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(54) **Title:** MULTI-PHASE INVERTER FOR MULTIPLE SOURCES IN A VEHICLE AND RELATED HIGH VOLTAGE TOPOLOGY

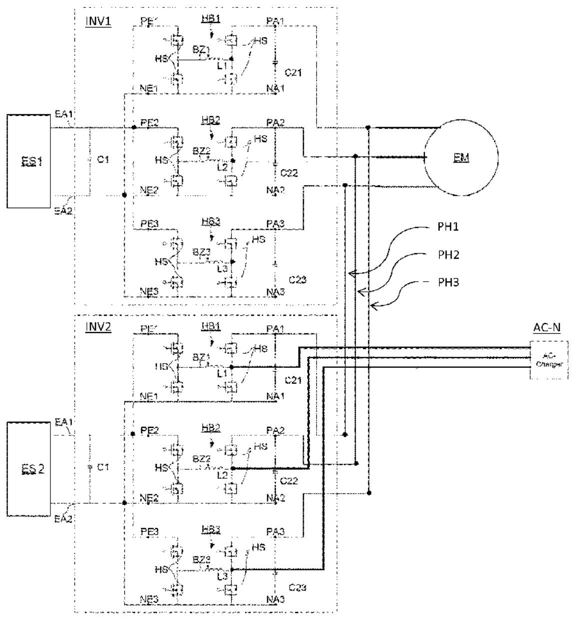

Fig. 2

(57) **Abstract:** An electrical system for operating an AC electric motor in conjunction with a DC electrical energy storage and a DC electrical energy source is presented. It includes a multi-phase inverter or set of inverters, wherein multiple AC phases of the inverter or inverters are coupled to the motor, and separate DC connections of the inverter or inverters are coupled to the DC electrical energy source and the DC electrical energy storage.

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[Continued on next page]

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MULTI-PHASE INVERTER FOR MULTIPLE SOURCES IN A VEHICLE AND RELATED HIGH VOLTAGE TOPOLOGY

The invention relates to an inverter 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 is situated in the field of motors or alternators powered by rechargeable batteries and/or 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 perhaps be recharged from an electrical network when the motor vehicle is at a standstill.

Electrified vehicles including hybrid-electric vehicles (HEVs) and battery electric vehicles (BEVs) typically comprise a traction (or high-voltage) battery which 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. The typical AC 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. In particular, a drive motor may have 6 phases.

An electrified vehicle may use a fuel cell to provide electrical power, either 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 possible to rectify the AC power from the electrical network to charge the batteries. 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 battery and the fuel cell are DC elements, and the drive motor may be an AC element, and inverters may be used to transfer the electrical energy between the different elements.

The inverter or inverters may be Analog Phase Voltage Inverters, as disclosed in the applications WO 2017211655 A1, WO 2017211656 A1, and WO 2017211657 A1, which documents are included by reference. Analog Phase Voltage (APV) Inverters typically use either a half bridge or H-bridge boost converter with a high frequency (for example, > 200 kHz) to do the necessary conversion between AC and DC voltages.

In some 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. An Analog Phase Voltage Inverter (APV), a Half-Bridge Boost converter operating at High Frequency (>200kHz), may be used to create a sinus wave on the boosted voltage side.

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. In addition, it may be possible to reuse the motor as part of the advantageous concept.

SUMMARY OF THE INVENTION

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. A particularly advantageous implementation comprises two 3-phase APV inverters, which on the AC side are connected to the same electrical machine (e-machine) or motor, and on the DC side one is connected to a battery, and the other is connected to a fuel cell. The AC phases form an AC link between the DC energy storage and energy source elements.

In embodiments, two inverters may be used to drive one motor using shared AC phases. For example, the inverters may share three AC phases to drive the motor or e-machine. Other embodiments may use phases which are not interconnected; rather, each inverter drives separate phases of a multi-phase motor. In the case of three-phase inverters, the resulting configuration has 6 phases available to drive the e-machine or motor. A strict galvanic separation can thus be achieved between the circuitry associated with an electrical storage (battery) via a first inverter, and the circuitry associated with an electrical source (fuel cell) via a second inverter.

An embodiment of the invention may use 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. Another embodiment of the invention may use H-bridges of the inverter for connection to a DC network or electrical grid, both as a charging source e.g. for a battery and/or to receive electrical power.

BRIEF DESCRIPTION OF THE DRAWINGS

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

Fig. 2 shows an embodiment of the invention using two APV inverters coupled to an AC motor.

Fig. 3 shows an alternative embodiment of the invention using two APV inverters coupled to an AC motor.

Possible basic electrical topologies of a fuel-cell vehicle are shown schematically in the Figures 1a-1ac. 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. The DC connection between fuel cell and inverter is also electrically connected or coupled to a DC-DC converter CV1a, which is in turn connected to a high-voltage DC battery HV. In this topology, the fuel cell and the DC side of the inverter operate at a common DC 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.

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 connection between battery and inverter is also electrically connected or coupled to a DC-DC converter CV1b, which is in turn connected to a fuel cell system FC. In this topology, the battery and the DC side of the inverter operate at a common DC 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 determined as appropriate for the motor and the drive which is desired from the motor, and is substantially independent of the DC voltages.

Figure 1c shows yet another topology. The AC side of an inverter INV1c drives an electric motor or e-machine EM. The DC side of the inverter gets power from, and is connected to, two DC-DC converters CV1c and CV2c. DC-DC converter CV1a is in turn connected to a high-voltage DC battery HV. DC-DC converter CV1b is connected to a fuel cell system FC. In this topology, the voltages for the fuel cell and the battery voltage are independent of each other and the DC side of the inverter, and vice versa, due to the operation of the two DC-DC converters. The AC voltage for different phases of the electric or traction motor EM is still determined as appropriate for the motor and the drive which is desired from the motor, and remains substantially independent of the DC voltages.

Turning to Figure 2, an embodiment of the invention is shown with two inverters, INV1 and INV2. The first inverter is shown in this embodiment as electrically connected on the DC side to a DC energy storage ES1 such as a battery. The second inverter is shown in this embodiment as electrically connected to a DC energy source

ES2 such as a fuel cell. Other embodiments might include additional inverters coupled to additional energy storage or sources. Both inverters are shown as electrically connected on the AC side to an electrical motor or electrical machine (e-motor or e-machine) shown as EM. The connection is via the three AC phases shown as PH1, PH2, PH3.

In this embodiment, INV1 and INV2 are both multi-phase inverters, and multiple AC phases of the inverter or inverters are adapted to be coupled to the motor. Separate DC connections of the inverter or inverters are adapted to be coupled to the DC electrical energy source and the DC electrical energy storage, such that there is no DC electrical connection between the DC electrical energy source and the DC electrical energy storage.

An optional connection to an AC charger (AC-N) is shown as part of inverter INV2. This connection uses the H-bridges HB1, HB2, HB3 of inverter 2. The charger AC-N might also be replaced by a connection to supply power to an AC network as AC-N, or AC-N might be a bi-directional connection to an AC power network. When the system is implemented in a vehicle, AC-N would be the connection to the immobile AC network, for example in a parking garage or parking lot.

The inverters INV1, INV2 are preferably APV networks, which use a higher frequency across inductors L1, L2, L3 of the respective inverters to transform the voltage levels as needed. Each inverter has 3 H-bridges HB1, HB2, HB3. Each H-bridge comprises 4 switches, labelled HS. The power switches in embodiments may be MOSFET’s or IGBT’s, or other semiconductor devices, or other electrical switches.

Turning now to Figure 3, this shows an embodiment of the invention with two inverters, INV1 and INV2, where there is no electrical connection between the AC site of INV1 and INV2. The first inverter is shown in this embodiment as electrically connected on the DC side to a DC energy storage ES1 such as a battery. The second inverter is shown in this embodiment as electrically connected to a DC energy source ES2 such as a fuel cell. Other embodiments might include additional inverters coupled to additional energy storage or sources. Each inverter is shown as separately electrically connected on the AC side to separate phases of electrical motor or electrical machine (e-motor or e-machine) shown as EM.

Inverter INV1 on the AC side generates 3 phases (PH1, PH2, PH3) for the electric motor EM. Likewise, INV2 on the AC side generates 3 additional phases (PH4, PH5, PH6) for the electric motor EM. The 2 x 3 phase configuration is given as an example, and the person of skill will recognize other configurations as possible, depending particularly on the mechanical configuration of the electric motor EM. Depending on the requirements of the system, the electrical activation of the phases PH1, PH2, PH3 and PH4, PH5, PH6 may be simultaneous at 0 degrees offset (e.g. PH1 and PH4 simultaneously). Alternatively, the phases may be offset by 60 degrees, or some other offset.

As in Fig. 2, an optional connection to an AC charger or network (mains) is shown as (AC-N) being a part of inverter INV2.

Claims

1. An electrical system for operating an AC electric motor in conjunction with a DC electrical energy storage and a DC electrical energy source, comprising a multi-phase inverter or set of inverters, wherein multiple AC phases of the inverter or inverters are adapted to be coupled to the motor, and separate DC connections of the inverter or inverters are adapted to be coupled to the DC electrical energy source and the DC electrical energy storage, such that there is no DC electrical connection between the DC electrical energy source and the DC electrical energy storage.

2. The system of claim 1 wherein multiple AC phases of an inverter adapted to be coupled to the DC source are electrically connected to multiple AC phases of an inverter coupled to the DC storage.

3. The system of claim 1 wherein AC phases of an inverter adapted to be coupled to the DC source are not electrically connected to an inverter coupled to the DC storage.

4. The system of a previous claim wherein the DC electrical energy storage is a battery.

5. The system of a previous claim wherein the DC electrical energy source is a fuel cell.

6. 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.

7. The system of a previous claim wherein two H-bridges of an inverter are additionally adapted to be electrically connected to a DC network.

8. The system of a previous claim wherein at least two H-bridges of an inverter or inverters are adapted to be electrically connected to an AC network.

9. The system of claim 8 wherein three H-bridges of an inverter or inverters are adapted to be electrically connected to the AC network.

10. A method of operating an electrical system comprising an AC electric motor in conjunction with a DC electrical energy storage and a DC electrical energy source, wherein a multi-phase inverter or set of inverters is used to provide multiple AC phases of electrical power to the motor, and separate DC connections of the inverter or inverters are used to transfer electrical power to and from the DC electrical energy source and the DC electrical energy storage.

11. The method of claim 10 wherein multiple AC phases of the inverter which transfers electrical power from the DC source are electrically connected to multiple AC phases of an inverter which transfers electrical power to and from the DC storage.

12. The method of claim 10 wherein AC phases of the inverter which transfers electrical power from the DC source are not electrically connected to AC phases of an inverter which transfers electrical power to and from the DC storage.

13. The method of claims 10 to 12 wherein the DC electrical energy storage is a battery.

14. The method of claims 10 to 12 wherein the DC electrical energy source is a fuel cell.

15. An electrically-driven motor vehicle comprising an AC electric drive or traction motor, a battery, a fuel cell, and a system according to any of claims 1-9, wherein the system is electrically coupled to the electric motor, the battery and the fuel cell.

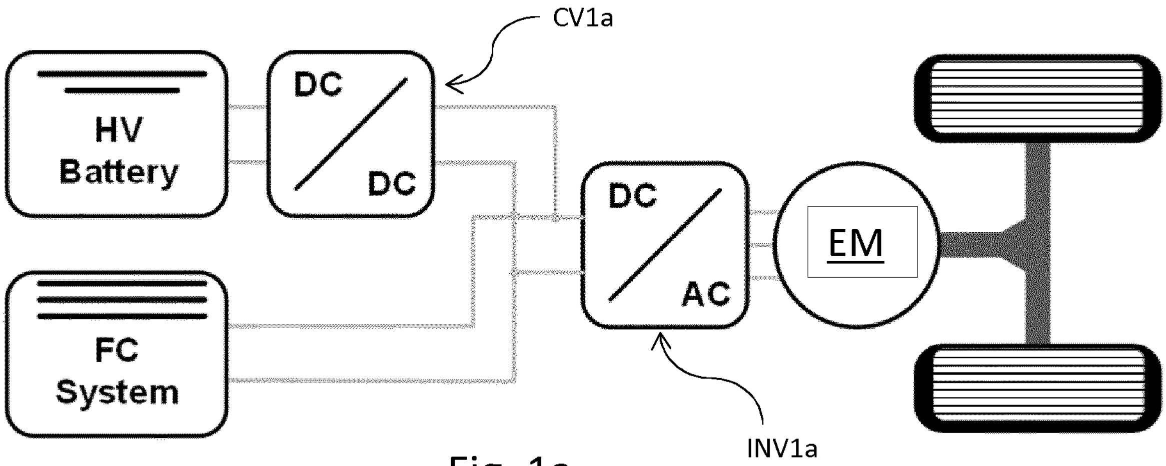


Fig. 1a

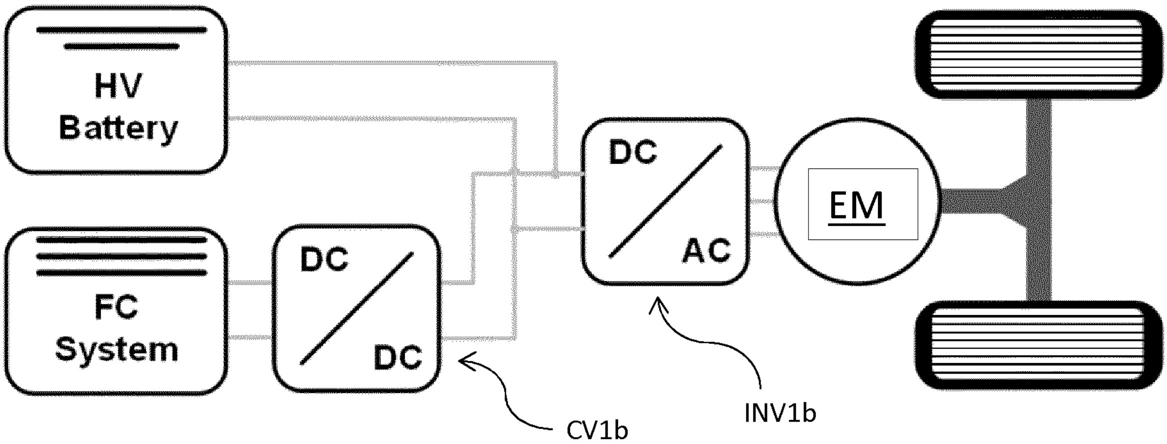


Fig. 1b

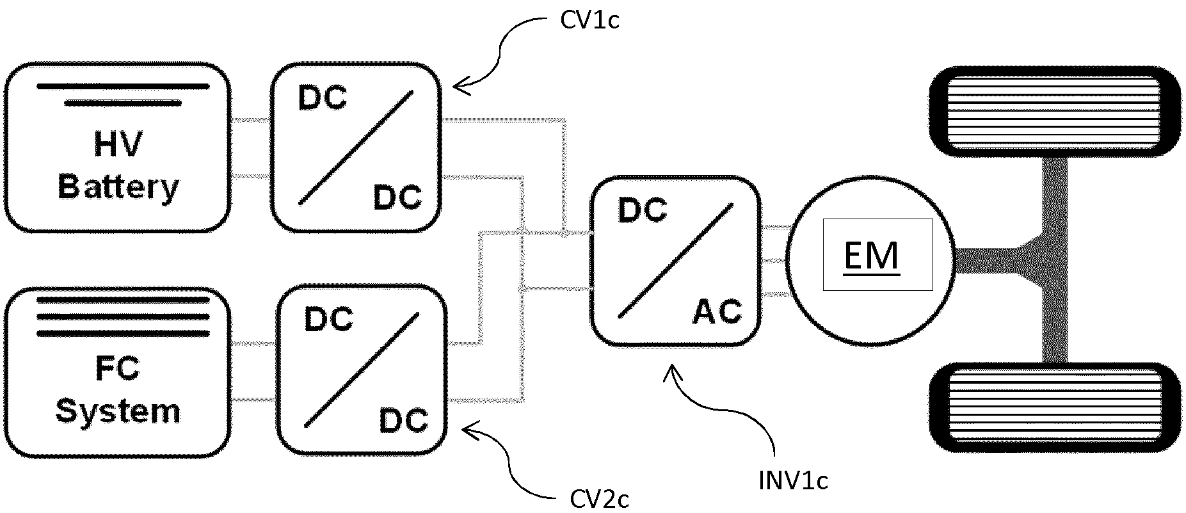
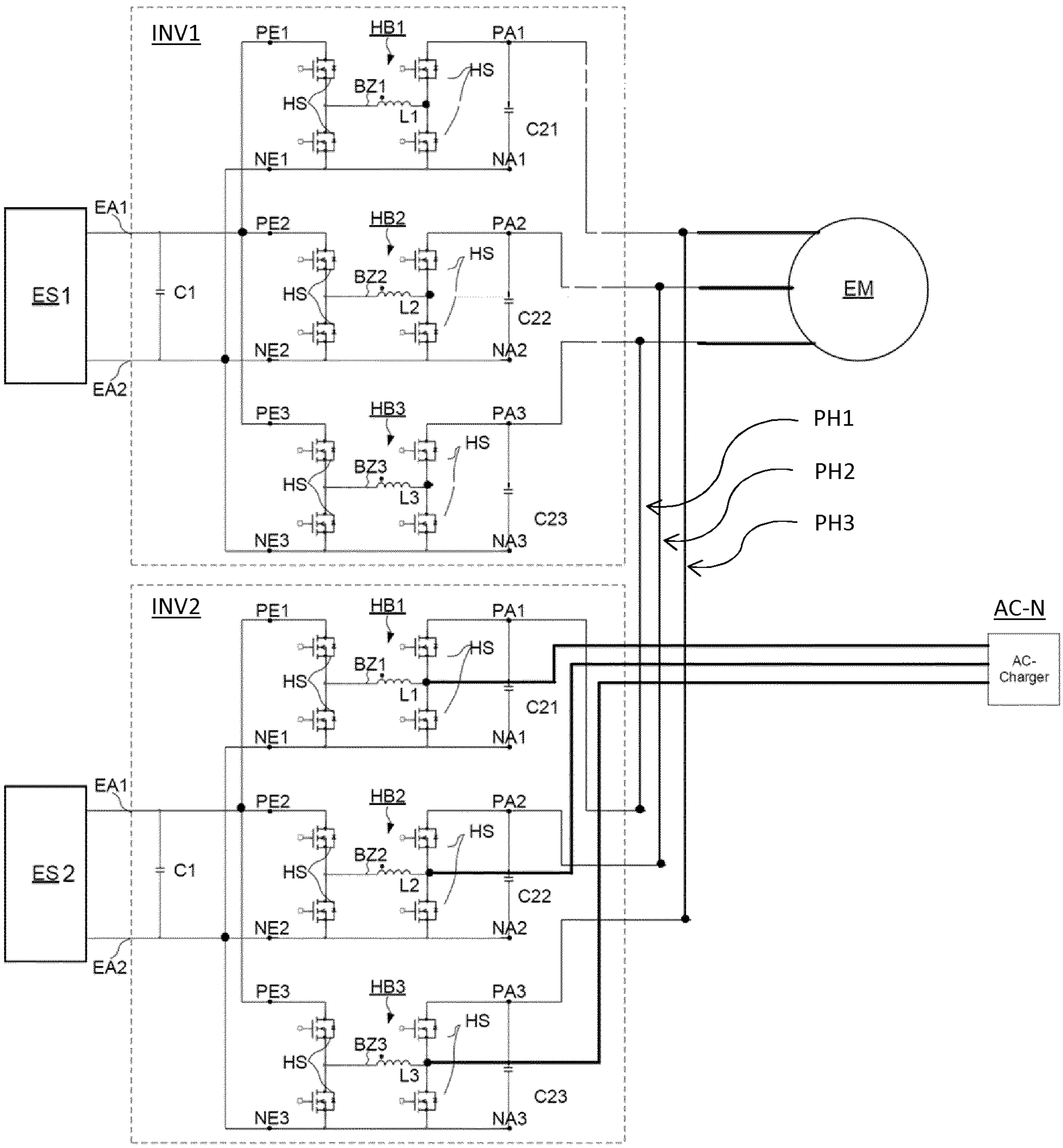


Fig. 1c


INV1
PE1
HB1
PA1
HS
BZ1
HS
L1
C21
NE1
NA1
EA1
PE2
HB2
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HS
ES1
C1
BZ2
HS
L2
C22
EM
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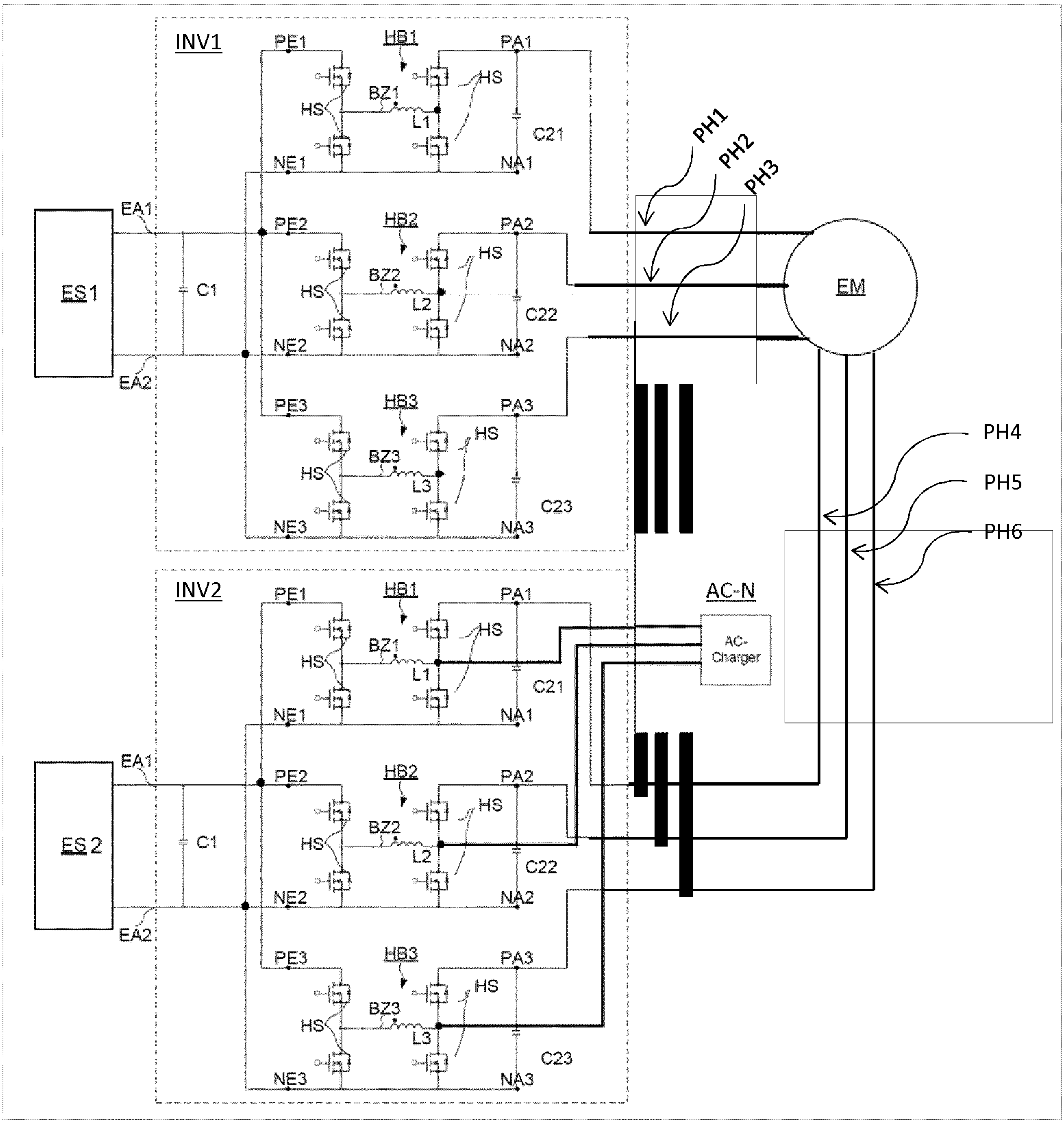
Fig. 2



INV1
PE1
HB1
PA1
HS
BZ1
L1
C21
NE1
NA1
PH1
PH2
PH3
EA1
PE2
HB2
PA2
ES1
C1
BZ2
L2
C22
EM
NE2
NA2
EA2
PE3
HB3
PA3
BZ3
L3
C23
NE3
NA3
PH4
PH5
PH6
INV2
AC-N
AC-Charger
ES2

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/077246

A. CLASSIFICATION OF SUBJECT MATTER
INV. B60L15/00 B60L50/75 B60L53/24
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	US 2009/033251 A1 (PERISIC MILUN [US] ET AL) 5 February 2009 (2009-02-05) paragraph [0031] - paragraph [0035]; figure 2 -----	1,3-5, 8-10, 12-15
X	US 8 487 568 B2 (FRANKE TORSTEN [DE]; BAYERISCHE MOTOREN WERKE AG [DE]) 16 July 2013 (2013-07-16) figure 2 -----	1,2,4,5
X	US 2014/239869 A1 (GORKA MATTHIAS [DE] ET AL) 28 August 2014 (2014-08-28) figure 1 -----	1,3
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 January 2020	20/01/2020

Name and mailing address of the ISA/	Authorized officer
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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2013/182212 A1 (VOLVO LASTVAGNAR AB [SE]; HOEVENAARS ERIK [NL]; ALAKULA MATS [SE]) 12 December 2013 (2013-12-12) figures 1,2 -----	1,3,4,6, 7
X	US 2013/293165 A1 (FEUERSTACK PETER [DE] ET AL) 7 November 2013 (2013-11-07) abstract; figure 1 paragraph [0013] -----	1,2,10, 11

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2019/077246

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2009033251 A1	05-02-2009	CN 101357595 A	04-02-2009
		US 2009033251 A1	05-02-2009
US 8487568 B2	16-07-2013	CN 102089963 A	08-06-2011
		DE 102008037064 A1	11-02-2010
		EP 2308164 A1	13-04-2011
		US 2011133677 A1	09-06-2011
		WO 2010015322 A1	11-02-2010
US 2014239869 A1	28-08-2014	CN 103906650 A	02-07-2014
		DE 102011085731 A1	08-05-2013
		US 2014239869 A1	28-08-2014
		WO 2013064486 A2	10-05-2013
WO 2013182212 A1	12-12-2013	EP 2856634 A1	08-04-2015
		US 2015306972 A1	29-10-2015
		WO 2013182212 A1	12-12-2013
US 2013293165 A1	07-11-2013	CN 103269901 A	28-08-2013
		DE 102010064317 A1	05-07-2012
		EP 2658738 A2	06-11-2013
		KR 20130133801 A	09-12-2013
		US 2013293165 A1	07-11-2013
		WO 2012089398 A2	05-07-2012