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(54) **Title:** ENERGY-CONVERSION APPARATUS OF A DC-DC TYPE OPERATING BETWEEN A LOW-VOLTAGE SYSTEM AND A HIGH-VOLTAGE SYSTEM OF A VEHICLE COMPRISING AN ENERGY-RECOVERY STAGE, AND CORRESPONDING METHOD

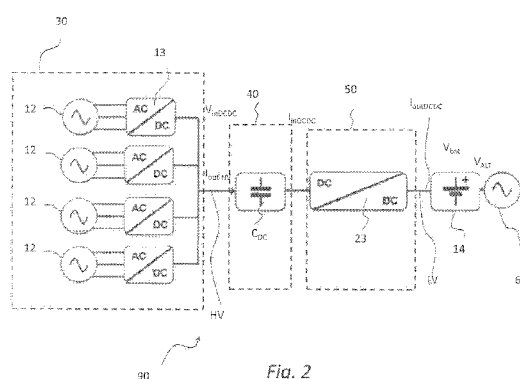


Fig. 2

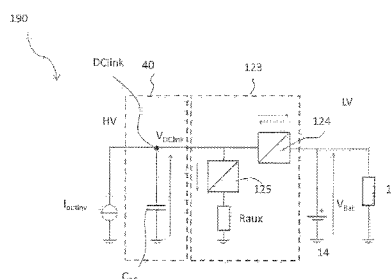


Fig. 3

(57) **Abstract:** An energy-conversion apparatus of a DC-DC type operating between a low-voltage system (LV) and a high-voltage system (HV) of a vehicle comprising an energy-recovery stage (30), said low-voltage system (LV), which operates at a first voltage (V_{bat}), comprising a battery (14) that supplies said first voltage (V_{bat}) on a low-voltage bus (LV), said high-voltage system (HV), which operates at a second voltage (V_{inDCDC} , V_{DCLink}) higher than said first voltage (V_{bat}), comprising said energy-recovery stage (30) of the vehicle that supplies said second voltage (V_{inDCDC} , V_{DCLink}), said second voltage (V_{inDCDC} , V_{DCLink}) being supplied through an intermediate energy-storage system (40) to a DC-DC conversion module (23; 123), which converts said second voltage (V_{inDCDC}).



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V_{DClink}) into said first voltage (V_{bat}) for said low-voltage bus (LV), said apparatus (90; 190) comprising an auxiliary load (R_{aux}), in particular an external load, which can be connected in order to enable dissipation of the excess energy supplied by the energy-recovery system (30). Said DC-DC conversion module (123) comprises a first bidirectional DC-DC converter (124) connected between the intermediate energy-storage stage (40) and the vehicle battery (14), and a second DC-DC converter (125) connected between the intermediate energy-storage stage (40) and said auxiliary load (R_{aux}).

ENERGY-CONVERSION APPARATUS OF A DC-DC TYPE OPERATING BETWEEN A
LOW-VOLTAGE SYSTEM AND A HIGH-VOLTAGE SYSTEM OF A VEHICLE COMPRISING
AN ENERGY-RECOVERY STAGE, AND CORRESPONDING METHOD

5

TEXT OF THE DESCRIPTION

The present invention relates to an apparatus and a method for energy conversion of a DC-DC type, in particular bidirectional conversion, operating between
10 a low-voltage system and a high-voltage system of a vehicle comprising an energy-recovery stage, said low-voltage system, which operates at a first voltage, comprising a battery that supplies said first voltage on a low-voltage bus, said high-voltage system, which
15 operates at a second voltage higher than said first voltage, comprising said energy-recovery stage of the vehicle that supplies said second voltage, said second voltage being supplied through an intermediate energy-storage system to a bidirectional DC-DC conversion
20 module, which converts said second voltage into said first voltage for said low-voltage bus.

In the automotive field, energy-recovery systems are known. In particular, energy-recovery systems are known that use regenerative shock absorbers, which
25 convert movements of the shock absorber into electrical energy.

In this context, for example, of particular interest from the standpoint of efficiency of conversion are regenerative shock absorbers that
30 envisage a conversion of the linear motion of the stem into a rotary motion of the shaft of an electric generator from which it is hence possible to recover in the form of electricity the energy that would otherwise be dissipated in heat. It is known to carry out this
35 conversion using mechanical or hydraulic means in such

a way that the rotation of the shaft of the electric generator will occur always in the same direction of rotation, irrespective of the direction of the velocity of the stem. This enables a higher efficiency of energy conversion, from kinetic to electrical energy. The electric generator is usually a DC generator which supplies a DC voltage at output. If, instead, a synchronous generator is used, an inverter is employed. In either case, it is anyway necessary to use a DC-DC converter to match the output voltage of the electric generator to the battery of the vehicle, in particular a motor vehicle.

It is likewise known to use a stage for conversion from high voltage to low voltage, specifically a DC-DC converter that is controlled in output voltage, to be matched to the battery voltage, in a way similar to the regulator of an alternator.

Illustrated in Figure 1 is a diagram representing an electro-mechanical model of a known energy-recovery apparatus, designated as a whole by the reference number 10. Designated by 11 is a shaft of an electric generator 12, associated to which are an angular velocity ω and a torque τ . R_{og} denotes the output resistance of the electric generator 12, for example a DC generator, whereas R_e denotes the equivalent resistance of the circuits of the portion of apparatus downstream of the electric generator 12, i.e., the resistance seen by the electric generator 12, the equivalent resistance R_e being regulated, for example, by the aforementioned inverter. Denoted by V_{og} is the loadless voltage of the electric generator 12, denoted by I_g is the current of the generator 12, and denoted by V_{inDCDC} is the voltage that is set up on the equivalent resistance R_e .

Consequently, from what has been discussed so far,

it follows that it is possible to control damping of the shock absorber by acting on the equivalent resistance R_e seen by the electric generator 12, but the fact of having to act on the equivalent resistance R_e to control damping renders it, however, impossible to operate, as in other energy-harvesting systems, by matching the impedance seen by the generator, which, in particular, depends upon the inverter, to the output impedance of the electric generator 12 in order to maximize power transfer.

Illustrated in Figure 2 is a conversion apparatus designated as a whole by the reference number 90.

The above conversion apparatus 90 comprises an energy-recovery stage 30, which includes a plurality of regenerative shock absorbers 12, in particular four regenerative shock absorbers, associated to respective DC-DC converters in the form of inverters 13, the outputs of which are gathered in a single output node of the energy-recovery stage 30.

The output node of the energy-recovery stage 30 basically corresponds to a high-voltage bus HV, set up on which are a voltage V_{inDCDC} , which is the voltage on the DC side of the inverter 13 and an output current from the inverter I_{outINV} , which is the sum of the four currents at output from the inverters 13. The voltage V_{inDCDC} of the high-voltage bus HV is sent to the input of a high-voltage-to-low-voltage conversion stage 50, which in the example comprises a DC-DC converter 23, set in parallel on the input of which is a storage element, i.e., a capacitance, C_{DC} . In variant embodiments, the storage element may be a battery. Entering the DC-DC converter 23 is an input current I_{inDCDC} that is equal to the current at output from the inverter I_{outINV} minus the current that flows in the storage element C_{DC} . Of course, in the present context,

the voltage on the bus HV is defined high with respect to the voltage on the other end of the DC-DC converter 23, on the low-voltage bus LV, which is, instead, of a lower value and in general corresponds to the voltage of the electrical systems of the vehicle, usually 12 V.

In the systems as the one described in which a system at a higher voltage is connected, by means of a converter, to a system at lower voltage, in particular to the electrical systems connected to the vehicle battery, the bus on the DC side of the inverter, which is also the high-voltage side HV, is in what follows referred to as "DC-link bus", and the storage element C_{DC} is referred to as "DC-link capacitance". The DC-link capacitance corresponds in general to the capacitor connected to the input of the DC-DC converter 23, where the DC voltage to be converted to a lower voltage arrives. The DC-link capacitance is usually obtained via an electrolytic or film capacitor that decouples the input of the DC-DC converter.

The aforesaid DC-link capacitance C_{DC} , in the example described, provides an intermediate energy-storage stage 40 at the input of the DC-DC converter 23. The voltage of the DC-link bus has, for example, a value of 48 V.

Set between the intermediate energy-storage stage 40 and the low-voltage bus LV, on which the battery 14 is connected, is the bidirectional DC-DC converter 23, which converts the high voltage of the high-voltage bus HV into a low voltage on the low-voltage bus LV, for charging the battery 14, but, if need be, can operate in the other direction to convert the low voltage on the low-voltage bus LV into high voltage on the high-voltage bus HV. This bidirectionality is frequently required in hybrid or electric vehicles.

The battery 14 is also connected to an alternator

60, which applies thereto a charging voltage V_{ALT} .

A drawback of the aforesaid systems is the management of any excess energy produced, for example, by the energy-recovery system 30.

5 Known from the Italian patent application No. 102016000112547 is an apparatus for energy conversion between a low-voltage system and a high-voltage of a vehicle comprising an energy-recovery stage, which regulates the DC-link voltage via a control procedure
10 of a hysteretic type comprising an operation of threshold comparison with hysteresis of the value of the DC-link voltage and the activation or deactivation of a DC-DC converter according to the result of the operation of comparison. This apparatus comprises an
15 additional load set in parallel to the input of the DC-DC converter, which can be selectively connected to the high-voltage bus (HV). If the power supplied by the energy-recovery stage is higher than a power absorbed by the DC-DC converter, the apparatus is configured for
20 maintaining the DC-DC converter always activated, with a current limitation, and for selecting the connection of the additional load according to a further hysteretic control procedure, based upon the DC-link voltage or upon the state of charge.

25 The above solution manages the excess power provided by the energy-recovery system, but presents some drawbacks. In the first place, it is a solution that does not envisage bidirectional conversion. Moreover, control of the DC-link voltage of a
30 hysteretic type determines a high voltage ripple, discontinuity of operation, high peak powers with respect to the mean powers involved (aspect ratio), and high ripple currents in the capacitors. In addition, this solution has a circuit for following a
35 slow drift (growth) of the DC-link voltage, which

requires supercapacitors capable of storing energy even when the system would not require it.

The object of the present invention is to provide an improved apparatus and an improved method that will
5 enable the drawbacks mentioned above to be overcome.

According to the present invention, the above object is achieved thanks to an apparatus, as well as to a corresponding method, having the characteristics referred to specifically in the ensuing claims.

10 The invention will now be described with reference to the annexed drawings, which are provided purely by way of non-limiting example and in which:

- Figure 1 and 2 have already been described previously;

15 - Figures 3 illustrates a general diagram of the apparatus described herein;

- Figure 4 shows a converter used by the apparatus described herein;

20 - Figure 5 illustrates a regulation circuit of the apparatus described herein;

- Figures 6, 7, and 8 illustrate implementations of the converter of Figure 4;

25 - Figures 9, 10, and 11 illustrate control signals and signals that are set up in the apparatus of Figure 3 in different configurations of operation of the apparatus.

In brief, the solution according to the invention regards a bidirectional energy-conversion apparatus of a DC-DC type operating between a low-voltage system and
30 a high-voltage system of a vehicle comprising an energy-recovery stage,

- said low-voltage system, which operates at a first voltage, comprising a battery that supplies said first voltage on a low-voltage bus,

35 said high-voltage system, which operates at a

second voltage higher than said first voltage, comprising said energy-recovery stage of the vehicle that supplies said second voltage,

5 said second voltage being supplied through an intermediate energy-storage system to a DC-DC conversion module, which converts said second voltage into said first voltage (for said low-voltage bus),

10 said apparatus comprising an auxiliary load, in particular an external load, in order to enable dissipation of the excess energy supplied by the energy-recovery system,

According a main aspect of the solution described herein, said DC-DC conversion module comprises a bidirectional DC-DC converter connected between the 15 intermediate energy-storage stage and the vehicle battery, and a second DC-DC converter connected between the intermediate energy-storage stage and said auxiliary load, in particular an external load, in order to enable dissipation of the excess energy 20 supplied by the energy-recovery system.

In this connection, Figure 3 illustrates a bidirectional energy-conversion apparatus of a DC-DC type, designated by the reference 190, which comprises a bidirectional DC-DC conversion module 123, which 25 comprises a first bidirectional DC-DC converter 124 connected between the intermediate energy-storage stage 40 and the vehicle battery 14 and a second auxiliary DC-DC converter 125 connected between the intermediate energy-storage stage 40 and an auxiliary load R_{aux} . As 30 may be noted, for the rest the apparatus corresponds to the one described in the figure, where the energy-recovery system 30 is represented via a current generator, which generates the current at output from the inverter I_{outINV} . Represented connected in parallel 35 to the battery 14, on which a battery voltage drop V_{bat}

is present, is a generic electrical load 19, representing the electrical loads of the vehicle that are connected to the low-voltage bus LV (e.g., the heated rear window).

5 Figure 4 illustrates a possible topology for providing the converter module 123. This topology, which is one of the simplest topologies for obtaining a bidirectional conversion and to which reference will be made in what follows for illustrating the solution
10 described herein, comprises the bidirectional DC-DC converter 124 configured with buck topology, i.e., comprising a switch that connects (and disconnects) a series inductor to (from) the input, i.e., the voltage V_{DClink} that is the energy source, so that the inductor
15 charges with magnetic energy and then discharges into the battery, in this circumstance a diode connected with its anode to ground enabling a path for the current from ground to the battery. The buck topology of the bidirectional converter 124, however, comprises
20 in this case two switches, designated by Q_{Buck} and Q_{Boost} in Figure 4, obtained for example via MOSFET transistors, for providing the characteristic of bidirectionality, in such a way one implements, seen from the high-voltage terminals HV, the buck behaviour,
25 and the other implements, seen from the low-voltage terminals LV, the boost behaviour. Each of the switches Q_{Buck} and Q_{Boost} is represented with a diode in parallel connected so as to enable flow, when the switch Q_{Buck} or Q_{Boost} is open, of a current in a direction opposite to
30 that in which the switch Q_{Buck} or Q_{Boost} causes flow of the current when it is closed. This may, for example, be obtained via the reverse diode between the source and the drain that is normally present in the MOSFET. This diode completes in the case of the buck switch the
35 boost scheme and in the case of the boost switch the

buck scheme.

Hence, the bidirectional DC-DC converter 124 comprises an input capacitance C_{in} connected from the DC-link node to ground and a first switch Q_{Buck} connected to the node of the DC-link bus, with a reverse diode D_{Boost} in parallel with its cathode connected to the DC-link node, which separates the latter from a series inductor L in which an inductor current I_L flows. The series inductor L is connected to an output node, which presents towards ground an output capacitor C_{out} , to which the battery 14 is connected in parallel. Connected to ground between the buck switch Q_{Buck} and the series inductor L is a second switch, the boost switch Q_{Boost} . Seen from the terminals of the battery 14 said second switch Q_{Boost} with the series inductor L provides, in the direction of conversion from the low-voltage bus HV to the high-voltage bus LV, a converter with boost topology.

Likewise connected to the DC-link node is the input of the unidirectional auxiliary converter 125, which also envisages, as has been said, a buck topology. Hence, the unidirectional auxiliary DC-DC converter 125 comprises an auxiliary switch Q_{aux} , connected to the DC-link node, which separates the latter from an auxiliary series inductor L_{aux} in which an auxiliary-inductor current $I_{L_{aux}}$ flows. The auxiliary series inductor L_{aux} is connected to an output node, which presents towards ground an auxiliary output capacitor C_{aux} , to which the auxiliary load R_{aux} is connected in parallel. In this case, since there is no dual boost switch as in the converter 124, a diode D_{aux} with its anode connected to ground and its cathode connected between the auxiliary switch Q_{aux} and the auxiliary series inductor L_{aux} completes the buck-converter scheme of the converter 125.

According to the solution described herein, the two converters 124 and 125 are controlled in closed loop in such a way that the controlled quantity is the DC-link voltage V_{DClink} , hence, the input voltage in the case of the first bidirectional DC-DC converter 124 in forward mode and of the second auxiliary DC-DC converter 125, and the output voltage in the case of the first bidirectional DC-DC converter 124 in reverse mode. In this way, the regulation guarantees an extremely low voltage ripple and continuity of operation.

The second auxiliary DC-DC converter 125 enables dissipation of the excess energy in a load at a higher voltage (up to that of the DC-link bus) with respect to the voltage of the battery 14, hence with lower currents, in addition to the advantage of not burdening the low-voltage system with a further load. Moreover, also for this converter closed-loop (non-hysteretic) operation enables a better aspect ratio of the dissipated power.

The first bidirectional DC-DC converter 124 and the auxiliary DC-DC converter 125 are driven according to different modes on the basis of the operating conditions of the system, in particular of the voltage on the bus V_{DClink} , and, possibly of a reference voltage V_{ref} , as described more fully hereinafter.

The bidirectional DC-DC converter 124 can be activated in forward or reverse mode, according to the type of conversion required by the vehicle, whereas the second auxiliary DC-DC converter 125 is activated only in the condition in which there becomes necessary dissipation of excess energy in conversion from the energy-recovery system 30 to the battery 14 (from the high-voltage bus HV to the low-voltage bus LV).

In order to determine the direction of operation

of the bidirectional DC-DC converter 124, as has been said, it is envisaged to carry out substantially only reading of the voltage on the bus V_{DClink} with consequent determination of the direction of operation of the first bidirectional DC-DC converter 124 and possible activation of the second auxiliary converter 125.

This is obtained using a comparator with hysteresis, designated by 141 in Figure 5, where represented in detail is a regulation module 140, which as a function of the voltage on the bus V_{DClink} , is configured for generating PWM (Pulse-Width Modulation) driving signals PWM_{Buck} , PWM_{Boost} , and PWM_{Aux} to control the switches Q_{Buck} , Q_{Boost} , and Q_{Aux} , respectively. The comparator with hysteresis 141 is configured with an upper hysteresis threshold V_{TH} and a lower hysteresis threshold V_{TL} . This DC-link voltage V_{DClink} is compared with a reference voltage V_{ref} , the value of which is intermediate between the value of the two hysteresis thresholds V_{TH} and V_{TL} and corresponds to a nominal voltage value of the high-voltage bus HV or, in any case, to a target voltage value. For example, the nominal voltage value of the high-voltage bus HV may be 48 V, the upper hysteresis threshold V_{TH} and the lower hysteresis threshold V_{TL} may be 46V and 50V, respectively, and the reference voltage V_{ref} may be 48 V.

When the voltage on the bus V_{DClink} exceeds the upper threshold V_{TH} (for example, on account of an event of generation of energy by the shock absorbers 12) a (status) signal is generated for enabling operation in buck mode $Buck_mode$, so that the flow of energy will go from the DC-link bus to the battery 14 in order to cause a reduction of the DC-link voltage V_{DClink} on the DC-link bus.

Instead, if the DC-link voltage V_{DClink} becomes

lower than the lower threshold V_{TL} (for example, on account of a demand for actuation) a (status) signal is generated for enabling the operation in boost mode Boost_mode, so that the flow of energy will go from the battery 14 to the DC-link bus in order to cause a rise of the DC-link voltage V_{DClink} on the DC-link bus.

If the voltage V_{DClink} remains within the two thresholds V_{TH} and V_{TL} the most recent setting is maintained. The target, or nominal, voltage of the DC-link bus does not change in the various operating modes, so that, within the two thresholds V_{TH} and V_{TL} , the bidirectional DC-DC converter 124 seeks to set the nominal voltage (or in any case the target voltage) whether it is in buck mode or in boost mode. Activation of the auxiliary converter 125 of a buck type is subordinate to the presence of the signal for enabling operation in buck mode Buck_mode to prevent operation thereof during the boost operation of the bidirectional DC-DC converter 124 (this would amount to a transfer from the battery 14 to the high-voltage bus HV, with useless dissipation of energy). The reference voltages of the two converters 124 and 125 must be set so as to guarantee precedence of operation for the bidirectional DC-DC converter 124, which is the main converter and generates recovery of energy, over operation of the auxiliary converter 125, which, instead, determines dissipation of energy. To guarantee this, two values of reference voltage are considered: the first is the reference voltage V_{ref} , which is used for regulating the bidirectional DC-DC converter 124, the second is a maximum overvoltage V_{max} , which is higher than the reference voltage V_{ref} and corresponds to the value of overvoltage accepted in conditions of excess regenerated energy, which is used for regulating the auxiliary DC-DC converter 125. If the bus voltage is

lower than both of the values of the voltage references V_{ref} and V_{max} , the two converters 124 and 125, which are both in buck configuration, do not work; i.e., their operation is not enabled. With the bus voltage V_{Dclink} comprised between the two voltage references V_{ref} and V_{max} operation only of the bidirectional DC-DC converter 124 is enabled. With a voltage higher than both of the voltage references V_{ref} and V_{max} both of the converters 124 and 125 are enabled and active.

Hence, Figure 5 illustrates an implementation of the regulation module 140 that comprises the voltage comparator with hysteresis 141, which receives on its inputs the bus voltage V_{Dclink} and the reference voltage V_{ref} and generates at output a comparison logic signal HC, which is picked up to obtain a buck-mode-enable signal Buck_mode, and is in parallel picked up and inverted via an inverter 145 to obtain a boost-mode-enable signal Boost_mode.

The boost-mode-enable signal Boost_mode is sent to an AND logic gate 146 together with a boost PWM signal PWM_{Boost} originated by a boost regulation circuit 142, which regulates the pulse-width modulation that is used for controlling the boost switch Q_{Boost} so as to obtain the desired voltage regulation V_{Dclink} , in a way in itself known to the person skilled in the branch, in particular by controlling the inductor current I_L , i.e., the input current, on the low-voltage vehicle side, i.e., on the battery, of the converter 124 when it operates in the above boost mode. The regulation circuit 142 also receives the reference voltage value V_{ref} , as control quantity of a voltage control loop, as described in greater detail in what follows. If the boost-mode-enable signal Boost_mode is active, i.e., in the case illustrated has the value of a logic one, at output from the AND logic gate 146 there is the boost

PWM signal PWM_{Boost} , which can be sent to the switch Q_{Boost} of the bidirectional DC-DC converter 124, as represented in greater detail in Figure 6.

The buck-mode-enable signal $Buck_mode$ at output
5 from the inverter 145, is sent to an AND logic gate 147 together with a buck PWM signal PWM_{Buck} originated by a buck regulation circuit 143, which regulates the pulse-width modulation so as to obtain the desired voltage regulation V_{DCLink} , in a way in itself known to the
10 person skilled in the branch, in particular by controlling the inductor current I_L , i.e., the output current of the converter 124 operating in forward mode (buck mode). The regulation circuit 143 also receives the reference voltage value V_{ref} , as control quantity of
15 a voltage control loop, as described in greater detail in what follows. If the buck-mode-enable signal, $Buck_mode$, is active, i.e., in the case illustrated is a logic one, at output there is has the buck PWM signal PWM_{Buck} , which can be sent to the switch Q_{Buck} of the
20 bidirectional DC-DC converter 124.

The buck-mode-enable signal $Buck_mode$ is also sent to an AND logic gate 148 together with a auxiliary PWM signal PWM_{aux} originated by a auxiliary regulation circuit 144, which regulates the pulse-width modulation
25 so as to obtain the desired voltage drop V_{DCLink} , in particular by controlling the auxiliary-inductor current I_L , i.e., the output current of the converter 125. The regulation circuit 144 also receives the maximum overvoltage value V_{max} , as control quantity of a
30 voltage control loop, as described in greater detail in what follows. It is clear how with this configuration if the buck-mode-enable signal $Buck_mode$ is deactivated, i.e., it is a logic zero, the output of the logic gate 148 is always at zero, and hence operation
35 of the converter 125 is inhibited, in so far as the

auxiliary switch Q_{aux} remains open.

The auxiliary load R_{aux} must be sized so as to guarantee the entire dissipation of the excess energy; i.e., it must have a resistive value not higher than, i.e., lower than or equal to, the value that would cause a voltage drop across it equal to the voltage on the bus V_{DClink} in the presence of the maximum current deriving from the auxiliary DC-DC converter 125 of a buck type.

The operation described, in particular for the regulation circuit of Figure 5, is obtained via the use of the three regulation circuits 142, 143, 144, one for each mode, the boost mode, the buck mode, and the auxiliary mode, the latter mode being enabled only during buck-mode operation. Each regulation circuit 142, 143, 144 envisages a respective voltage control loop on the bus V_{DClink} and a pulse-width modulator, where this is understood as being a circuit that generates a PWM signal with a pulse-width modulation determined by one or more control signals, which regulates an internal inductor-current loop (for example, a loop operating in Peak-Current Mode). The outputs of the three pulse-width modulators are enabled by the boost-mode-enable signal $Boost_mode$ or buck-mode-enable signal $Buck_mode$ described above and directed to the switches Q_{Boost} , Q_{Buck} , Q_{Aux} (or to their drivers) for operating in the required configuration.

For example, with reference to Figure 6, the control loop comprises an adder 143a, which receives as control quantity, or setpoint, the reference voltage V_{ref} , which it compares with the bus voltage V_{DClink} picked up on the input of the converter 123, to obtain an error signal that drives, through a compensation circuit 143b, an internal current loop 143c, which, for example, carries out a current limitation. The output

of the current loop is supplied as control signal to a pulse-width modulator 143d, which also receives also the current value I_L of the inductor L for controlling the pulse-width-modulation value and, as illustrated in Figure 5, supplies a signal PWM_{Buck} to the logic gate 147, which also receives the buck-mode-enable signal Buck_mode. At output from the logic gate 147 is the signal PWM_{buck} , which controls, preferably through drivers, opening and closing of the buck switch Q_{Buck} .

10 The boost switch Q_{Boost} is kept open.

In Figure 7 the boost regulation circuit 142 is similar, with an internal current loop 142c that carries out a current limitation of its own at a limit current value.

15 In Figure 8 the auxiliary regulation circuit 144 is similar, with an internal current loop 144c that carries out a current limitation of its own, and moreover the maximum overvoltage V_{max} is given as reference or setpoint value for limiting the voltage value.

Figure 9 illustrates diagrams that plot as a function of time the waveforms of signals of the apparatus described herein in a condition of turning-on and successive entry of excess energy on the bus.

25 The voltage on the bus V_{DClink} upon the turning-on rises, while the converter 23 is operating in boost mode (signal Boost_mode at high level). When the voltage on the bus V_{DClink} exceeds the upper hysteresis threshold V_{TH} of the comparator 141, this switches its output, the boost-mode-enable signal Boost_mode drops to the low logic level, and the buck-mode-enable signal Buck_mode goes to high logic level, enabling the bidirectional DC-DC converter 124 to function in buck mode converting the high voltage of the HV side into low voltage on the LV side. The auxiliary DC-DC

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converter 125 is enabled if the voltage on the bus V_{DClink} has exceeded the maximum overvoltage V_{max} and the bidirectional converter 124 is in buck mode (the driving signal PWM_{aux} is issued). The auxiliary
5 converter 125 is disabled when the voltage on the bus V_{DClink} has dropped below the maximum overvoltage V_{max} . When the voltage on the bus V_{DClink} drops below the lower hysteresis threshold V_{TL} of the comparator 141, the apparatus returns into boost mode.

10 Figure 10 illustrates diagrams that plot as a function of time the waveforms of signals of the apparatus in a condition in which the input energy, coming from the energy-recovery system 30 is in excess with respect to the energy that can be transferred into
15 the battery 14.

In this case, the converter 123 is in buck mode; when the voltage on the bus V_{DClink} exceeds the maximum overvoltage V_{max} the auxiliary converter 125 is enabled (the driving signal PWM_{aux} is issued).

20 Figure 11 illustrates diagrams that plot as a function of time the waveforms of signals of the apparatus in an additional condition that represents the case where the maximum overvoltage V_{max} is set at a value higher than that of the other thresholds. In this
25 mode, the voltage ripple increases, but a better mean energy transfer is obtained, in so far as dissipation of the excess energy is limited by storing it temporarily in the storage element.

Also in this case, the converter 123, initially in
30 buck mode with the bidirectional DC-DC converter 124 activated in buck mode to convert the high voltage into low voltage, activates the auxiliary DC-DC converter 125 when the voltage on the bus V_{DClink} exceeds the maximum overvoltage V_{max} and de-activates it, instead,
35 when the voltage on the bus V_{DClink} subsequently drops

below the maximum overvoltage $V_{\max}$.

The solution proposed may be applied also in the case in which is energy-management strategies are to be implemented by varying the voltage of the high-voltage
5 bus (for example, in the presence of an energy-storage element such as supercapacitors or a Li-ion battery). In this case, the reference voltages V_{ref} , the threshold hysteresis voltages V_{TH} , V_{TL} , and the maximum overvoltage $V_{\max}$ must be rendered settable in time.

10 Hence, from the foregoing description the advantages of the solution emerge clearly.

Advantageously, the apparatus and method described enable management of bidirectional conversions, for example in situations of key-on and active driving of
15 the regenerative shock absorbers or other actuators (for example, slow-active functions).

Advantageously, the apparatus and method described enable reduction of the ripple and improvement of the aspect ratio.

20 Advantageously, the apparatus and method described enable elimination of the supercapacitors if the application does not contemplate temporary storage of energy. They can be maintained for slow-active functions if temporary storage necessary for limiting
25 impulsive power that would be required of the battery.

It should moreover be noted that the known solutions for determining the direction of operation of a bidirectional DC-DC converter envisage acquisition of the sign of the currents at input and output at and in
30 consequent setting of the control. In the case where the devices connected to the bus are numerous (at least four controllers for the shock absorbers) this approach may be complex. The solution proposed envisages, instead, just reading of the voltage on the high-
35 voltage bus, with consequent determination of the

direction of operation of the first converter and possible activation of the second converter.

Of course, without prejudice to the principle of the invention, the details of construction and the
5 embodiments may vary widely with respect to what has been described and illustrated herein purely by way of example, without thereby departing from the scope of the present invention.

CLAIMS

1. An apparatus for energy conversion, in particular bidirectional conversion, of a DC-DC type
5 operating between a low-voltage system (LV) and a high-voltage system (HV) of a vehicle comprising an energy-recovery stage (30),

said low-voltage system (LV), which operates at a first voltage (V_{bat}), comprising a battery (14) that
10 supplies said first voltage (V_{bat}) on a low-voltage bus (LV),

said high-voltage system (HV), which operates at a second voltage (V_{inDCDC} , V_{DClink}) higher than said first voltage (V_{bat}), comprising said energy-recovery stage
15 (30) of the vehicle that supplies said second voltage (V_{inDCDC} , V_{DClink}),

said second voltage (V_{inDCDC} , V_{DClink}) being supplied through an intermediate energy-storage system (40) to a DC-DC conversion module (23; 123), which converts said
20 second voltage (V_{inDCDC} , V_{DClink}) into said first voltage (V_{bat}) for said low-voltage bus (LV),

said apparatus (90; 190) comprising an auxiliary load (R_{aux}), in particular an external load, which can be connected in order to enable dissipation of the
25 excess energy supplied by the energy-recovery system (30),

said apparatus being characterized in that:

said DC-DC conversion module (123) comprises a first bidirectional DC-DC converter (124) connected
30 between the intermediate energy-storage stage (40) and the vehicle battery (14) and a second DC-DC converter (125) connected between the intermediate energy-storage stage (40) and said auxiliary load (R_{aux}).

2. The apparatus according to Claim 1,
35 characterized in that said apparatus is configured for

selecting a direction of conversion of the first bidirectional converter (124), from high voltage (HV) to low voltage (LV) or from low voltage (LV) to high voltage (HV)), and the activation or deactivation of
5 said second auxiliary converter (124) via a control circuit (140) as a function of the value of the voltage (V_{DClink}) on the high-voltage bus (HV).

3. The apparatus according to any one of the preceding claims, characterized in that said first
10 bidirectional converter (124) is configured for operating in a buck-conversion mode (Q_{Buck} , L , D_{Buck}) from high voltage to low voltage and a boost-conversion mode (Q_{Boost} , L , D_{Boost}), said modes being selectable by said control circuit (140) for operating, respectively,
15 the conversion from high voltage (HV) to low voltage (LV) or from low voltage (LV) to high voltage (HV), and an auxiliary buck converter (Q_{Aux} , L_{Aux} , D_{Aux}), which can be selected if selected active said buck-converter conversion mode (Q_{Buck} , L , D_{Buck}) is selected active in
20 order to convey the bus voltage (V_{DClink}) onto the auxiliary load (R_{Aux}).

4. The apparatus according to any one of the preceding claims, characterized in that said control circuit (140) comprises a comparator with hysteresis
25 (141) with an upper hysteresis threshold (V_{TH}) and a lower hysteresis threshold (V_{TL}) configured for comparing the voltage on the bus (V_{DClink}) with a reference voltage (V_{ref}), and, if the voltage on the bus (V_{DClink}) exceeds the upper threshold (V_{TH}), a status
30 signal is generated for enabling the operation of conversion from high voltage to low voltage, or buck mode (Buck_mode),

if the voltage on the bus (V_{DClink}) drops below the lower threshold (V_{TL}), a status signal is generated for
35 enabling the operation of conversion from low voltage

to high voltage, or boost mode (Boost_mode).

5. The apparatus according to any one of the preceding claims, characterized in that said control circuit (140) is configured for:

5 disabling operation of the first converter (124) and of the second converter (125) if the bus voltage is lower both than the reference voltage value (V_{ref}) and than a maximum overvoltage value (V_{max}),

10 enabling operation only of the bidirectional DC-DC converter (124) if the bus voltage (V_{DCLink}) is comprised between the reference voltage value (V_{ref}) and the maximum overvoltage value (V_{max}), and

15 enabling operation of the first converter (124) and of the second converter (125) if the bus voltage (V_{DCLink}) is higher both than a reference voltage value (V_{ref}) and than a maximum overvoltage value (V_{max}).

20 6. The apparatus according to any one of the preceding claims, characterized in that it is configured for activating the auxiliary converter (125) only when the bidirectional converter (124) is configured for operating in a buck-conversion mode.

25 7. The apparatus according to any one of the preceding claims, characterized in that said auxiliary load (R_{aux}) has a resistive value that is lower than or equal to the resistive value that causes a voltage drop across it equal to the bus voltage (V_{DCLink}) in the presence of the maximum current derived from the auxiliary DC-DC converter (125) of a buck type.

30 8. The apparatus according to any one of the preceding claims, characterized in that said regulation circuit (140) comprises respective regulation circuits (142, 143, 144) for the buck, boost, and auxiliary modes that generate respective PWM (Pulse-Width Modulation) driving signals (PWM_{Buck} , PWM_{Boost} , PWM_{Aux}) for
35 driving respective switches (Q_{Buck} , Q_{Boost} , Q_{Aux}) of said

buck converter (Q_{Buck} , L , D_{Buck}), boost converter (Q_{Boost} , L , D_{Boost}), and auxiliary buck converter (Q_{Aux} , L_{Aux} , D_{Aux}), and logic circuits (147, 148, 149) for selectively supplying at output from said regulation
5 circuit (140) said PWM driving signals (PWM_{Buck} , $\text{PWM}_{\text{Boost}}$, PWM_{Aux}) to said respective switches (Q_{Buck} , Q_{Boost} , Q_{Aux}) under the control of said status signal for enabling the operation of conversion from high voltage to low voltage (Buck_mode) and said status signal for enabling
10 the operation of conversion from low voltage to high voltage (Boost_mode).

9. A method for energy conversion, in particular bidirectional one conversion, between a low-voltage system (LV) and a high-voltage system of a vehicle
15 according to any one of Claims 1 to 8, said method comprising selecting a direction of conversion of the first bidirectional converter (124), from high voltage (HV) to low voltage (LV) or from low voltage (LV) to high voltage (HV)), and activation or deactivation of
20 said second auxiliary converter (124) as a function of the value of the voltage (V_{DClink}) on the high-voltage bus (HV).

10. The method according to Claim 9, characterized in that it comprises executing an operation of
25 comparison with hysteresis (141) with an upper hysteresis threshold (V_{TH}) and a lower hysteresis threshold (V_{TL}), and, if the voltage on the bus (V_{DClink}) exceeds the upper threshold (V_{TH}), a status signal is generated for enabling the operation of conversion from
30 high voltage to low voltage, or buck mode (Buck_mode),
if the voltage on the bus (V_{DClink}) drops below the lower threshold (V_{TL}), a status signal is generated for enabling the operation of conversion from low voltage to high voltage, or boost mode (Boost_mode).

35 11. The method according to Claim 9, characterized

in that it comprises:

disabling operation of the first bidirectional DC-DC converter (124) and of the second auxiliary DC-DC converter (125) if the bus voltage is lower both than a
5 reference voltage value (V_{ref}) and than a maximum overvoltage value (V_{max}),

enabling operation only of the bidirectional DC-DC converter (124) if the bus voltage (V_{DClink}) is comprised between the reference voltage value (V_{ref}) and the
10 maximum overvoltage value (V_{max}), and

disabling operation of the first converter (124) and of the second converter (125) if the bus voltage (V_{DClink}) is higher both than a reference voltage value (V_{ref}) and than a maximum overvoltage value (V_{max}).

15 **12.** The method according to Claim 9, characterized in that it is configured for activating the auxiliary converter (125) only when the bidirectional converter (124) is configured for operating in a buck-conversion mode.

20

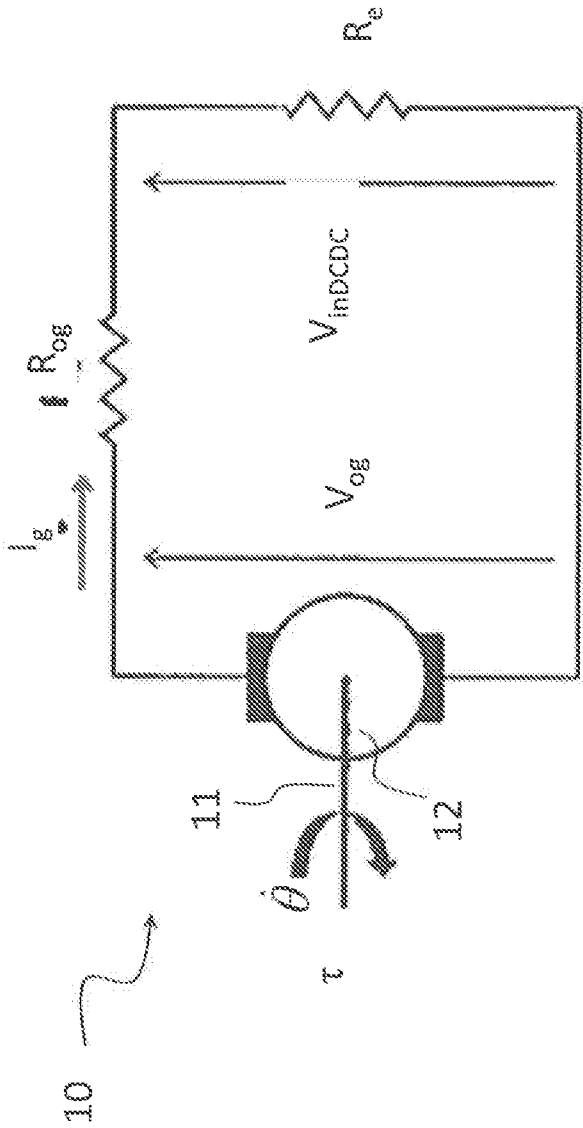


Fig. 1

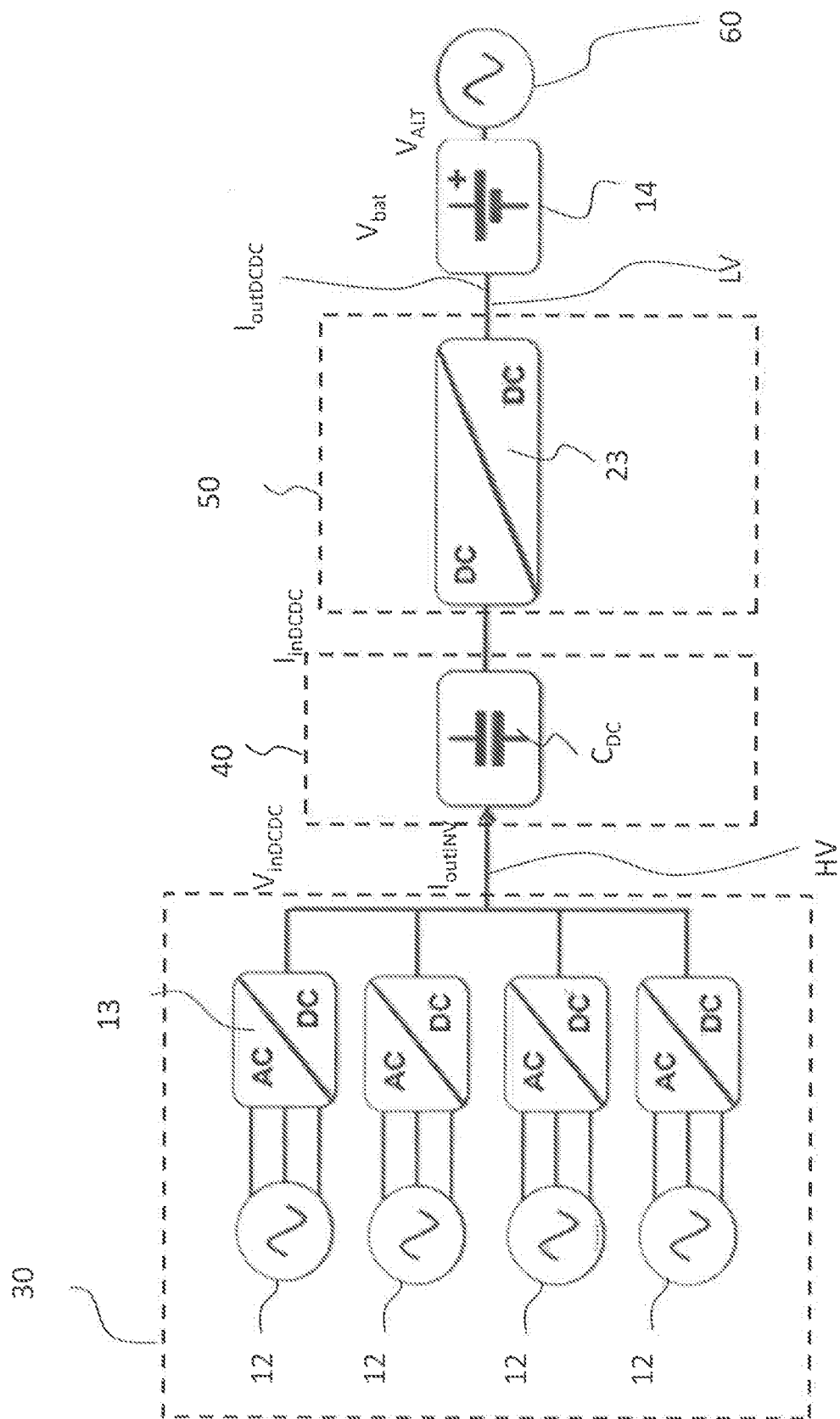


Fig. 2

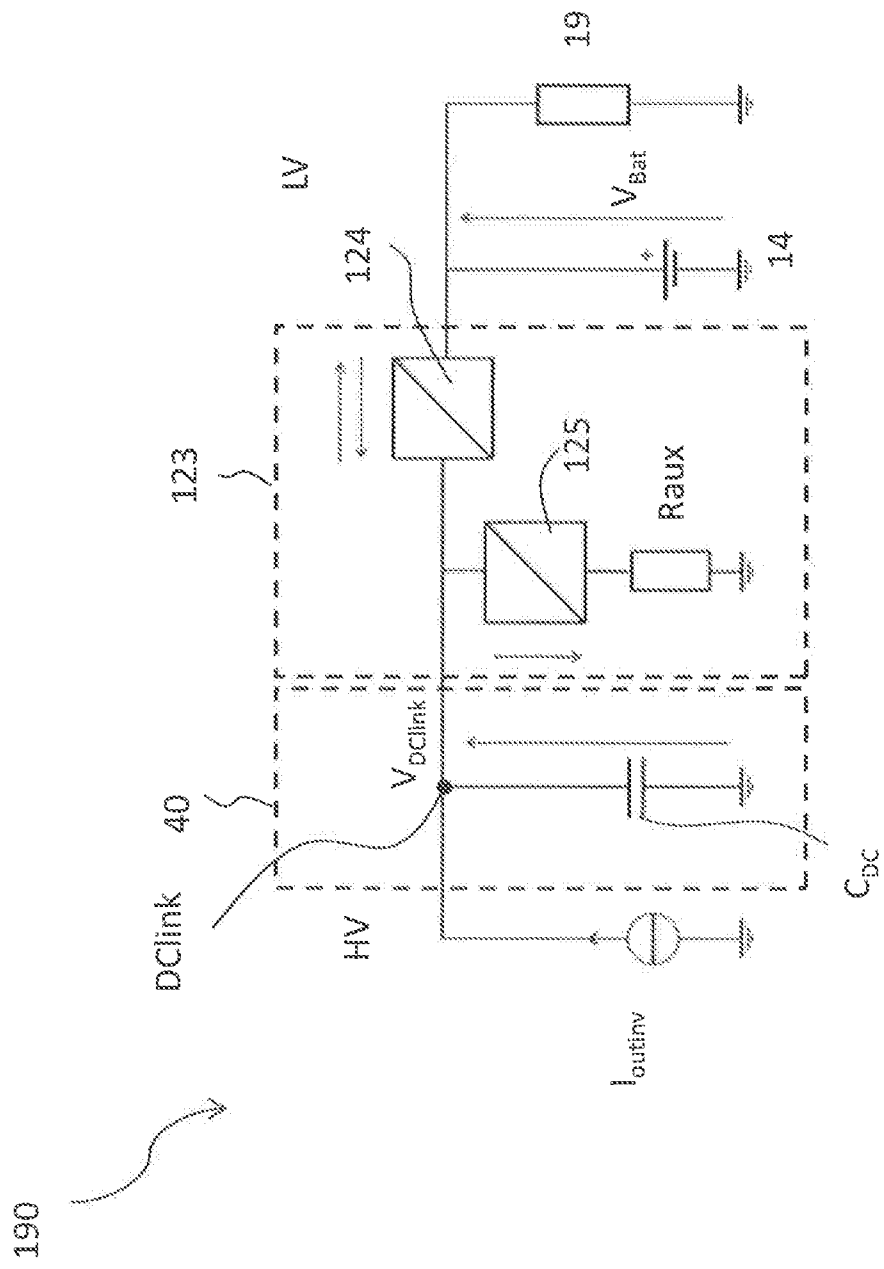


Fig. 3

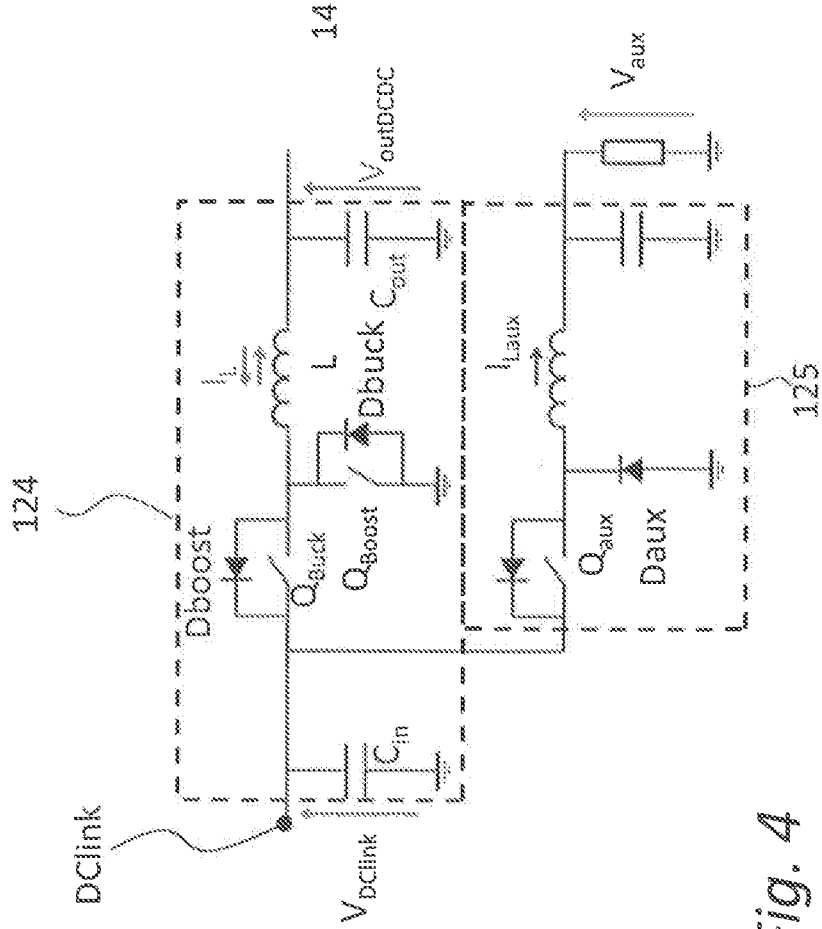


Fig. 4

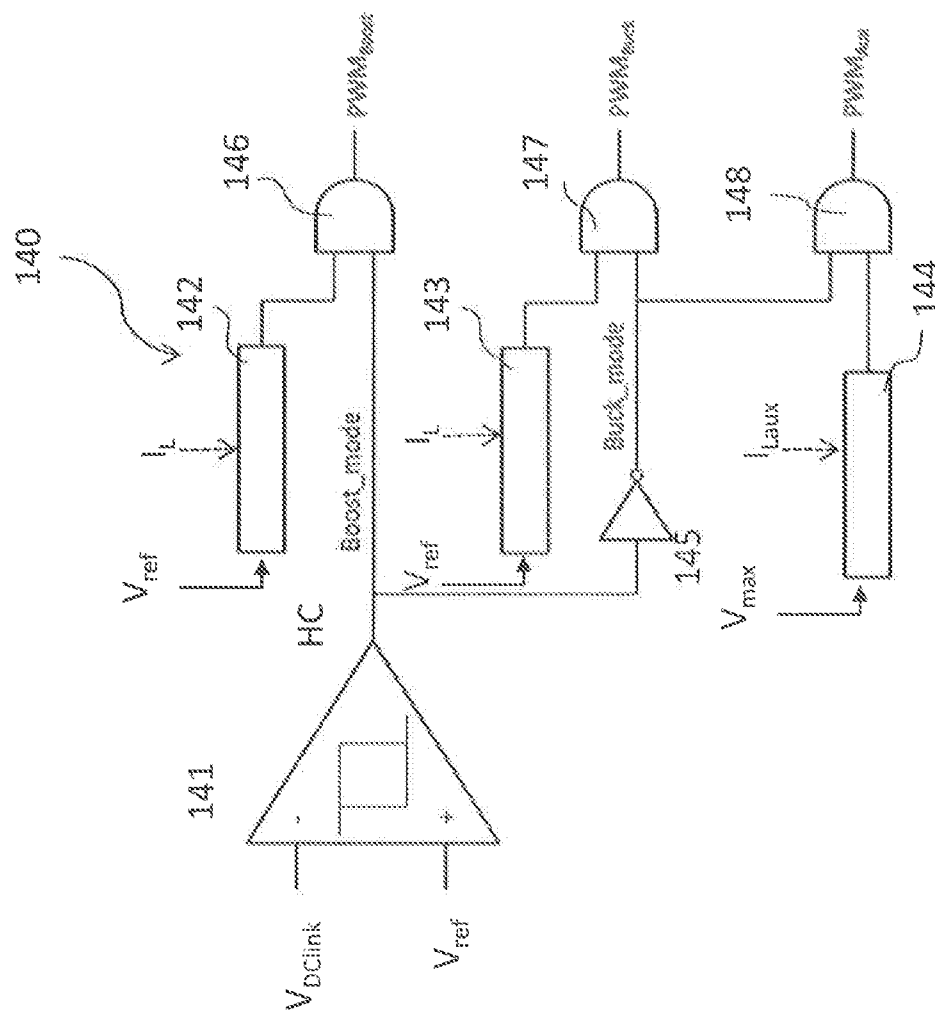


Fig. 5

Fig. 6

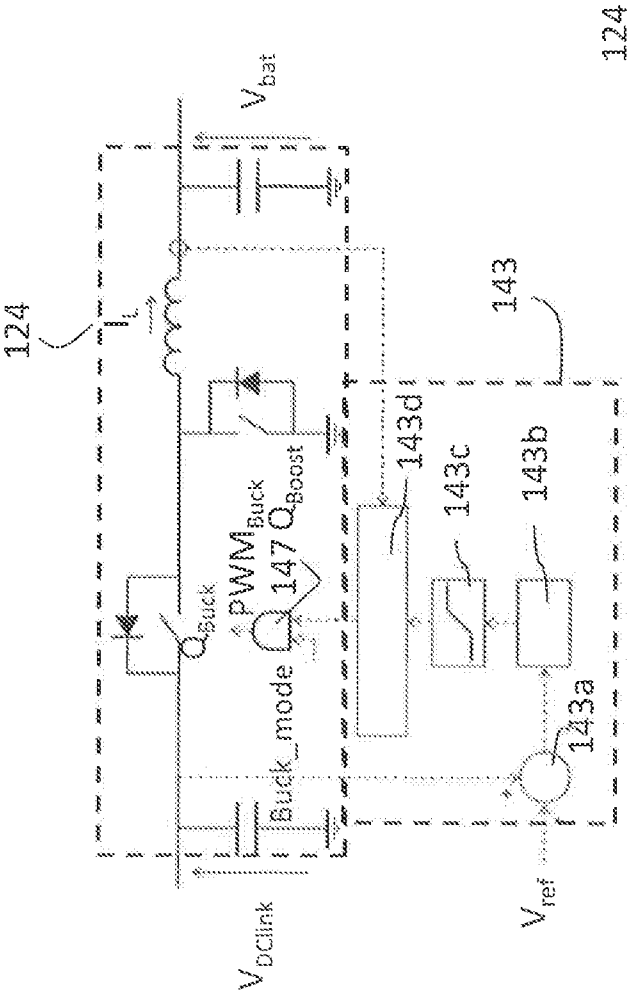
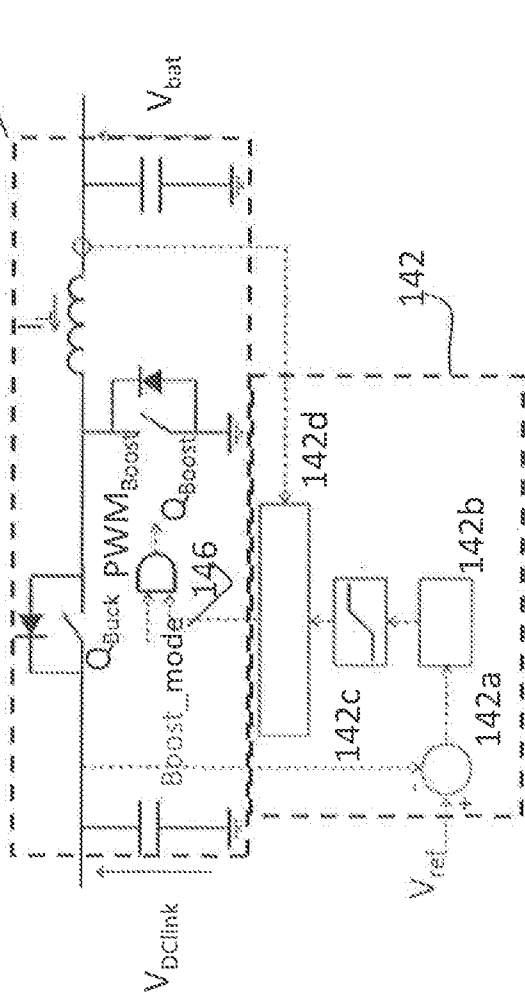


Fig. 7



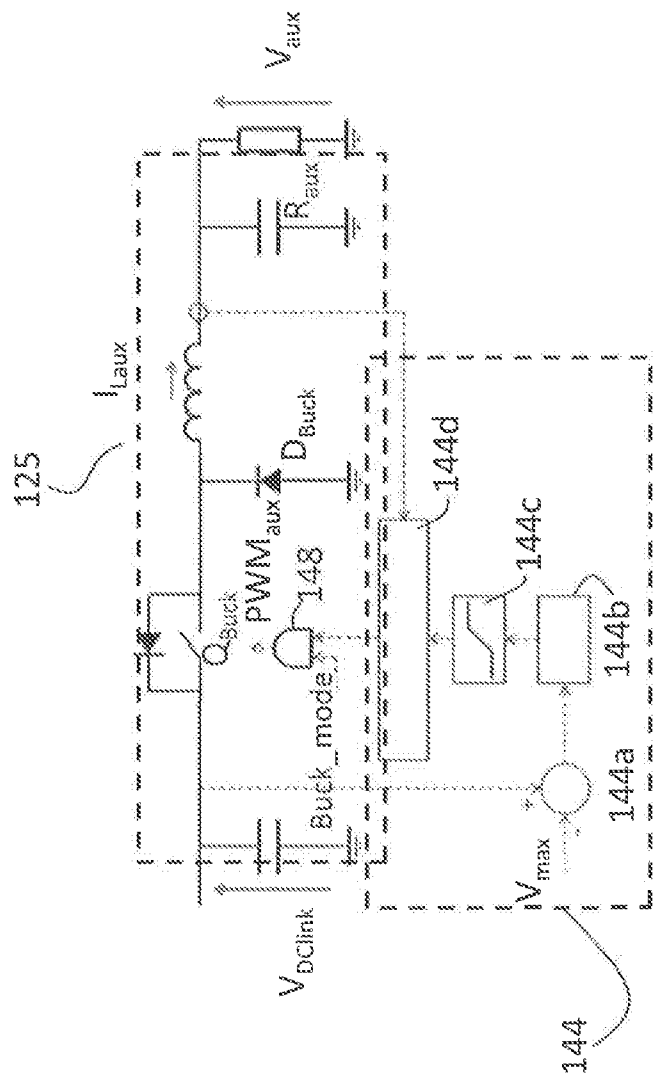


Fig. 8

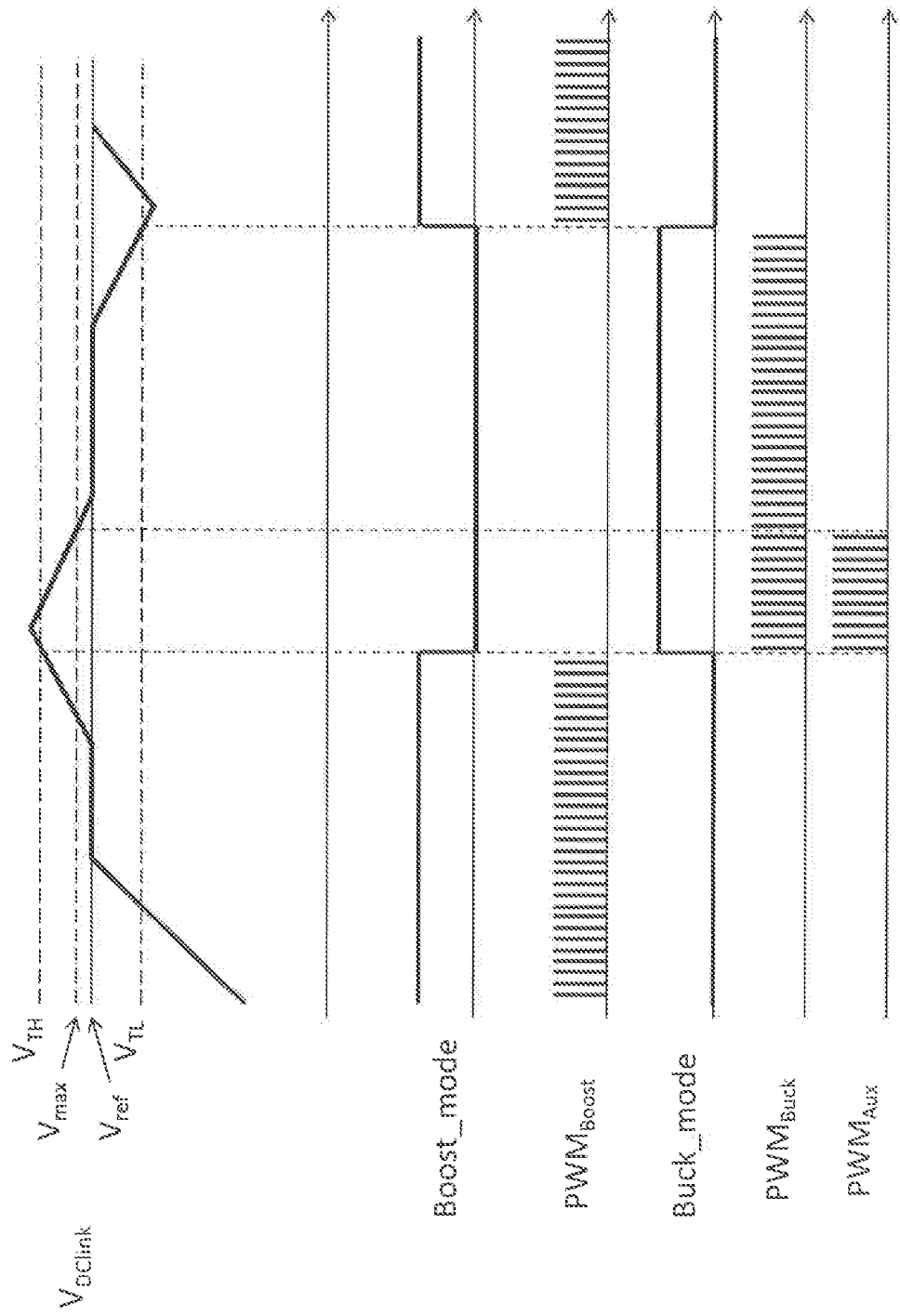


Fig. 9

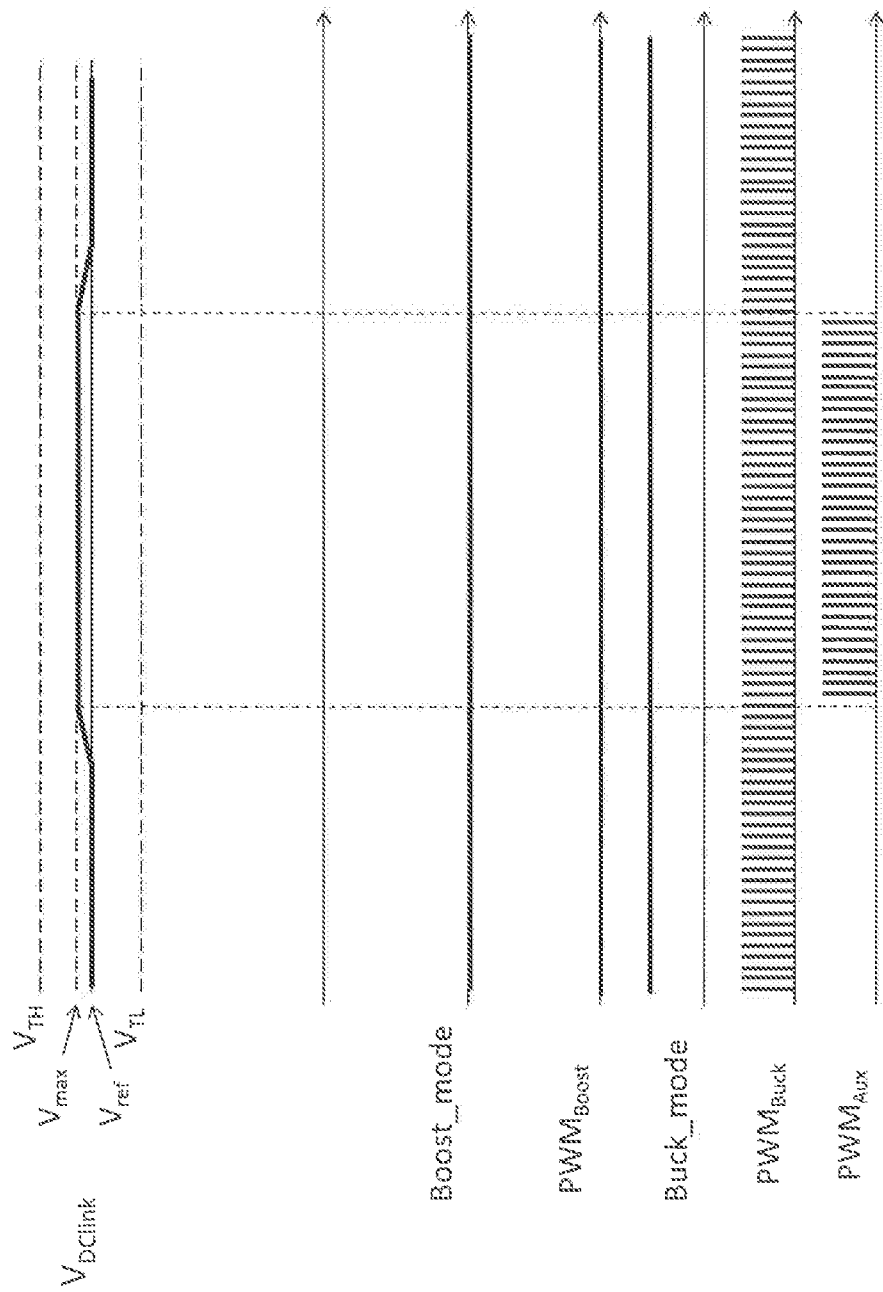


Fig. 10

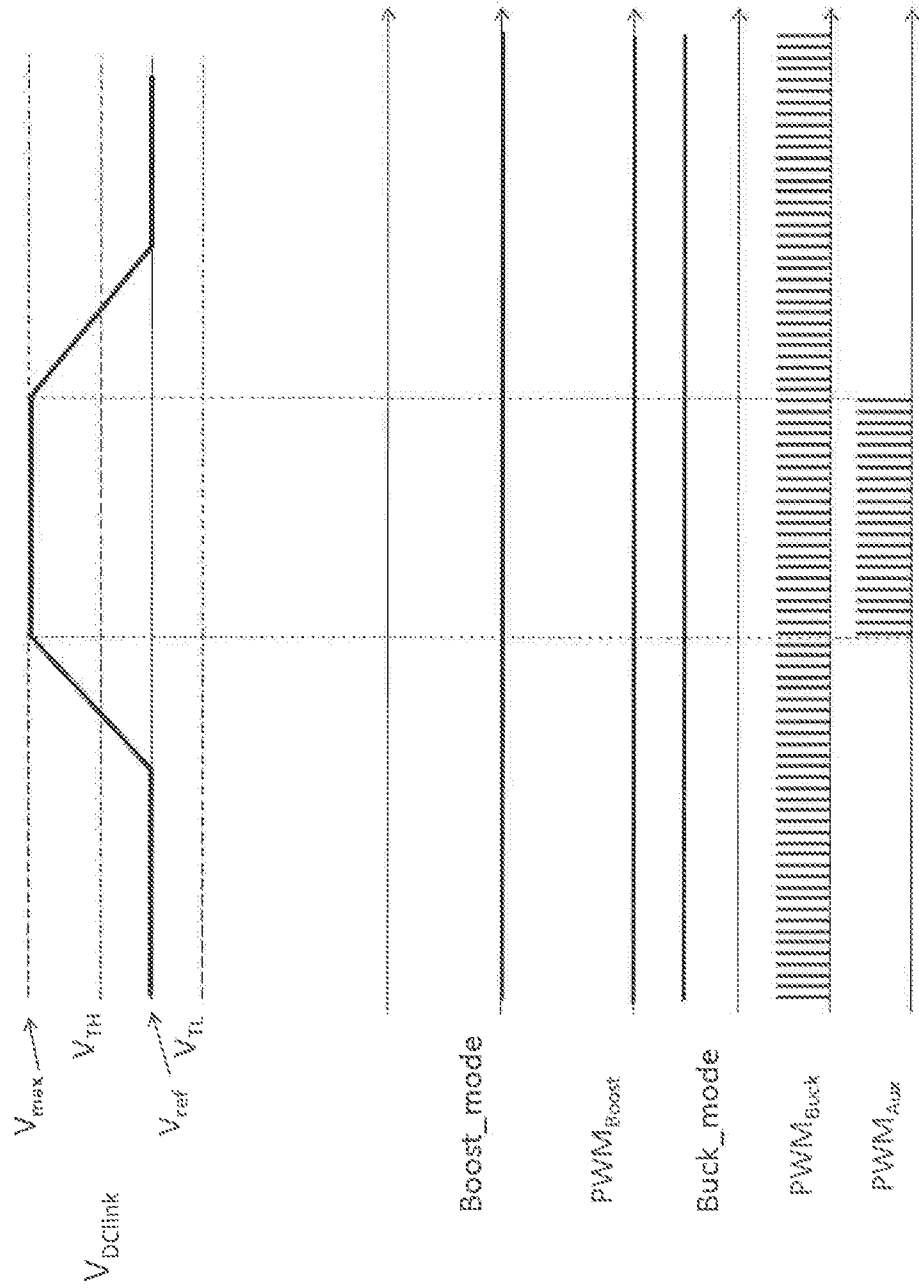


Fig. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2018/056668

A. CLASSIFICATION OF SUBJECT MATTER

INV. H02M1/32 H02M3/158 B60G13/14 B60G17/0165 B60G17/06
ADD. H02M1/00

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H02M B60G

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)

EP0-Internal, WPI Data

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Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	abstract paragraphs [0001] - [0004], [1067], [1069] - [1071], [1074], [1075], [1089] - [1091], [1122]; figures 1-2, 3-2, 4-1, 4-9G	4,10
A	----- EP 2 821 265 A1 (MAGNETI MARELLI SPA [IT]; SISTEMI SOSPENSIONI SPA [IT]) 7 January 2015 (2015-01-07) abstract; figures 3, 4, 8, 10	1-12
A	----- EP 2 193 954 A1 (GEN ELECTRIC [US]) 9 June 2010 (2010-06-09) abstract paragraphs [0022], [0023], [0028]; figures 2-4	1-12
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Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

7 November 2018

Date of mailing of the international search report

14/11/2018

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INTERNATIONAL SEARCH REPORT

International application No
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	abstract; figure 3 -----	4,10
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