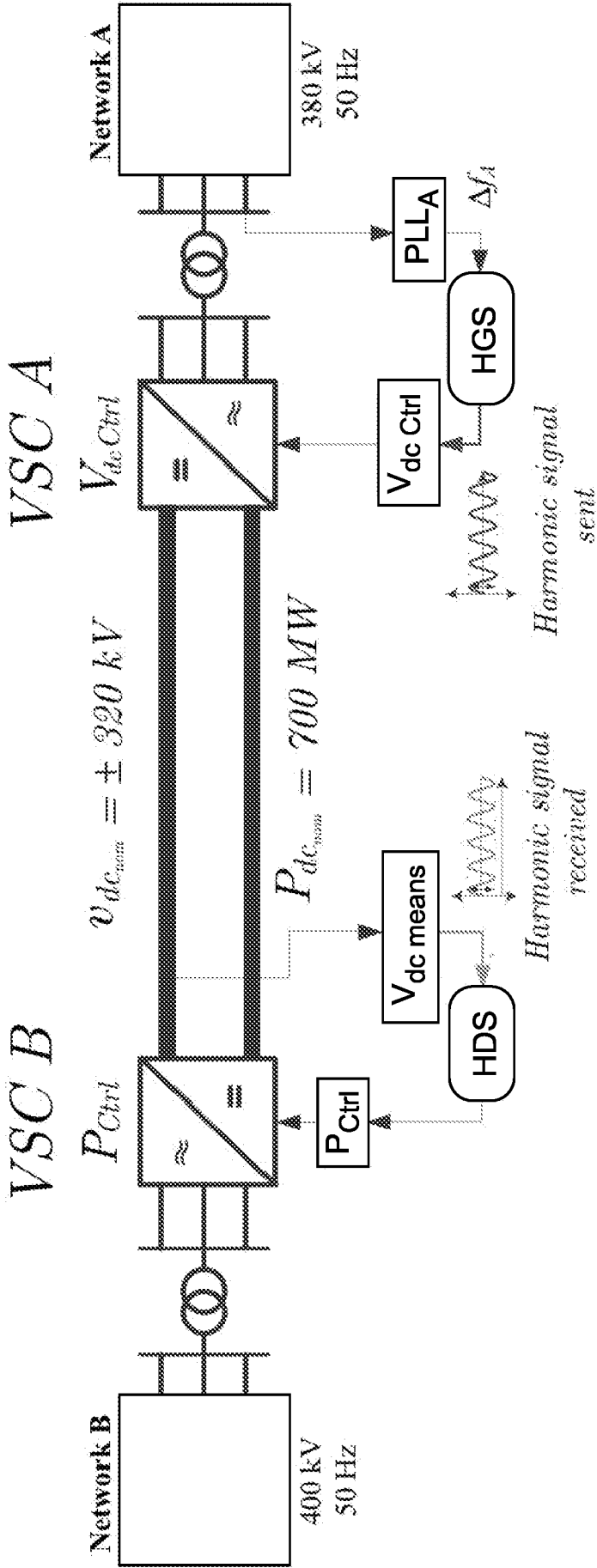


Fig. 6

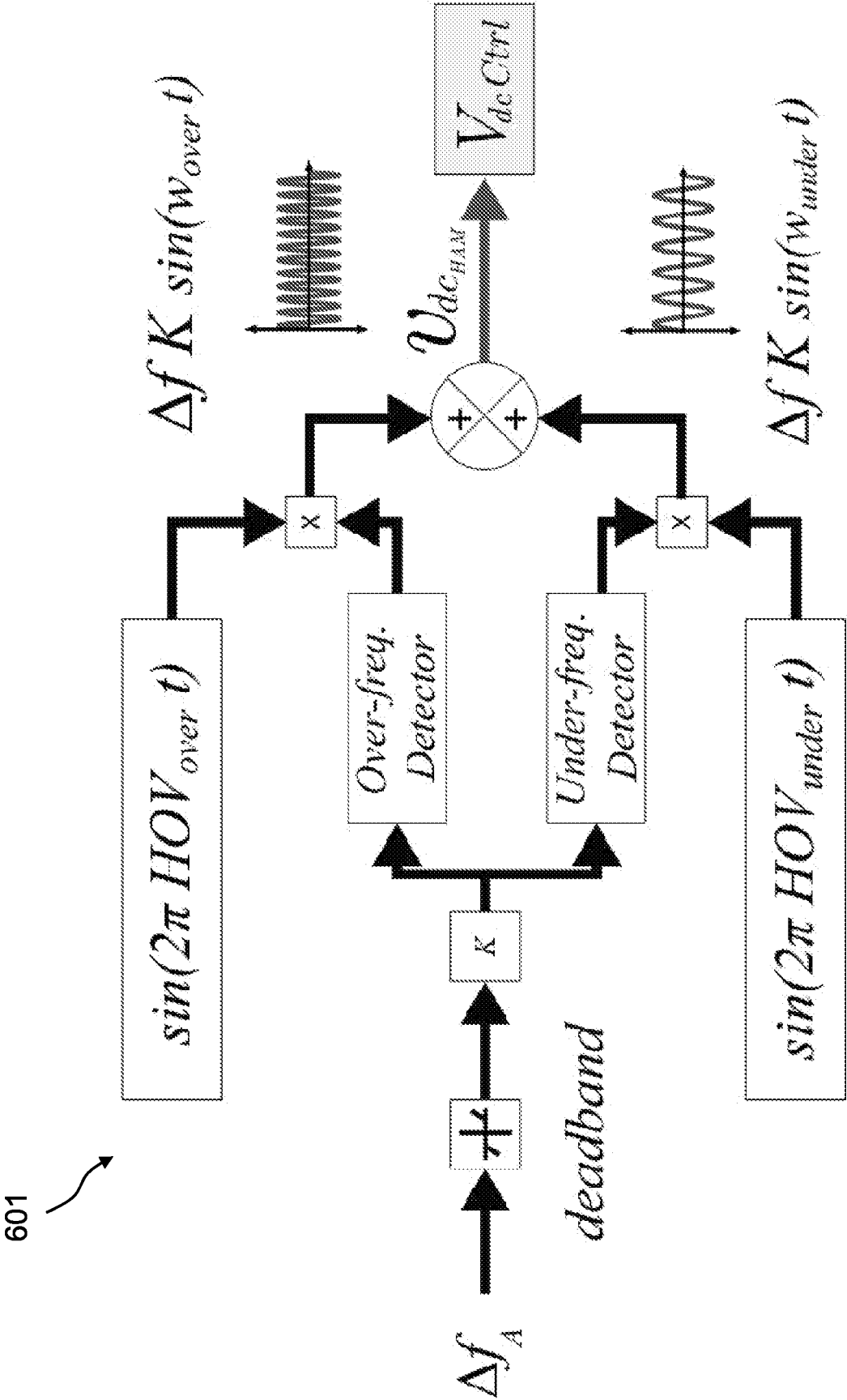


Fig. 7

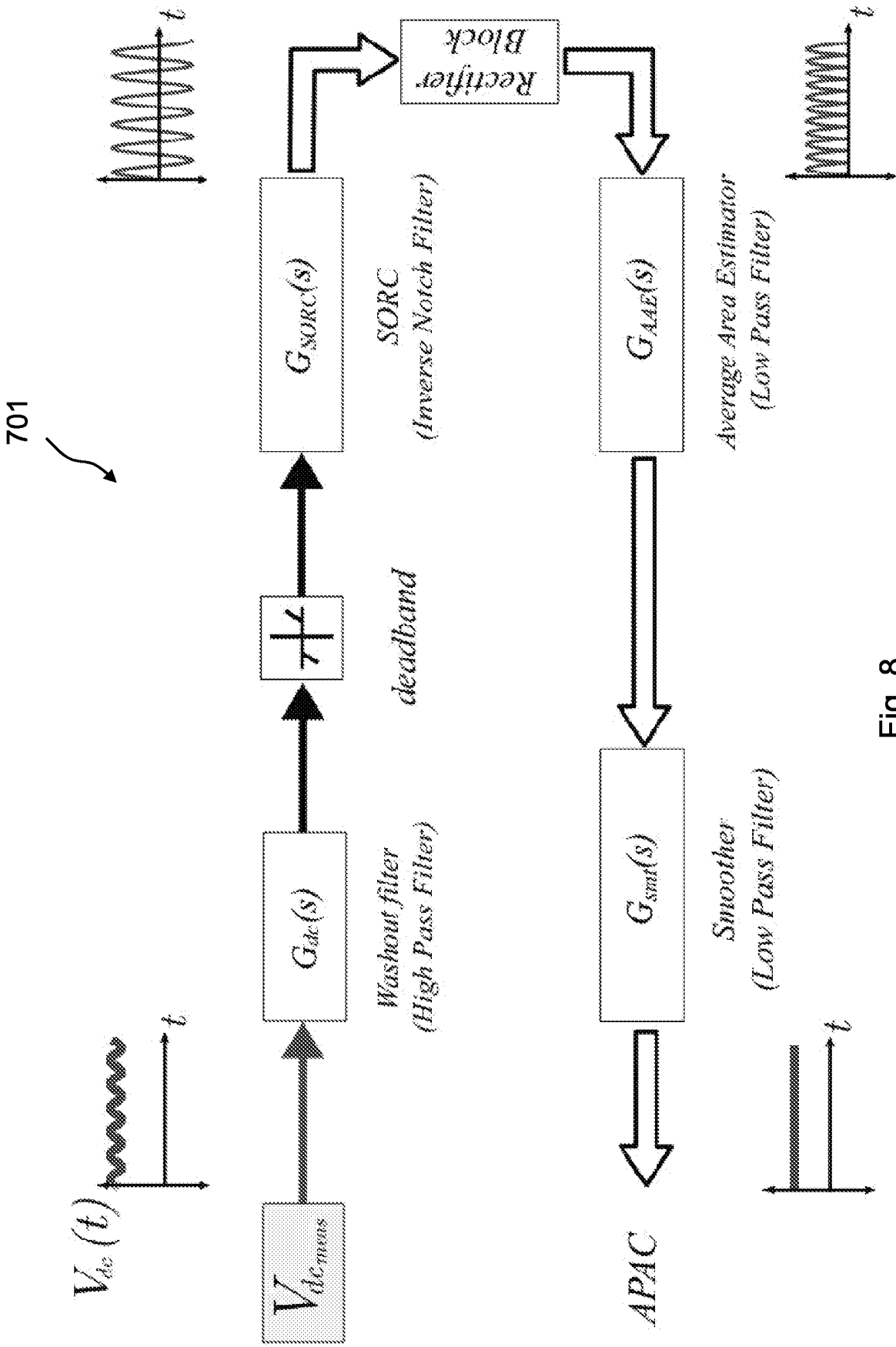


Fig. 8

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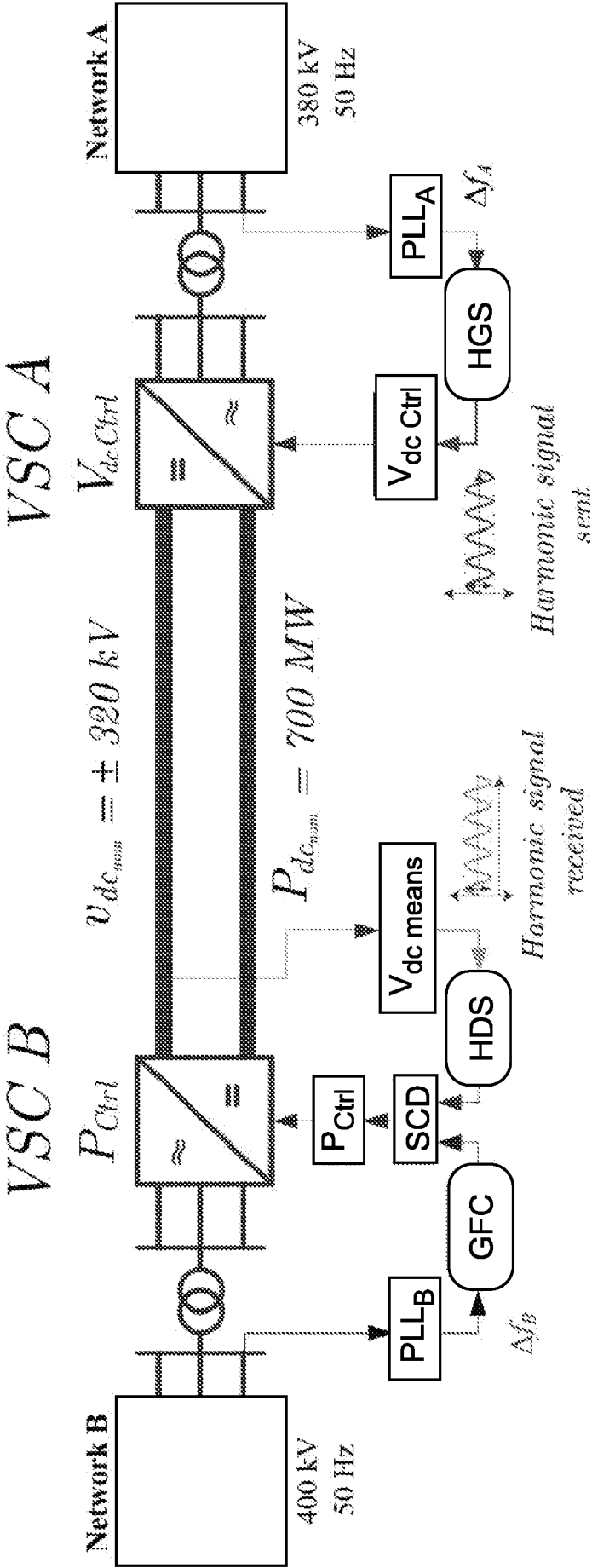


Fig. 9

INTERNATIONAL SEARCH REPORT

International application No

PCT/NL2024/050141

A. CLASSIFICATION OF SUBJECT MATTER

INV. H02J3/36 H02J13/00
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

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, WPI Data**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 3 843 231 A1 (GENERAL ELECTRIC TECHNOLOGY GMBH [CH]) 30 June 2021 (2021-06-30) figures 1-8 paragraphs [0001], [0003], [0007], [0016], [0023], [0027] - [0032], [0033], [0037] -----	1 - 16
A	EP 2 768 105 A1 (GEN ELECTRIC [US]) 20 August 2014 (2014-08-20) figure 1 paragraphs [0001], [0003], [0005], [0015], [0016], [0020] -----	1 - 16



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search

26 July 2024

Date of mailing of the international search report

07/08/2024

Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/NL2024/050141

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
EP 3843231	A1	30-06-2021	EP 3843231 A1	30-06-2021
			US 2023028868 A1	26-01-2023
			WO 2021130317 A1	01-07-2021

EP 2768105	A1	20-08-2014	BR 102013032167 A2	08-12-2015
			CA 2836097 A1	19-08-2014
			CN 103997032 A	20-08-2014
			EP 2768105 A1	20-08-2014
			US 2014233277 A1	21-08-2014
