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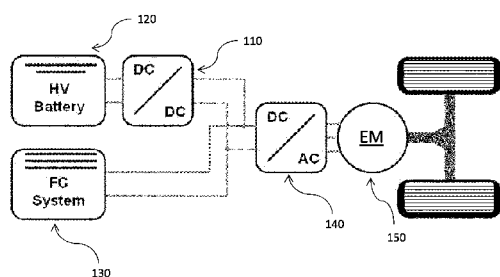


Fig. 1a

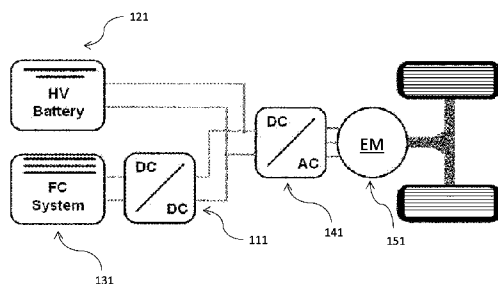


Fig. 1b

(57) Abstract: An electrical system for operating an AC electric motor in conjunction with at least one DC electrical energy storage and a DC electrical energy source is presented. It features a DC inverter link, wherein the inverter link is coupled via a direct DC link to the energy source and via a DC voltage booster link to the at least one energy storage.



Description

Improved topology for a Fuel-Cell Powertrain

5 The invention relates to a powertrain electrical configuration, and in particular a configuration which is advantageous for vehicles with electric drive motor, drive or traction battery, and fuel cell. The present invention improves systems with a combination of different power supplies and charging devices, provides associated methods, and in embodiments is adapted to motors or alternators powered by both
10 rechargeable batteries and fuel cells. The invention may advantageously be applied to electric motor vehicles in which the fuel cell and/or battery can power the motor via an inverter, and also exchange electrical power with an electrical network or grid when the motor vehicle is at a standstill.

15 Electrified vehicles including hybrid-electric vehicles (HEVs) and battery electric vehicles (BEVs) typically comprise a traction (or high-voltage) battery which functions as an electrical energy storage and provides power to an electric drive or traction motor or machine for propulsion. Power inverters are used to convert direct current (DC) power to alternating current (AC) power for the motor. The typical AC
20 traction machine is a 3-phase motor that may be powered by 3 sinusoidal currents each driven with 120 degrees phase separation, but any number of phases may be envisaged.

An electrified vehicle may use a fuel cell to provide electrical energy or power, either
25 as the sole source of electrical power to the battery and the motor, or in addition to an external DC or AC network supply with which the battery may be charged.

In order to recharge the high voltage batteries, the vehicle may also be equipped with an embedded charging device comprising an AC/DC converter which makes it
30 possible to rectify AC power from the electrical network or grid to charge the batteries, and also in the opposite direction, to take electrical power from batteries or the fuel cell of the vehicle and provide it to the network or grid. The AC/DC converter may also be used to take power from batteries or a fuel cell and provide it as auxiliary power within the vehicle, for example to outlets for powering tools,
35 refrigerators, etc. The vehicle may also be equipped with a DC/DC converter to adapt the network voltage level to the voltage level of the batteries.

In such a configuration, the system for operating an AC electric motor in conjunction with at least one DC electrical energy storage and a DC electrical energy source may include a inverter link to an external electrical network, wherein the inverter link is coupled via a direct DC link to the energy source and via a DC voltage booster link to the at least one energy storage.

In various configurations, fuel cell and battery may be connected in different topologies with one or more DC/DC converters and a DC link. An inverter to drive the motor may also be connected to the DC link.

However, given the number of elements in a vehicle with battery and fuel cell (or perhaps multiple instances of each), it may be advantageous to reduce the complexity of the interconnect topology in order to optimize costs, and in particular the cost of electronics for voltage converters and inverters.

The power switches of an inverter or inverters in particular may add additional cost due to the high current and or voltage requirements. Typical power switches may be MOSFET's or IGBT's. The more power storage or power generation or power consumption elements are involved, the higher the costs. Therefore, it may be desirable to find approaches which reduce the costs of the power electronics, especially in architectures and topologies where there are multiple power storage, power generation, and power consuming elements.

In some systems, a high-voltage DC link between battery and inverter brings a voltage independence between drivetrain inverter and battery voltage.

A battery requires a DC voltage, but typically a different voltage than that provided by a fuel cell system or stack. Likewise, the battery voltage and the voltage of an external infrastructure for DC charging (e.g. a charging station for electric vehicles) will likely be different. Therefore, it may well be advantageous to use a DC/DC converter between the battery, and the DC voltage supplies such as a fuel cell stack or network infrastructure, to adapt the respective voltage levels. The voltage level of the fuel cell stack may vary, and may be lower or higher than battery voltage, depending in part if the battery power is less than the fuel cell power or vice versa.

The voltage of a DC storage such as a battery may also vary depending on the state of charge. For example, the operating voltage of a 400V nominal voltage battery may drop to 300V when the battery is nearing a discharged state.

Voltage conversion between the fuel cell and network infrastructure or other electrical energy sources may not be required because all supply electricity, and therefore may be used exclusively, i.e. only one source is active at a given time.

- 5 An electrical energy source may by its nature have a poorly defined operating voltage. For example, solar cells used as an energy source to supply DC voltage may have a varying voltage depending on the amount of sunlight available. Other energy sources may also have varying voltages.
- 10 An AC/DC conversion source may be used to connect to an AC network such as a plug in a residential setting such as a garage. This AC electrical energy source may or may not have a consistent and reliable voltage level.

- The inverter which drives the electric motor can operate relatively independently of the voltage supplied by either an electrical energy source or an electrical energy storage. Therefore, the number of voltage-changing steps or DC boosters can be reduced by only using one converter or DC booster between an electrical energy storage and at least one electrical energy supply. If multiple electrical energy sources are used in parallel, then multiple voltage boosters may be necessary in order to bring the supplied voltages to a common value.
- 15
- 20

- The voltage at the inverter link or connection to the inverter need not be held constant, and in this way, allowing varying voltage at the inverter link allows an improved electrical architecture with advantages as presented below.
- 25

BRIEF DESCRIPTION OF THE DRAWINGS

- Figs. 1a-1b show different topologies of battery and fuel cell which are used in electrically-driven vehicles.
- 30

Fig. 2 shows an embodiment of the invention using an inverter coupled to an AC motor and which may further be coupled to an AC grid.

- 35 Possible basic electrical topologies of a fuel-cell vehicle are shown schematically in the Figures 1a-1b. Figure 1a shows a topology where the AC side of an inverter INV1a drives an electric motor or e-machine EM. The motor in turn drives the wheels. The DC side of the inverter gets power from, and is connected to, a fuel cell

system FC as electrical energy source via a DC link. The DC link between fuel cell and inverter is also electrically connected or coupled to a DC-DC converter or booster CV1a, which is in turn connected with a booster link to a high-voltage DC battery HV as electrical energy storage. In this topology, the fuel cell and the DC
5 side of the inverter operate at a common DC inverter link voltage, which is typically determined by an appropriate operating voltage for the fuel cell system. The AC voltage for the electric or traction motor EM is determined by the inverter as appropriate for the motor and the drive which is desired from the motor.

10 Figure 1b shows a different topology. Again, the AC side of an inverter INV1b drives an electric motor or e-machine EM. The motor in turn drives the wheels. The DC side of the inverter gets power from, and is connected to, a high-voltage DC battery HV. The DC inverter link between battery and inverter is also electrically connected or coupled to a DC-DC converter or booster CV1b, which is in turn connected with a
15 booster link to a fuel cell system FC. In this topology, the battery and the DC side of the inverter operate at a common DC link voltage, which is typically determined by an appropriate operating voltage for the battery. The voltage for the fuel cell is independent of the battery voltage, due to the operation of the DC-DC converter. The AC voltage for different phases of the electric or traction motor EM is
20 determined as appropriate for the motor and the drive which is desired from the motor, and is substantially independent of the DC voltages.

In the topologies of Figures 1a, and 1b are shown electrical system for operating an AC electric motor in conjunction with at least one DC electrical energy storage and a
25 DC electrical energy source. The electric traction or drive motor 150, 151 is driven by an inverter 140, 141 comprising a bidirectional converter-inverter connection to an external electrical network. The link to the external network may be bidirectional or unidirectional. The inverter 140 is coupled via a direct DC inverter link to the energy source 130 shown as a fuel cell system or stack and from the DC inverter link
30 via a DC voltage booster 110 link to the at least one energy storage 120 shown as a high-voltage battery. The inverter 141 is coupled from a DC inverter link via a DC voltage booster 111 link to the energy source 131 shown as a fuel cell system or stack and via a direct DC inverter link to the at least one energy storage 121 shown as a high-voltage battery. In embodiments the DC electrical energy storage is a
35 battery or multiple batteries. In embodiments the DC electrical energy source is a fuel cell or a stack of fuel cells. In embodiments, the inverter is adapted to be coupled via the inverter link to additional DC electrical energy storage and/or additional DC or rectified AC electrical energy sources.

The electrical system described above, with an AC electric motor in conjunction with a DC electrical energy storage and a DC electrical energy source, where a multi-phase inverter is used to provide multiple AC phases of electrical power to the motor, may use separate DC connections of the inverter to transfer electrical power to and from the fuel cell stack and the battery via a converter-inverter connection. The multiple AC phases of the inverter which transfers electrical power from the DC source are electrically connected to multiple AC phases of an interface to the AC power network or grid.

An electrically-driven motor vehicle may advantageously use an AC electric drive or traction motor, a battery, a fuel cell, and a system connected as in Figure 1a or 1b.

Turning to Figure 2, an embodiment of the invention is shown with inverter 240 and DC-DC converter or booster 210. The inverter is shown as electrically connected on the AC side to an electrical motor or electrical machine (e-motor or e-machine) 250. The connection is via the AC phases of the electrical motor or electrical machine, in this case the three AC phases. The AC phases are further connected to an AC grid via a grid interface 260. The link with the DC connection of the inverter 240 and the DC-DC converter 210 are also accessible to a DC charging interface. The charging interface may be a cable with plug, or it may be inductive charging, or both.

Electric components of the power supply subsystem and of the charging subsystem may add additional cost. Powering the motor and charging the batteries are performed with different phases. Therefore, it may be advantageous to reuse the components used to supply the electric motor with power, to implement the electrical power transfer and battery charging, especially for the interface to the AC power network or grid. In addition, it may be possible to reuse the motor as part of the advantageous concept for the connection to the AC grid.

The interface to an AC network infrastructure or "grid" may be accomplished by taking advantage of the legs of an electric drive motor or machine working together with an inverter to convert between AC network voltage and a first DC voltage, where the first DC voltage may be converted again to provide a second DC voltage for the battery.

An embodiment of the invention comprises a multi-phase inverter or set of inverters, with AC phases being used between a DC electrical energy source and electrical

machine or motor, and DC electrical energy storage and electrical machine or motor. The DC sides of the inverter or inverters may be coupled to an electrical energy storage such as a battery and/or may be coupled to an electrical energy source such as a fuel cell.

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For example, an inverter may be used to drive a motor using AC phases. An embodiment of the invention may use the phases of the electric motor connected to the H-bridges of the inverter for connection to an AC network or electrical grid, both as a charging source e.g. for a battery and/or to receive electrical power, creating a converter-inverter.

10

The energy storage in the battery can be switchably coupled to an external AC supply via the converter-inverter connection consisting of inverter 240, electrical machine 250, and grid interface 260. The grid interface connects to the external electrical network, such as a home AC socket or public AC charging infrastructure. The energy storage battery can be switchably coupled to an external DC supply without going via the converter-inverter connection to an external electrical network.

15

Since the fuel cell 230 needs no charging, the first DC voltage or inverter link voltage may also be adapted to the voltage of the battery 220. DC charging can occur directly either from a DC infrastructure or with inductive charging, or from a different supply of DC voltage such as solar cells or rectified AC voltage. The DC supply goes directly to the DC-DC converter 210.

20

In an alternative configuration, the battery may be connected directly to the DC link of the inverter and the fuel cell system may be connected to the DC link of the inverter via a DC-DC converter or booster.

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Patent claims

1. An electrical system for operating an AC electric motor (250) in conjunction with an inverter (140, 141, 240), at least one DC electrical energy storage (220) and a DC electrical energy source (230), comprising a DC inverter link to the inverter, whereby the inverter link is coupled directly to the energy source and via a DC voltage booster (210) link to the at least one energy storage.
2. An electrical system for operating an AC electric motor (250) in conjunction with an inverter (140, 141, 240), least one DC electrical energy storage (220) and a DC electrical energy source (230), comprising a DC inverter link to the inverter, whereby the inverter link is coupled directly to the at least one energy storage and via a DC voltage booster (210) link to the energy source.
3. The system of claim 1 or 2 wherein the DC voltage level at the DC inverter link is variable.
4. The system of any previous claim wherein the energy storage is adapted to be switchably coupled to an external AC supply via a converter-inverter link to an external electrical network, and wherein the energy storage is adapted to be switchably coupled to an external DC supply without going via the converter-inverter link to an external electrical network.
5. The system of a previous claim wherein the DC electrical energy storage is a battery.
6. The system of a previous claim wherein the DC electrical energy source is a fuel cell.
7. The system of a previous claim wherein the inverter or inverters are adapted to be coupled to additional DC electrical energy storage and/or additional DC electrical energy sources.
8. A method of operating an electrical system comprising an AC electric motor (150, 151) in conjunction with a DC electrical energy storage (120, 121) and a DC electrical energy source (130, 131), comprising a DC

inverter link, wherein the voltage at the inverter link varies with one of the energy storage or energy source voltages, and a DC booster (110,111) is used to adapt the voltage of the inverter link to the other of the energy storage or energy source voltages.

5

9. The method of claim 8 wherein the DC electrical energy storage is a battery and/or wherein the DC electrical energy source is a fuel cell.

10 10. An electrically-driven motor vehicle comprising an AC electric drive or traction motor (150, 151), a battery (120, 121), a fuel cell (130, 131), and a system according to any of claims 1-7, wherein the system is electrically coupled to the electric motor, the battery and the fuel cell.

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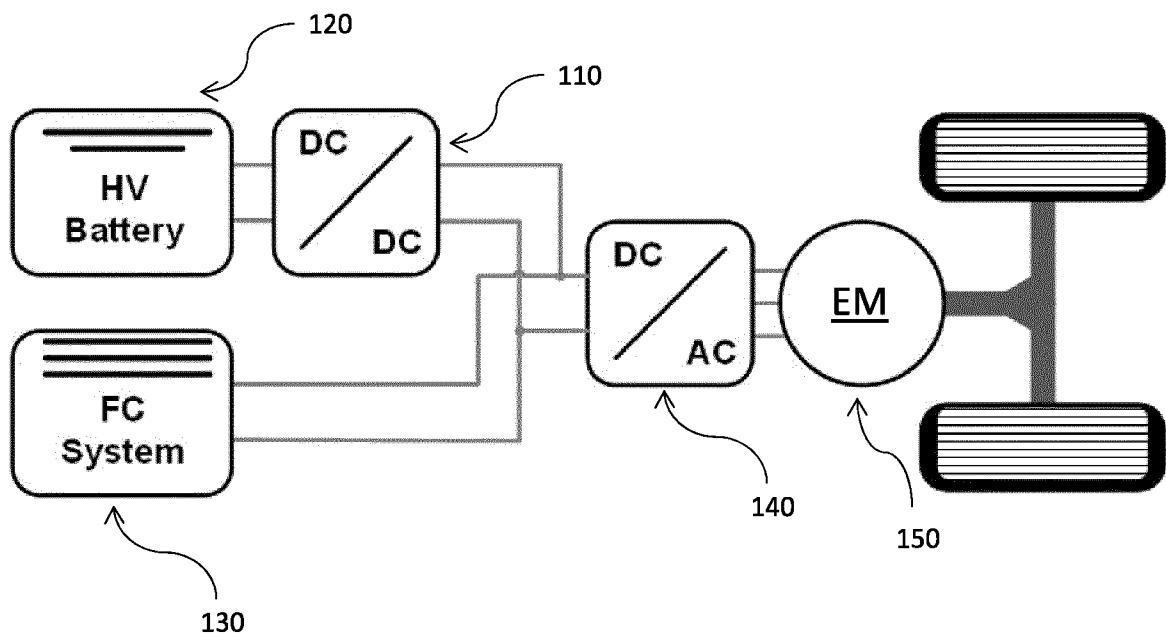


Fig. 1a

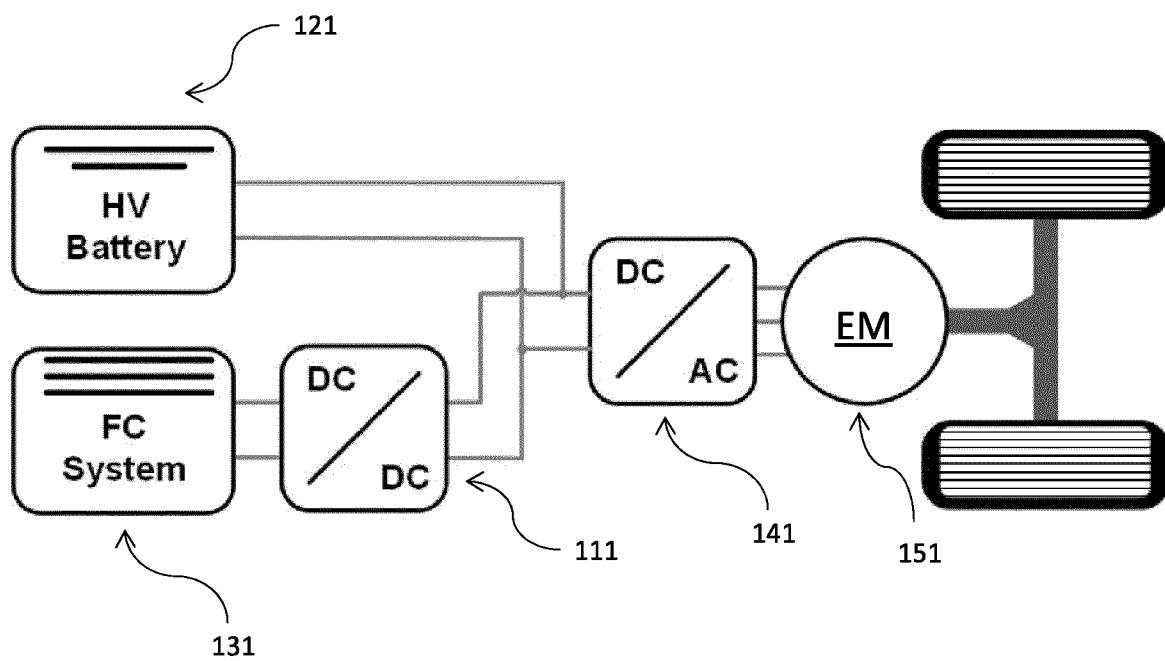


Fig. 1b

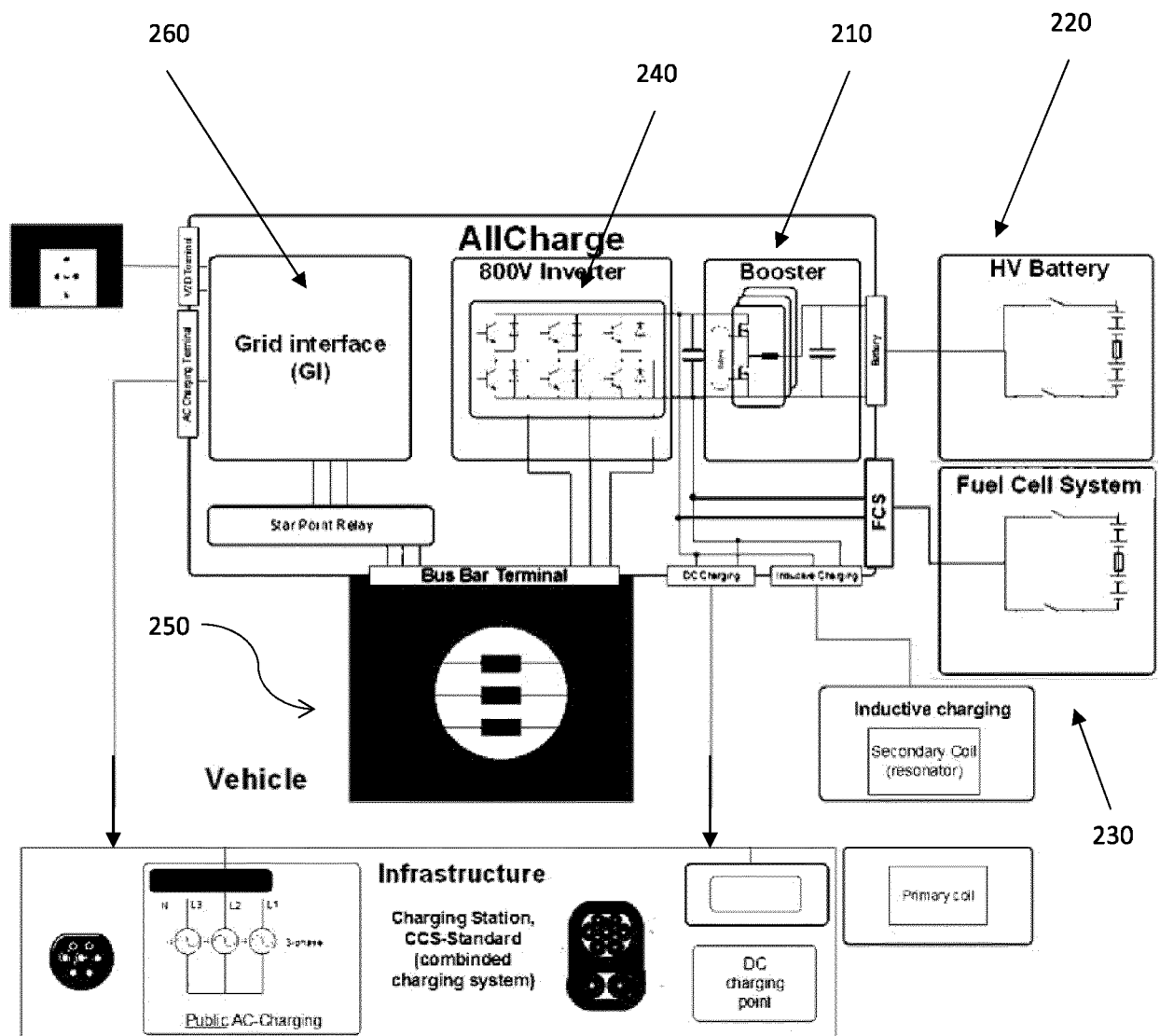


Fig. 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2020/069345

A. CLASSIFICATION OF SUBJECT MATTER INV. B60L15/20 B60L50/15 B60L50/50 B60L50/75 B60L53/20 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) B60L		
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.
X	DE 10 2011 088457 A1 (BOSCH GMBH ROBERT [DE]) 13 June 2013 (2013-06-13) abstract figures 1c-d paragraphs [0042] - [0044]	1-10
X	US 2013/057292 A1 (HASEGAWA TAKAHIKO [JP] ET AL) 7 March 2013 (2013-03-07) abstract figures 1,6 paragraphs [0021] - [0024], [0038]	1-10
A	US 2019/193581 A1 (BEULICH KLAUS [DE]) 27 June 2019 (2019-06-27) abstract figure 1 paragraphs [0028] - [0030]	1-10
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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