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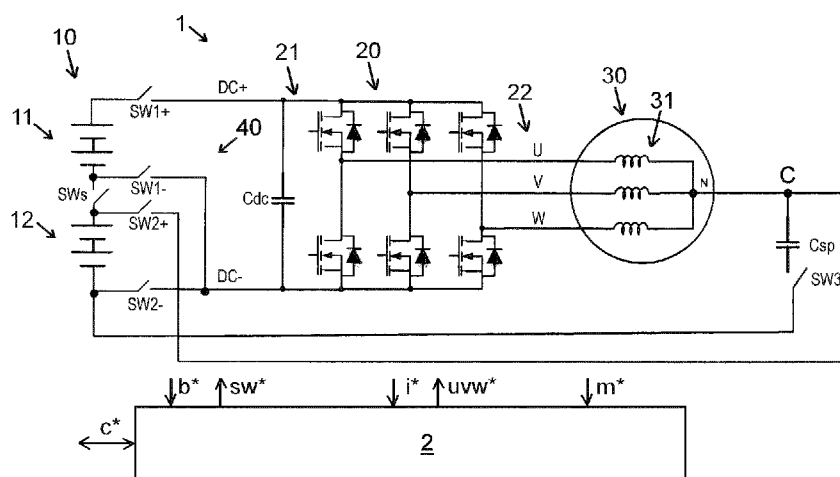


Fig. 1

(57) Abstract: The invention proposes an electric drive system (1) comprising an electric storage (10) having first and second batteries (11, 12); a multi-phase inverter (20) having a DC terminal side (21) and an AC terminal side (22); a multi-phase AC electric machine (30) comprising a winding arrangement (31) electrically coupled to the AC terminal side (22) of the inverter (20); a connecting arrangement (40) comprising electrical connection paths with controllable switches (SW1+, SW1-, SWs, SW2+, SW2-, SW3, SW4, SW5, SW6) for establishing and interrupting electrical connections, for providing a drive mode and a transfer mode of the electric drive system (1). In the drive mode, one or both of the first and second batteries (11, 12) are electrically coupled to the DC terminal side (21), for supplying electrical energy from the respective battery or both batteries (11, 12) via the inverter (20) to the electric machine (30), or vice versa. In the transfer mode, the first battery (11) is electrically coupled to the DC terminal side (21) and the second battery (12) is electrically coupled to the winding arrangement (31) of the electric machine (30), for transferring electrical energy from the first battery (11) via the inverter (20) and the winding arrangement (31) to the second battery (12), or vice versa. Advantageously, the invention enables a battery self-heating as well as a battery balancing, according to need. The invention further proposes a corresponding control device and control method for such a drive system (1).

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**ELECTRIC DRIVE SYSTEM, CONTROL DEVICE AND CONTROL METHOD FOR SUCH
A DRIVE SYSTEM AND COMPUTER PROGRAM**

Description

Electric drive system, control device and control method for such a drive system

- 5 The present invention relates to an electric drive system and to a control device and a control method for such an electric drive system, in particular for use in a vehicle such as a battery electric vehicle (BEV) or a hybrid electric vehicle (HEV).

Such electric drive systems are known from the prior art, usually comprising the
10 following components:

- an electric storage comprising one or more batteries,
 - a controllable bidirectional multi-phase inverter having a DC terminal side
15 and an AC terminal side,
 - a multi-phase AC electric machine comprising a winding arrangement (for example stator windings) electrically coupled to the AC terminal side of the inverter,
- 20 wherein in a drive mode of the electric drive system, the one or more batteries are electrically coupled to the DC terminal side of the inverter, for supplying electrical energy from the battery or batteries via the inverter to the electric machine (propulsion mode), or vice versa (recuperation mode).

25 In cold conditions, the batteries of such a drive system need to be preheated before operation, whether an operation in the above mentioned drive mode or an operation in a charge mode (especially when charging at high power), in which the batteries of the electric storage are coupled to an electric charging device.

30 For this use case, in the prior art a big and costly heater was often used to perform the preheating. In such cases, the preheating is carried out, for example, by heating a cooling liquid, which then heats a cooling plate of the respective battery. In order to enable a "self-heating" of batteries, another solution was presented in which the energy storage is divided into two smaller packs (batteries) and a DC/DC converter
35 is connected therebetween to transfer energy back and forth between the two battery packs. In this way, the electrical losses generated by the battery cells in the batteries can heat up the batteries without the need for external heating. Although this solution looks promising, the additional DC/DC converter disadvantageously

adds cost and volume to the electric drive system or powertrain of a respective vehicle.

In particular in autonomous driving (AD) applications, an electric storage is typically divided into two battery packs (batteries). The main reason for this is to increase the system's redundancy. In case of one battery is defect, the other one can be used to drive the vehicle. To increase the DC charging flexibility, the two batteries can be switched/connected either in series or in parallel. This means, the battery arrangement can provide two different levels of voltage to a DC-link of a charging device and advantageously can charge from different charging stations. Having two batteries to be switched from series to parallel and vice versa is not a trivial task. One must take care of the balancing of the batteries (i.e. matching in respect of their charge states and/or voltage levels), especially when switched from series to parallel. Using conventional passive or active balancing techniques according to the prior art, this can take a long time since small and cheap electronics are used to accomplish the balancing.

It is an object of the invention to overcome the aforementioned disadvantages and to provide an electric drive system as well as control device and a control method for such an electric drive system which allow in a simple way to heat and/or balance the batteries of an electric storage in the electric drive system.

The object is achieved by the features of the independent patent claims. Advantageous embodiments are indicated in the dependent claims.

According to a first aspect the object is achieved by an electric drive system. The electric drive system comprises:

- an electric storage comprising a first battery and a second battery,
- a controllable bidirectional multi-phase inverter having a DC terminal side and an AC terminal side,
- a multi-phase AC electric machine comprising a winding arrangement electrically coupled to the AC terminal side of the inverter,
- a connecting arrangement comprising electrical connection paths with controllable switches for establishing and interrupting electrical connections, for providing at least

- a drive mode of the electric drive system, in which the first battery or the second battery or a serial arrangement of the first battery and the second battery or

a parallel arrangement of the first battery and the second battery is electrically coupled to the DC terminal side of the inverter, for supplying electrical energy from the respective battery or battery arrangement via the inverter to the electric machine, or vice versa, and

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- a transfer mode of the electric drive system, in which the first battery is electrically coupled to the DC terminal side of the inverter and the second battery is electrically coupled to the winding arrangement of the electric machine, for transferring electrical energy from the first battery via the inverter and the winding arrangement to the second battery, or vice versa.

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Advantageously, the invention enables a battery self-heating as well as a battery balancing by use of components which, at least for the most part, are typically provided anyway as components of the electric drive system in vehicles of the kind interested here (e.g. BEV, HEV, etc.).

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The invention is based on the concept of using the bidirectional inverter and the winding arrangement of the electric machine to perform a DC/DC conversion for transferring electrical energy between the two concerned batteries. With this, by a back and forth transfer, the aforementioned self-heating can be accomplished in the "transfer mode" according to the invention. Furthermore, also the balancing of two batteries can be accomplished in such a transfer mode by a transfer of a suitable amount of energy from one to the other of these batteries.

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In an embodiment, the DC terminal side of the inverter comprises a positive terminal (and a corresponding line) of the inverter and a negative terminal (and corresponding line) of the inverter and the AC terminal side of the inverter comprises multiple AC phase terminals (and corresponding lines), wherein the inverter comprises multiple series connections each comprising an upper switch (e.g. MOSFET) connected to the positive terminal and a lower switch (e.g. MOSFET) connected to the negative terminal of the inverter, with a respective one of the AC phase terminals of the inverter formed therebetween. In this respect, the concrete design of the inverter in the present invention can advantageously be based on well-established inverter configurations known from the prior art.

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In an embodiment, the electric machine is a synchronous machine in which the winding arrangement of the electric machine is formed by multiple stator windings of the electric machine. Also in this respect, the concrete design of the electric

machine can advantageously be based on well-established configurations known from the prior art.

In an embodiment, the connecting arrangement comprises one or more, and in particular all, of the following connection paths:

- a connection path with a controllable switch between a positive terminal of the first battery and a positive terminal of the inverter,
 - a connection path with a controllable switch between a negative terminal of the first battery and a negative terminal of the inverter,
 - 10 - a connection path with a controllable switch between the negative terminal of the first battery and a positive terminal of the second battery,
 - a connection path with a controllable switch between a positive terminal of the second battery and a connection node at the winding arrangement,
 - a connection path with a controllable switch between a negative terminal of the second battery and the negative terminal of the inverter,
 - 15 - a connection path with a controllable switch and a capacitor between the negative terminal of the second battery and the connection node at the winding arrangement.
- 20 The "connection node" at the winding arrangement can be a node in the system's electrical circuit arrangement, which is electrically connected to an end (terminal) of at least one of the multiple windings which constitute the winding arrangement.

For example, in an embodiment, the winding arrangement of the electric machine is formed by multiple (for example three) stator windings in star configuration, wherein the connection node at the winding arrangement is the star-point of the star configuration.

According to another embodiment, the winding arrangement of the electric machine is formed by multiple (for example three) stator windings in star configuration, wherein the connecting arrangement further comprises a controllable switch in a phase line connecting one of the AC phase terminals of the inverter to a respective one (winding terminal) of the stator windings of the electric machine, and wherein the connection node at the winding arrangement is a node at the phase line between the controllable switch and the respective stator winding.

In still another embodiment, the winding arrangement of the electric machine is formed by multiple (for example three) stator windings in delta configuration,

wherein the connecting arrangement further comprises a controllable switch in a phase line connecting one of the AC phase terminals of the inverter to a respective terminal node (at a "delta corner") of the winding arrangement, and wherein the connection node at the winding arrangement is said terminal node of the winding arrangement.

According to a second aspect the object is achieved by an electric drive system comprising:

- 10 - an electric storage comprising the first battery and the second battery,
- first and second controllable bidirectional multi-phase inverters each having a DC terminal side and an AC terminal side,
- first and second multi-phase AC electric machines each comprising a winding arrangement electrically coupled to the AC terminal side of a respective one
- 15 of the first and second inverters,
- a connecting arrangement comprising electrical connection paths with controllable switches for establishing and interrupting electrical connections, for providing at least
- 20 - the drive mode of the electric drive system, in which the first battery is electrically coupled to the DC terminal side of the first inverter, for supplying electrical energy from the first battery via the first inverter to the first electric machine, or vice versa, and in which the second battery is electrically coupled to the DC terminal side of the second inverter, for supplying electrical energy from the
- 25 second battery via the second inverter to the second electric machine, or vice versa, and
- the transfer mode of the electric drive system, in which the first battery is electrically coupled to the DC terminal side of the first inverter and the second
- 30 battery is electrically coupled to the DC terminal side of the second inverter, such that the second battery is indirectly electrically coupled, via the second inverter and the winding arrangement of the second electric machine, to the winding arrangement of the first electric machine, for transferring electrical energy from the first battery via the first inverter, the winding arrangement of the first electric
- 35 machine, the winding arrangement of the second electric machine and the second inverter to the second battery, or vice versa.

According to an embodiment of the second aspect, the connecting arrangement comprises

- a connection path, optional with a controllable switch, between a positive terminal of the first battery and a positive terminal of the first inverter,
- 5 - a connection path, optional with a controllable switch, between a negative terminal of the first battery and a negative terminal of the first inverter,
- a connection path, optional with a controllable switch, between a positive terminal of the second battery and positive terminal of the second inverter,
- a connection path, optional with a controllable switch, between a negative terminal of the second battery and a negative terminal of the second inverter,
- 10 - a connection path, optional with a controllable switch, between the negative terminal of the first inverter and the negative terminal of the second inverter,
- a connection path with a controllable switch between a connection node at the winding arrangement of the first electric machine and a connection node at the winding arrangement of the second electric machine.
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The above statements about the (one) connection node in a system with one electrical machine analogously also apply to each of the (two) connection nodes in the system with first and second electrical machines, i.e. each connection node can be a node which is electrically connected to a winding terminal of at least one winding constituting the respective winding arrangement.

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In an embodiment according to the second aspect, the winding arrangements of the first and second electric machines each are formed by multiple (for example three) stator windings in a respective star configuration, wherein the connection nodes at the winding arrangements each are the star-point of the respective star configuration.

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In an embodiment according to the second aspect, the winding arrangements of the first and second electric machines each are formed by multiple (for example three) stator windings in a respective star configuration, wherein the connecting arrangement further comprises a controllable switch in a phase line connecting one of the AC phase terminals of the first inverter to a respective one (i.e. winding terminal) of the stator windings of the first electric machine, wherein the connecting arrangement further comprises a controllable switch in a phase line connecting one of the AC phase terminals of the second inverter to a respective one (i.e. winding terminal) of the stator windings of the second electric machine, and wherein the

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connection nodes at the winding arrangements each are a node at the phase line between the respective controllable switch and the respective stator winding.

5 In an embodiment according to the second aspect, the drive system further comprises a DC charging terminal device comprising a positive charging terminal and a negative charging terminal, wherein the connecting arrangement further provides a charging mode of the electric drive system, in which the first battery or the second battery or a serial arrangement of the first battery and the second battery or a parallel arrangement of the first battery and the second battery is electrically
10 coupled to the DC charging terminal device, for supplying electrical energy from the DC charging terminal device to the respective battery or battery arrangement, or vice versa.

15 In an embodiment according to the second aspect, the connection arrangement of the drive system is configured in such a way that more than one of the aforementioned coupling options, and in particular all of these coupling options (i.e. first battery, second battery, both batteries in series, and both batteries in parallel electrically coupled to the charging terminal device) can be implemented as desired.

20 For example, in an embodiment, the connecting arrangement comprises

- a connection path with a controllable switch between the positive charging terminal and the positive terminal of the first battery,
- a connection path with a controllable switch between the negative charging terminal and the negative terminal of the first battery,
- 25 - a connection path with a controllable switch between the positive charging terminal and the positive terminal of the second battery,
- a connection path with a controllable switch between the negative charging terminal and the negative terminal of the second battery.

30 According to a third aspect the above-mentioned object is achieved by a control device for controlling an electric drive system of the type described herein. The control device comprises:

- a communication interface for receiving information representative of an operating mode of the drive system to be controlled,
- 35 - a selection module for selecting an operating mode of the drive system to be controlled according to the received information,
- a switch control module for controlling the controllable switches of the connecting arrangement for providing the selected operating mode, and

- an inverter control module for controlling the inverter for providing a transfer of electrical energy according to the provided operating mode.

The selection module, the switch control module and the inverter module can be implemented as software modules, each comprising one or more computer programs, the computer programs being executed by means of one or more processors/controllers, or as hardware modules comprising one or more special electrical circuits, or as hybrid modules comprising software components and hardware components.

Here, the operating modes from which a selection is made can include, in addition to the aforementioned drive mode and the aforementioned transfer mode, in particular a charging mode, for example.

In an embodiment, the control method for controlling an electric drive system comprises:

- receiving information representative of an operating mode of the drive system to be controlled,
- selecting an operating mode of the drive system to be controlled according to the received information,
- controlling the controllable switches of the connecting arrangement for providing the selected operating mode, and
- controlling the inverter for providing a transfer of electrical energy according to the provided operating mode.

According to a fourth aspect, the above-mentioned object is achieved by a computer program comprising instructions which, when the program is executed by a computer cause the computer to perform the method according to the third aspect.

In the context of this document, mentioning of such a computer program is synonymous with the term program element and/or a computer program product containing instructions for controlling a computer to suitably coordinate the operation of a system or method to achieve the effects associated with the method of the invention. The computer program may be implemented as computer readable instruction code in any suitable programming language such as JAVA, C++, etc.

The computer comprises a processor and a program memory. Alternatively, the program memory may be associated with the computer. The processor may have a

central processing unit (CPU). The processor may be a general-purpose processor, a microprocessor, a microcontroller, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA), or other programmable logic device, a discrete gate or transistor logic device, a discrete hardware component, or the like.

According to a fourth aspect, the above-mentioned object is achieved by a computer-readable medium comprising instructions which, when executed by a control computer of "a high-voltage system of an electric vehicle", cause the control computer,

The computer may be implemented by a program-controlled control device (of the type described herein), for example installed or available/useable in a vehicle. The computer program may be stored on a computer-readable storage medium (CD-Rom, DVD, Blu-ray disc, removable drive, volatile or non-volatile memory, built-in memory/processor, etc.). The instruction code may program a computer or other programmable device, such as in particular a control unit for an electric vehicle, in such a way that the desired functions are executed. Further, the computer program may be provided on a network, such as the Internet, from which it may be downloaded by a user as needed.

According to a further aspect of the invention, a use of an electric drive system of the type described herein in a vehicle, such as for example a battery electric vehicle (BEV) or a hybrid electric vehicle (HEV), is proposed. In this case, the electric drive system can constitute the powertrain of the vehicle or at least a component of such powertrain.

The invention will now be described by way of exemplary embodiments with reference to the accompanying drawings, in which

Fig. 1 shows a first example of an electric drive system, comprising an electric machine in star configuration and an inverter providing a three-phase operation in a "transfer mode" of the electric drive system,

Fig. 2 illustrates a "boost operation" in the transfer mode of the system shown in Fig. 1,

Fig. 3 illustrates a "buck operation" in the transfer mode of the system shown in Fig. 1,

Fig. 4 shows a second example of an electric drive system, also having the electric machine in star configuration, but providing a two-phase operation in the transfer mode,

Fig. 5 shows a third example of an electric drive system, having the electric machine configured in delta connection, illustrating the drive mode of the system,

Fig. 6 illustrates the transfer mode of the system shown in Fig. 5,

Fig. 7 shows a fourth example of an electric drive system, comprising two batteries, two inverters and two electric machines (according to a "two drive" redundancy concept), having both electric machines in star configuration and providing a three-phase operation in the transfer mode of the system,

Fig. 8 shows a fifth example of an electric drive system, similar to the fourth example, but providing a two-phase operation in the transfer mode,

Fig. 9 illustrates a basic concept of an electric drive system according to a sixth example,

Fig. 10 shows the sixth example of an electric drive system,

Fig. 11 illustrates the drive mode of the electric drive system 1 shown in Fig. 10,

Fig. 12 illustrates the transfer mode of the electric drive system 1 shown in Fig. 10,

Fig. 13 shows a flowchart illustrating an example of a method for controlling an electric drive system, and

Fig. 14 shows a seventh example of an electric drive system.

Fig. 1 shows an electric drive system 1 installed in a vehicle for driving the same, according to a first example, comprising:

- an electric storage 10 comprising a first battery 11 and a second battery 12;
- a controllable bidirectional multi-phase inverter 20 having a DC terminal side 21 with terminal lines DC+ and DC- and an AC terminal side 22 with AC phase lines U, V, W;

- 5 - a multi-phase AC electric machine 30 comprising a winding arrangement 31 electrically coupled to the AC terminal side 22 of the inverter 20; and
- a connecting arrangement 40 comprising electrical connection paths with controllable switches for establishing and interrupting corresponding electrical connections as shown in Fig. 1.

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As shown Fig. 1, the two terminal lines DC+ and DC- can be connected via a capacitor (buffer capacitor) Cdc. In the example, the AC terminal side 22 of the inverter 20 is formed by the three AC phase lines U, V, W for conducting corresponding (three) phase currents between the inverter 20 and the winding arrangement 31 (e.g. three stator windings in the example) of the electrical machine 30. The winding arrangement 31 and thus the electrical machine 30 in this example has a star configuration with a star-connection point N, i.e. for each winding, a first winding terminal is connected to the star point N, whereas the second winding terminal is connected to a respective one of the multiple AC phase lines U, V and W.

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In the example, the connecting arrangement 40 comprises:

- a connection path with a controllable switch SW1+ between a positive terminal of the first battery 11 and the positive terminal DC+ of the inverter 20,
- a connection path with a controllable switch SW1- between a negative terminal of the first battery 11 and the negative terminal DC- of the inverter 20,
- a connection path with a controllable switch SWs between the negative terminal of the first battery 11 and a positive terminal of the second battery 12,
- a connection path with a controllable switch SW2+ between the positive terminal of the second battery 12 and a connection node C at the winding arrangement 31 (which connection node C in the example is equivalent to the star-connection point N),
- a connection path with a controllable switch SW2- between a negative terminal of the second battery 12 and the negative terminal DC- of the inverter 20,
- a connection path with a controllable switch SW3 and (in series) a capacitor Csp between the negative terminal of the second battery 12 and the connection node C at the winding arrangement 31.

With the connecting arrangement 40 comprising the above-mentioned electrical connection paths, the electric drive system 1 can provide

- a drive mode of the electric drive system 1, in which a serial arrangement of the first battery 11 and the second battery 12 is electrically coupled to the DC terminal side 21 of the inverter 20, for supplying electrical energy from the battery arrangement 11, 12 via the inverter 20 to the electric machine 30 (propulsion mode), or vice versa (recuperation mode), and
- a transfer mode of the electric drive system 1, in which the first battery 11 is electrically coupled to the DC terminal side 21 of the inverter 20 and the second battery 12 is electrically coupled to the winding arrangement 31 of the electric machine 30, for transferring electrical energy from the first battery 11 via the inverter 20 and the winding arrangement 31 to the second battery 12, or vice versa.

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In the example shown in Fig. 1, the winding arrangement 31 of the electric machine 30 is formed by multiple (in the example: three) stator windings in star configuration, i.e. the electric machine 30 is configured in star-point connection, wherein the connection node C at the winding arrangement 31 is (equivalent to) the star-point N of the star configuration (since electrically connected therewith) as shown in Fig. 1.

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The electric drive system 1 is controlled by a control device 2 comprising a communication interface for receiving information c^* representative of an operating mode of the drive system 1 to be controlled. During operation of the vehicle, the information c^* is provided, for example, by a superordinate control device (e.g. central control unit, ECU) of the vehicle, to which, for example, via the same interface, also information concerning the operating state of the drive system 1 or operating parameters (voltages, currents, temperatures etc.) detected by sensors in the drive system 1 can be communicated to vehicle electronics, for example back to such a superordinate control device.

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The latter operating parameters may include, for example, information b^* concerning an operating state of the batteries 11, 12 (e.g. their states of charge (SoC), voltage levels, temperature(s), etc.), information i^* concerning an operating state of the inverter 20 (e.g. voltages and/or currents detected at the inverter), and information m^* concerning an operating state of the electric machine 30 (e.g. its rotational speed, etc.).

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The control device 2 further comprises a selection module for selecting an operating mode of the drive system 1 to be controlled according to the received information c^* ; a switch control module for controlling the controllable switches SW1+, SW1-, SW2+, SW2-, SWs, SW3 of the connecting arrangement 40 for providing the
5 selected operating mode; and an inverter control module for controlling the inverter 20 for providing a transfer of electrical energy according to the provided operating mode. The operating modes from which a selection is made include in particular the aforementioned drive and transfer modes.

10 In the example, the control device 2 is formed by a program-controlled electronic control device, on which a control program (software) for controlling the system 1 runs. Accordingly, the aforementioned "modules" of the control device 2 are suitably implemented here as corresponding partial functionalities of this control program.

15 For the controlling of the controllable switches SW1+, SW1-, SW2+, SW2-, SWs, SW3 of the connecting arrangement 40, the control device 2 generates and outputs corresponding control signals sw^* to these switches (for providing the selected operating mode in the electrical drive system 1).

20 As can be seen in Fig. 1, the electric storage 10 comprises a high voltage (HV) battery arrangement (e.g. 800 V) divided into two battery packs, i.e. the first battery 11 and the second battery 12 (e.g. 400 V each). In the aforementioned drive mode (for example when driving the vehicle), according to the shown example these two batteries 11, 12 are connected in series in order to deliver the requested traction
25 performance. In this case (drive mode) the switches SWs, SW1+, SW2- are closed, while SW1-, SW2+, SW3 are open.

In case, however, the battery arrangement needs to be preheated (for example in cold conditions before driving the vehicle), then, in the aforementioned transfer
30 mode, the two batteries 11, 12 are electrically split from one another by opening the switches SWs and SW2-. Rather, in the transfer mode, the first battery 11 is connected via the switches SW1+ and SW1- to the DC-link side 21, i.e. the terminal lines DC+, DC- of the inverter 20, while the second battery 12 is connected via the switches SW2+ and SW3 to the connection node C and the capacitor Csp,
35 respectively, wherein the capacitor Csp is also connected to the connection node C and thus to the star-point terminal N of the electric machine 30, as shown in Fig. 1.

Then, in the transfer mode, using the inductances of the three windings of the winding arrangement 31 of the electric machine 30 and the three-phase half bridges of the inverter 20, a DC/DC conversion can be achieved for transferring electrical energy from the first battery 11 via the inverter 20 and the winding arrangement 31 to the second battery 12, or vice versa.

This energy transfer is controlled by the inverter control module of the control device 2, which generates and outputs corresponding control signals uvw^* to the inverter 20 (for suitably switching the shown half bridges in the inverter 20). Using this circuit configuration and by adjusting the voltage set-point of each side by the inverter control module of the control device 2, the inverter 20 and the electric machine 30 are able to shuttle electrical energy back and forth between the two batteries 11, 12.

First, to start to move the energy from battery 12 to battery 11 by using a "boost mode" operation of the inverter 20 as shown (by current flow arrows) in Fig. 2. This function allows the batteries 11, 12 to be heated up. Next, the energy is shuttled back to the battery 11 by using the "buck mode" functionality as shown (by current flow arrows) in Fig. 3.

The performance of the DC/DC conversion is approximately the same performance as in the drive mode. By having this, the two batteries 11, 12 can be heated up very quickly and without adding any extra device. Advantageously, reusing the powertrain components enables the battery self-heating. In addition, the two batteries 11, 12 at the end of preheating process (and/or during the preheating process) can be balanced by using the inverter 20 and the electric machine 30. The controllable switches (SW1+, SW1-, ...) can comprise, for example, switching transistors (e.g., MOSFETs) or, e.g., relays or the like.

In summary, the operations for transfer of electrical energy are controlled by the control device 2, which defines the operating mode of the electrical drive system 1, including the direction of the corresponding electrical energy flow (by appropriately adjusting the voltage set-points of the inverter 20).

Instead of preheating the batteries 11, 12, the transfer mode can also serve to balance the two batteries 11, 12. This also applies to all other examples described herein.

In the first example, which is shown in Fig. 1 to 3, there is provided a three-phase operation of the inverter 20 for performing the transfer mode, using an electric machine 30 formed in star configuration. However, as will be evident from further exemplary embodiments (examples) described below, such details can also be modified.

In this following description of further exemplary embodiments, the same reference signs are used for the same components. Essentially, only the differences to the exemplary embodiment(s) described above will be discussed and, moreover, the description of the preceding exemplary embodiments is hereby referred to expressly.

For the sake of simplicity, a control device used for controlling the respective drive system is omitted in the figures of the succeeding examples. However, such a control device can be designed and function in particular as already described above with reference to Fig. 1.

Fig. 4 shows an electric drive system 1 according to a second example, in which the winding arrangement 31 of the electric machine 30 is also formed by multiple stator windings in star configuration, as in the example of Fig. 1 to 3.

However, in this example of Fig. 4, the connecting arrangement 40 further comprises a controllable switch SW4 in an AC phase line (W in the example) connecting one of the AC phase terminals of the inverter 30 to a respective one of the stator windings of the electric machine 30. A further modification to the first example is that the connection node C at the winding arrangement 31 is a node at this AC phase line W between the controllable switch SW4 and the respective stator winding.

In this example, for performing the transfer mode, a "two-phase operation" of the inverter 20 is foreseen, where one inverter leg (W in Fig. 4) is disconnected from the inverter 20 by the controllable switch SW4, and the respective (W) AC phase terminal of the electric machine 30 (winding arrangement 31) is connected to the second battery 12 as shown in Fig. 4. Besides, the same concept can be extended to a "single-phase" operation for performing the transfer mode.

Fig. 5 shows an electric drive system 1 according to a third example, in which the electric machine 30 is configured in delta connection, i.e. the winding arrangement 31 thereof is formed by multiple (three) stator windings in delta configuration.

5 Furthermore, the connecting arrangement 40, in addition to the switches SW1+, SW1-, SW2+, SW2-, SWs, SW3 provided in the first and second examples (star-connection topology), further comprises a controllable switch SW4 in an AC phase line (V in the example) connecting one (V) of the AC phase terminals of the inverter 20 to a respective terminal node ("delta corner") of the winding arrangement
10 31. The connection node C at the winding arrangement 31 in this example is said terminal node of the winding arrangement 31, as shown in Fig. 5.

With this topology, as shown in Fig. 5, in the drive mode the switches SW1+, SWs, SW2- and SW4 are closed, while SW1-, SW2+, SW3 are open.

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In the transfer mode the switches SW1+, SW1-, SW2+ and SW3 are closed, while SW2- and SW4 are open.

Fig. 6 illustrates the transfer mode of the electric drive system 1 in the third example.
20 In this transfer mode, for example a heating mode during standstill of the vehicle, as shown in Fig. 6, one inverter leg (phase line V in this example) is disconnected from the corresponding (V) terminal of the delta sides of the winding arrangement 31. Accordingly, to allow energy transfer from one of the batteries 11, 12 to the other one, the switches SW1+, SW1-, SW2+, SW3 are closed.

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Thus in summary, in the third example (Fig. 5 and 6), there is provided a two-phase operation of the inverter 20 for performing the transfer mode, using an electric machine 30 configured in delta connection.

30 In the future, for many electric vehicles and in particular to fulfill demanding autonomous driving requirements, a redundancy concept is needed. One of the options is to use an electric storage comprising (at least) two batteries and (at least) two electric drive units each comprising an electric machine. In order to reuse the two drivetrain components to heat up and/or balance the two batteries, an electric
35 drive system 1 as shown in Fig. 7 can be used.

Fig. 7 shows an electric drive system 1 according to a fourth example, comprising:

- the electric storage 10 comprising the first battery 11 and the second battery 12,
- first and second controllable bidirectional multi-phase inverters 20-1, 20-2 each having a DC terminal side 21 (with DC lines DC+ and DC-) and an AC terminal side 22 (with AC phase lines U, V, W in the example),
- first and second multi-phase AC electric machines 30-1, 30-2 each comprising a winding arrangement 31-1, 31-2 electrically coupled to the AC terminal side 21 of a respective one of the first and second inverters 20-1, 20-2,
- the connecting arrangement 40 comprising electrical connection paths with controllable switches for establishing and interrupting electrical connections, for providing the drive mode and the transfer mode.

In the shown example, the connecting arrangement 40 comprises

- a connection path with a controllable switch SW1+ between a positive terminal of the first battery 11 and a positive terminal (line DC+) of the first inverter 20-1,
- a connection path with a controllable switch SW1- between a negative terminal of the first battery 11 and a negative terminal (line DC-) of the first inverter 20-1,
- a connection path, optional with a controllable switch SW2+ between a positive terminal of the second battery 12 and positive terminal (line DC+) of the second inverter 20-2,
- a connection path with a controllable switch SW2- between a negative terminal of the second battery 12 and a negative terminal (line DC-) of the second inverter 20-2,
- a connection path with a controllable switch SW3 between the negative terminal (line DC-) of the first inverter 20-1 and the negative terminal (line DC-) of the second inverter 20-2,
- a connection path with a controllable switch SW4 between a connection node at the winding arrangement 31 of the first electric machine 30-1 and a connection node at the winding arrangement 31 of the second electric machine 30-2.

In this example, the winding arrangements 31 of the first and second electric machines 30-1, 30-2 each are formed by multiple stator windings in a respective star configuration, and the aforementioned "connection nodes" (connected via the connection path comprising the switch SW4) at the winding arrangements 31 are the star-points of the respective star configurations.

In the drive mode of the electric drive system 1, the two electric machines 30-1, 30-2 are kept separated by keeping the switches SW3 and SW 4 open. In this mode, the first battery 11 is electrically coupled to the DC terminal side 21 of the first inverter 20-1, for supplying electrical energy from the first battery 11 via the first inverter 20-1 to the first electric machine 30-1, or vice versa, whereas the second battery 12 is electrically coupled to the DC terminal side 21 of the second inverter 20-2, for supplying electrical energy from the second battery 12 via the second inverter 20-2 to the second electric machine 30-2, or vice versa.

In the transfer mode of the electric drive system 1, the switches SW3 and SW4 are closed. In this mode the first battery 11 is still electrically coupled to the DC terminal side 21 of the first inverter 20-1 and the second battery 12 is still electrically coupled to the DC terminal side 21 of the second inverter 20-2.

However, in the transfer mode the second battery 12 is indirectly electrically coupled, namely via the second inverter 20-2 and the winding arrangement 31 of the second electric machine 30-2, and the paths with the (closed) switches SW3 and SW4, to the winding arrangement 31 of the first electric machine 30-1.

Therefore, in the transfer mode, electrical energy can be transferred from the first battery 11 via the first inverter 20-1, the winding arrangement 31 of the first electric machine 30-1, the winding arrangement 31 of the second electric machine 30-2 and the second inverter 20-2 to the second battery 12, or vice versa.

In this way, in the transfer mode, the first and second drives are working as buck boost converters (by means of suitable control of the inverters 20-1, 20-2). To transfer electrical energy from battery 11 to battery 12, the first drive (with first inverter 20-1 and first electric machine 30-1) works as buck DC/DC converter, while the second drive (with second inverter 20-2 and second electric machine 30-2) works as boost DC/DC converter. The two buck and boost DC/DC converters add high flexibility to the operation.

A control device (not shown in Fig. 7) used to control the drive system 1 can be designed and function as already described with reference to Fig. 1, but in this case (Fig. 7) controls (with outputted signals uvw*) both inverters 20-1, 20-2 in a coordinated manner.

It is noted that the provision of the switches SW1+, SW1-, SW2+ and SW2- here is mainly useful for other reasons, including safety reasons (as is also the case in other of the examples described herein), but for instance in the example of Fig. 7 are not absolutely necessary for the principal functionality of the drive system 1.

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In summary, in the fourth example according to Fig. 7, there is provided a three-phase operation of two inverters 20-1, 20-2 for performing the transfer mode, using two electric machines 30-1, 30-2 each configured in star connection. For efficiency and operation improvement, two phase operation would also be possible.

10 A corresponding example is shown in Fig. 8.

Fig. 8 shows an electric drive system 1 according to a fifth example. As in the previous example (Fig. 7), the winding arrangements 31 of first and second electric machines 30-1, 30-2 each are formed by multiple stator windings in a respective star configuration.

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In difference to the previous example (Fig. 7), however, in the fifth example according to Fig. 8 the connecting arrangement 40 comprises

- a controllable switch SW5 in a phase line (W in the example) connecting one (W) of the AC phase terminals of the first inverter 20-1 to a respective one (W) of the stator windings of the first electric machine 30-1, and
- a controllable switch SW6 in a phase line (W in the example) connecting one (W) of the AC phase terminals of the second inverter 20-2 to a respective one (W) of the stator windings of the second electric machine 30-2,

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A further difference is that connection nodes C (at the ends of the connection path comprising the switch SW4) at the winding arrangements 31 each are a node at the aforementioned AC phase line W, between the respective controllable switch SW5 or SW6, respectively, and the stator winding of the respective one of the winding arrangements 31.

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Thus, in this example of Fig. 8, the switches SW5 and SW6 are used to disconnect one inverter leg (AC phase line W in the example) of the first inverter 20-1 and the second inverter 20-2 in the transfer mode.

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In summary, in the fifth example according to Fig. 8, there is provided a two-phase operation of two inverters 20-1, 20-2 for performing the transfer mode, using two electric machines 30-1, 30-2 each configured in star connection.

As already mentioned above, in autonomous driving (AD) applications, a high-voltage (HV) battery can be divided in two batteries for increasing the system's redundancy. In case of one battery is defect, the other one can be used to drive the vehicle to the destination.

Furthermore, such a battery arrangement divided in two batteries (first and second batteries) can advantageously also provide an increased DC charging flexibility, as will be described hereinafter with reference to Fig. 9 to 12.

Fig. 9 illustrates a basic concept of an electric drive system 1 according to another example, further comprising a DC charging terminal device 50 comprising a positive charging terminal and a negative charging terminal, which are connected via connection paths comprising controllable switches Ch+ and Ch- to the DC terminal side 21 of the inverter 20, i.e. lines DC+ and DC-.

The vehicle's DC charging terminal device 50 can for example be used for charging (or discharging) the electric storage 10 by means of an external charging station, when the terminal device 50 is connected to such a charging station.

In the shown example, the inverter 20 and the electric machine 30 in delta connection is considered as an example for the electric drivetrain in a vehicle. This can also be modified.

In the concept shown in Fig. 9, a connecting arrangement 40 of the electric drive system 1 provides a charging mode of the electric drive system 1, in which the first battery 11 or the second battery 12 or a serial arrangement of the first battery 11 and the second battery 12 or a parallel arrangement of the first battery 11 and the second battery 12 is electrically coupled to the DC charging terminal device 50, for supplying electrical energy via the DC charging terminal device 50 to the respective battery or battery arrangement (serial arrangement or parallel arrangement), or vice versa.

To this end, in the shown example, the connecting arrangement 40 comprises

- a connection path with a controllable switch SW1+ between the positive charging terminal (or switch Ch+ in the example) and the positive terminal of the first battery 11,

- a connection path with a controllable switch SW1- between the negative charging terminal (or switch Ch- in the example) and the negative terminal of the first battery 11,
- a connection path with a controllable switch SWs between the negative terminal of the first battery and the positive terminal of the second battery,
- a connection path with a controllable switch SW2+ between the positive charging terminal and the positive terminal of the second battery 12, and
- a connection path with a controllable switch SW2- between the negative charging terminal and the negative terminal of the second battery 12.

Since the DC charging terminal device 50 is connected via the switches Ch+ and Ch- to the electric storage 10 (for connecting/disconnecting the electric storage 10 to/from the DC charging terminal device 50), in the charging mode the switches Ch+ and Ch- have to be closed.

Advantageously, with the configuration as shown in Fig. 9, the two batteries 11, 12 can be switched/connected either in series or in parallel for performing the charging mode.

Namely, in case of switches SW1+, SWs, SW2- are closed and switches SW1- and SW2+ are open, the batteries 11, 12 are connected in series and the DC-link voltage (at the charging terminal device 50) is the sum of the voltages of both batteries 11 and 12 (for example $2 \times 400 \text{ V} = 800 \text{ V}$).

In case of switches SW1+, SW1-, SW2+, SW2- are closed and switch SWs is open, the two batteries 11 and 12 are connected in parallel. In this case the voltages of the two batteries 11, 12 should be equal (for example 400 V both).

This means, the electric storage 10 can provide two levels of voltage to the DC-link of the charging terminal device 50 and therefore can advantageously be charged (or discharged) at different charging stations (for example providing 400V or 800V).

Having the two batteries 11, 12 to be switched from series to parallel and vice versa is not a trivial task. One must take care of the balancing of the batteries 11, 12, especially when switched from series to parallel. The state of charges (SoCs) of the two batteries must be more or less equalized before to be switched in parallel. Using the state-of-the-art passive or active balancing techniques (inside a battery pack forming a respective battery), this can take a long time in particular when small and

cheap electronics are used to achieve such a balancing. During charging the two batteries SoCs can be deviating due to a difference in internal resistances, capacities, and temperatures. Even after complete charging, for example, one can not directly switch two battery packs in parallel and drive the vehicle. The mismatch
5 between the two batteries in terms of voltage can cause hazards and safety issues. For that reason, after charging (whether in series or in parallel), a balancing of the batteries 11 and 12 has to be accomplished. However, this takes time. In order to reduce the time needed for balancing, one can use high power electronics to allow high energy shuttling between the two batteries. However, this will drive high cost. In
10 order to avoid these disadvantages of the prior art, based on the concept shown in Fig. 9, there can be provided an electric drive system as shown in the Fig. 10 to 12.

Fig. 10 shows an electric drive system 1 according to a sixth example, in which a DC charging terminal device 50 is foreseen (as described above), and in which the
15 winding arrangement 31 of the electric machine 30 is formed by multiple (three in the example) stator windings in delta configuration, as in the (exemplary) basic concept shown in Fig. 9.

However, in this sixth example (Fig. 10) the connecting arrangement 40 further
20 comprises

- a connection path with a controllable switch SW3 and a capacitor Csp between the negative line DC- of the inverter's DC terminal side 21 and a connection node C at the winding arrangement 31, and
- a connection path with a controllable switch SW4 in one of the AC phase
25 lines (V in the example) connecting a respective (V) AC phase terminal of the inverter 20 to a respective (V) terminal node ("delta corner" in the shown delta configuration) of the winding arrangement 31,
wherein the connection node C at the winding arrangement 31 is identical (since electrically connected) to said terminal node of the winding arrangement 31.

In this case, in the transfer mode, by disconnecting one AC phase terminal (of AC phase line V in the example) of the electric machine 30 by the switch SW4 and connecting the extra capacitor Csp via the switch SW3 between said electric machine AC phase terminal and the battery arrangement (batteries 11, 12) as
35 shown in Fig. 10, the winding arrangement 31 and the inverter 20 can advantageously be used, for preheating or balancing the two batteries 11, 12 very quickly and efficiently.

Fig. 11 illustrates the drive mode of the electric drive system 1 shown in Fig. 10. In the drive mode (for example when driving the vehicle), the switches SW1+, SW2-, SWs and SW4 are closed and the switches Ch+, Ch-, SW1-, SW2+ and SW3 are opened. The switch SW3 is open and the switch SW4 is closed in order not to interrupt the normal (driving) operation of the system 1.

Fig. 12 illustrates the transfer mode of the electric drive system 1 shown in Fig. 10. In this transfer mode, the switches SW1+, SW1-, SW2+, SW2-, and SW3 are closed and the switches Ch+, Ch-, SWs, and SW4 are opened.

This reconfiguration by corresponding control of the connecting arrangement 40 allows the electric machine 30 and the inverter 20 to operate as buck/boost DC/DC converter. In the example of Fig. 12, the first battery 11 is connected to the inverter DC-link side 21 and the second battery 12 is connected to the aforementioned electric machine AC phase terminal (connecting node C). By adjusting the voltage set point of the thusly formed DC/DC converter, the control device 2 (not shown in Fig. 12) defines the mode of operation of the converter and the current flow direction, i.e. from battery 11 to battery 12, or vice versa.

The transfer mode can for example be carried out after completion of a charging operation, for example fast charging, in which the electric storage 10 with the batteries 11, 12 connected in series (or in parallel) was charged. After such a charging operation, the two batteries 11, 12 need to be balanced before switching/connecting them in parallel.

In a charging mode for charging/decharging the electric storage 10, the switches Ch+ and Ch- are closed. In this case, the switch SW3 is open and the switch SW4 is closed. With regard to the status of the remaining switches, reference is made to the above description of the concept with reference to Fig. 9. These switches can be switched differently, depending on whether the batteries are to be connected in series or in parallel in the charging mode.

In summary, in the sixth example according to Fig. 10 to 12, the electric drive system 1 comprises an electric machine in delta configuration, wherein a two-phase operation is used in the transfer mode. It is noted, however, that a single-phase operation would also be possible by disconnecting one of the inverter phases legs.

In all the examples described therein, a control device as for example shown in Fig. 1 can be provided for controlling the respective electric drive system 1. Such a control device can for example carry out a control method comprising:

- receiving information (see c* in Fig. 1) representative of an operating mode (including at least a drive mode and a transfer mode) of the drive system to be controlled, i. e. the received information may comprise a temperature of the first battery and/the second battery. For example, if the temperature is below 15°C when starting the vehicle, a preheating of the batteries (transfer mode) is required. Preferably, the received information comprises all the information which is required to select the operating mode appropriate to the situation,
 - selecting an operating mode of the drive system to be controlled according to the received information,
 - controlling the controllable switches in the of the connecting arrangement for providing the selected operating mode, and
 - controlling the inverter (or both inverters) for providing a transfer of electrical energy according to the provided operating mode.
- Fig. 13 is a flowchart illustrating an example of such a control method and the different operating modes of the drive system that are effected by this method. In this example, it is assumed that the control method provides
- a drive mode for supplying electrical energy from the electric storage 10 comprising the batteries 11, 12 to the electric machine 30 (propulsion mode), or vice versa (recuperation mode),
 - a transfer mode for transferring electrical energy from the first battery 11 to the second battery 12, or vice versa, and
 - a charging mode for supplying electrical energy from a DC charging terminal device 50 to the electric storage 10 (charging of electric storage 10), or vice versa (discharging of electric storage 10).

In Fig. 13, the procedure performed by the control device 2 starts at a step S1. In a subsequent step S2, a received information (as c* in Fig. 1) is used to check whether the drive system 1 is to be set to the drive mode. If this is the case, the procedure advances to a step S3, otherwise to a step S4.

In step S3, the connecting arrangement 40 is controlled such that the drive system 1 can be operated in the drive mode.

In the example of the drive system 1 of Figs. 10 to 12, this means that the switches SW1+, SW2-, SWs, SW4 are closed, while the switches SW1-, SW2+, SW3, Ch+,

Ch- are opened. For the other examples, reference is made to the description of the drive mode given for each of them.

5 In step S4, it is checked again on the basis of the received information whether the drive system 1 is to be set to the charging mode. If this is the case, procedure advances to a step S5, otherwise to a step S6.

10 In step S5, the connection arrangement 40 is controlled such that the drive system 1 can be operated in the charging mode.

In the example of the drive system 1 of Figs. 10 to 12, this means that the switches SW1+, SW1-, SW2+, SW2-, SW4, Ch+, Ch- are closed, while the switches SWs, SW3 are opened, when the batteries 11, 12 are to be connected in parallel in the charging mode. Of course, charging batteries 11, 12 connected in parallel is also
15 possible (by corresponding control of the switches).

In step S6, the connection arrangement 40 is controlled such that the drive system 1 can be operated in transfer mode.

20 In the example of the drive system 1 of Figs. 10 to 12, this means that the switches SW1+, SW1-, SW2+, SW2-, SW3 are closed, while the switches SWs, SW4, Ch+, Ch- are opened. For the other examples, reference is made to the description of the transfer mode given for each of them.

25 Furthermore, in the steps S3, S5 and S6, after the aforementioned respective control of the connecting arrangement 40, in each case the inverter 20 (or inverters 20-1, 20-2, respectively) then is (are) accordingly operated so that the drive mode, the charging mode or the transfer mode, respectively, is executed.

30 When executing the drive mode, the control device 2 can then control the inverter 20 (or inverters 20-1, 20-2, respectively) and thus the electrical energy transfer between the electric storage 10 and the electric machine 30 (or electric machines 30-1, 30-2, respectively) depending in particular, for example, on a position of an accelerator pedal of the respective vehicle (or depending on corresponding control
35 data in the case of an autonomous vehicle).

When the charging mode is executed, the control device 2 can deactivate the inverter (or inverters) so that an energy transfer only takes place between the

storage 10 and a charging terminal device 50. The charging mode can be terminated, for example, when a measured actual value of a state of charge, e.g. "SoC" of the storage 10 reaches a set value specified for the charging operation.

- 5 When executing the transfer mode for the purpose of balancing, the control device 2 can control the inverter (or inverters) and thus the energy transfer between the two batteries 11, 12 of the storage 10 depending in particular on measured states of charge and/or voltage levels of the two batteries 11, 12.
- 10 In the execution of the transfer mode for the purpose of preheating the storage device 10, the control device 2 controls the inverter (or inverters) for a back and forth energy transfer between the two batteries 11, 12 until the preheating is completed. This can be assumed by the control device 2, for example, after a predetermined period of time of preheating operation. Alternatively or additionally, the control
- 15 device 2 can provide for a termination of the transfer mode for example when a predetermined temperature has been reached in the area of the storage unit 10 (e.g. equipped with at least one temperature sensor communicating to the control device 2).
- 20 Fig. 14 shows an electric drive system 1 according to a seventh example, comprising an electric storage 10 with first and second batteries 11, 12, first and second inverters 20-1, 20-2, and first and second electric machines 30-1, 30-2 according to a redundancy concept (as in the fourth example shown in Fig. 7).
- 25 Furthermore, the electric drive system 1 of Fig. 14 comprises a DC charging terminal device 50 and a connecting arrangement 40 (as in the sixth example shown in Fig. 10 to 12).

- The first and second electric machines 30-1, 30-2 each are configured with a star
- 30 configuration, and the concept described above with reference to Fig. 7 here can be realized without a need for the switch SW3 (Fig. 7).

In case of the electric drive system 1 shown in Fig. 14, each inverter 20-1, 20-2 and associated electric machine 30-1, 30-2 represent a buck/boost DC/DC converter.

- 35 The two electric drives are connected via a switch SW4 to allow back-to-back buck/boost DC/DC conversion. The electrical energy can be moved from one battery (11 or 12) to the other one (12 or 11, respectively) very quickly and efficiently in basically the same manner as in the fourth example (Fig. 7). By having this, the

two batteries 11, 12 can be heated up very quickly and without adding any extra device.

5 As in the other examples described therein, reusing existing powertrain components in the vehicle enables the battery self-heating (or balancing of the batteries).

10 In summary, a main idea of this invention is to reuse in a vehicle some powertrain components (as HV inverter(s) and the electric machine(s)) by adding some switches (e.g. semiconductor switches, or e.g. relays) to realize a special "transfer mode", for example to achieve battery self-heating in standstill (while the vehicle is parked). This idea helps to reduce the total cost of development and total cost of ownership. The HV battery arrangement is divided into (at least) two batteries in order to allow shuttling the energy back and forth between them. The invention can be adapted to different configurations (Electric machine with star-point connection,
15 Electric machine with delta connection, Powertrain with two electric drives, etc.) to allow transferring the energy from one battery pack to the other.

List of reference signs

	1	electric drive system
	2	control device
5	10	electric storage
	11	first battery
	12	second battery
	20	bidirectional multi-phase inverter
	21	DC terminal side (of inverter)
10	22	AC terminal side (of inverter)
	30	multi-phase AC electric machine
	31	winding arrangement (of electric machine)
	40	connecting arrangement
	50	DC charging terminal device
15		

Claims

1. An electric drive system (1) comprising:

- 5 - an electric storage (10) comprising a first battery (11) and a second battery (12),
- a controllable bidirectional multi-phase inverter (20) having a DC terminal side (21) and an AC terminal side (22),
- 10 - a multi-phase AC electric machine (30) comprising a winding arrangement (31) electrically coupled to the AC terminal side (22) of the inverter (20),
- a connecting arrangement (40) comprising electrical connection paths with
- 15 controllable switches (SW1+, SW1-, SWs, SW2+, SW2-, SW3, SW4, SW5, SW6) for establishing and interrupting electrical connections, for providing
- a drive mode of the electric drive system (1), in which the first battery (11) or the second battery (12) or a serial arrangement of the first battery (11) and the
- 20 second battery (12) or a parallel arrangement of the first battery (11) and the second battery (12) is electrically coupled to the DC terminal side (21) of the inverter (20), for supplying electrical energy from the respective battery or battery arrangement via the inverter (20) to the electric machine (30), or vice versa, and
- 25 - a transfer mode of the electric drive system (1), in which the first battery (11) is electrically coupled to the DC terminal side (21) of the inverter (20) and the second battery (12) is electrically coupled to the winding arrangement (31) of the electric machine (30), for transferring electrical energy from the first battery (11) via the inverter (20) and the winding arrangement (31) to the second battery (12), or
- 30 vice versa.

2. The drive system (1) according to claim 1, wherein the DC terminal side (21) of the inverter (20) comprises a positive terminal of the inverter (20) and a negative terminal of the inverter (20) and the AC terminal side (22) of the inverter (20)

35 comprises multiple AC phase terminals, wherein the inverter (20) comprises multiple series connections each comprising an upper switch connected to the positive terminal and a lower switch connected to the negative terminal of the

inverter (20), with a respective one of the AC phase terminals of the inverter (20) formed therebetween.

3. The drive system (1) according to claim 1 or 2, wherein the electric machine (30) is a synchronous machine in which the winding arrangement (31) of the electric machine (30) is formed by multiple stator windings of the electric machine (30).

4. The drive system (1) according to any of the preceding claims, wherein the connecting arrangement (40) comprises

- a connection path with a controllable switch (SW1+) between a positive terminal of the first battery (11) and a positive terminal of the inverter (20),
- a connection path with a controllable switch (SW1-) between a negative terminal of the first battery (11) and a negative terminal of the inverter (20),
- a connection path with a controllable switch (SWs) between the negative terminal of the first battery (11) and a positive terminal of the second battery (12),
- a connection path with a controllable switch (SW2+) between a positive terminal of the second battery (12) and a connection node at the winding arrangement (31),
- a connection path with a controllable switch (SW2-) between a negative terminal of the second battery (12) and the negative terminal of the inverter (20),
- a connection path with a controllable switch (SW3) and a capacitor (Csp) between the negative terminal of the second battery (12) and the connection node at the winding arrangement (31).

5. The drive system (1) according to claim 4, wherein the winding arrangement (31) of the electric machine (30) is formed by multiple stator windings in star configuration, and wherein the connection node at the winding arrangement (31) is the star-point of the star configuration.

6. The drive system (1) according to claim 4, wherein the winding arrangement (31) of the electric machine (30) is formed by multiple stator windings in star configuration,

wherein the connecting arrangement (40) further comprises a controllable switch (SW4) in a phase line connecting one of the AC phase terminals of the inverter (20) to a respective one of the stator windings of the electric machine (30),

and wherein the connection node at the winding arrangement (31) is a node at the phase line between the controllable switch (SW4) and the respective stator winding.

7. The drive system (1) according to claim 4, wherein the winding arrangement (31) of the electric machine (30) is formed by multiple stator windings in delta configuration,

wherein the connecting arrangement (40) further comprises a controllable switch

5 (SW4) in a phase line connecting one of the AC phase terminals of the inverter (20) to a respective terminal node of the winding arrangement (31),

and wherein the connection node at the winding arrangement (31) is said terminal node of the winding arrangement (31).

10 8. The drive system (1), comprising

- an electric storage (10) comprising the first battery (11) and the second battery (12),

15 - first and second controllable bidirectional multi-phase inverters (20-1, 20-2) each having a DC terminal side (21) and an AC terminal side (22),

- first and second multi-phase AC electric machines (30-1, 30-2) each comprising a winding arrangement (31) electrically coupled to the AC terminal side
20 (22) of a respective one of the first and second inverters (20-1, 20-2),

- a connecting arrangement (40) comprising electrical connection paths with controllable switches (SW1+, SW1-, SWs, SW2+, SW2-, SW3, SW4, SW5, SW6) for establishing and interrupting electrical connections, for providing
25

- a drive mode of the electric drive system (1), in which the first battery (11) is electrically coupled to the DC terminal side (21) of the first inverter (20-1), for supplying electrical energy from the first battery (11) via the first inverter (20-1) to the first electric machine (30-1), or vice versa, and in which the second battery (12)
30 is electrically coupled to the DC terminal side (21) of the second inverter (20-2), for supplying electrical energy from the second battery (12) via the second inverter (20-2) to the second electric machine (30-2), or vice versa,

- the transfer mode of the electric drive system (1), in which the first battery
35 (11) is electrically coupled to the DC terminal side (21) of the first inverter (20-1) and the second battery (12) is electrically coupled to the DC terminal side (21) of the second inverter (20-2), such that the second battery (12) is indirectly electrically coupled, via the second inverter (20-2) and the winding arrangement (31) of the

second electric machine (30-2), to the winding arrangement (31) of the first electric machine (30-1), for transferring electrical energy from the first battery (11) via the first inverter (20-1), the winding arrangement (31) of the first electric machine (30-1), the winding arrangement (31) of the second electric machine (30-2) and the second inverter (20-2) to the second battery (12), or vice versa.

9. The drive system (1) according to claim 8, wherein the connecting arrangement (40) comprises

- a connection path, optional with a controllable switch (SW1+), between a positive terminal of the first battery (11) and a positive terminal of the first inverter (20-1),
- a connection path, optional with a controllable switch (SW1-), between a negative terminal of the first battery (11) and a negative terminal of the first inverter (20-1),
- a connection path, optional with a controllable switch (SW2+), between a positive terminal of the second battery (12) and positive terminal of the second inverter (20-2),
- a connection path, optional with a controllable switch (SW2-), between a negative terminal of the second battery (12) and a negative terminal of the second inverter (20-2),
- a connection path, optional with a controllable switch (SW3), between the negative terminal of the first inverter (20-1) and the negative terminal of the second inverter (20-2),
- a connection path with a controllable switch (SW4) between a connection node at the winding arrangement (31) of the first electric machine (30-1) and a connection node at the winding arrangement (31) of the second electric machine (30-2).

10. The drive system (1) according to claim 9, wherein the winding arrangements (31) of the first and second electric machines (30-1, 30-2) each are formed by multiple stator windings in a respective star configuration, and wherein the connection nodes at the winding arrangements (31) each are the star-point of the respective star configuration.

11. The drive system (1) according to claim 9, wherein the winding arrangements (31) of the first and second electric machines (30-1, 30-2) each are formed by multiple stator windings in a respective star configuration, wherein the connecting arrangement (40) further comprises a controllable switch (SW5) in a phase line connecting one of the AC phase terminals of the first inverter (20-1) to a respective one of the stator windings of the first electric machine (30-1), wherein the connecting arrangement (40) further comprises a controllable switch (SW6) in a

phase line connecting one of the AC phase terminals of the second inverter (20-2) to a respective one of the stator windings of the second electric machine (30-2), and wherein the connection nodes at the winding arrangements (31) each are a node at the phase line between the respective controllable switch (SW5, SW6) and the
5 respective stator winding.

12. The drive system (1) according to any of the preceding claims, further comprising a DC charging terminal device comprising a positive charging terminal and a negative charging terminal, wherein the connecting arrangement (40) further
10 provides

- a charging mode of the electric drive system (1), in which the first battery (11) or the second battery (12) or a serial arrangement of the first battery (11) and the second battery (12) or a parallel arrangement of the first battery (11) and the
15 second battery (12) is electrically coupled to the DC charging terminal device, for supplying electrical energy from the DC charging terminal device to the respective battery or battery arrangement, or vice versa.

13. The drive system (1) according to claim 12, wherein the connecting
20 arrangement (40) comprises

- a connection path with a controllable switch (SW1+) between the positive charging terminal and the positive terminal of the first battery (11),
- a connection path with a controllable switch (SW1-) between the negative charging terminal and the negative terminal of the first battery (11),
25 - a connection path with a controllable switch (SW2+) between the positive charging terminal and the positive terminal of the second battery (12),
- a connection path with a controllable switch (SW2-) between the negative charging terminal and the negative terminal of the second battery (12).

14. A control device for controlling an electric drive system (1) according to any one of the preceding claims, comprising:

- a communication interface for receiving information representative of an operating mode of the drive system (1) to be controlled,
- a selection module for selecting an operating mode of the drive system (1)
35 to be controlled according to the received information,
- a switch control module for controlling the controllable switches (SW1+, SW1-, SWs, SW2+, SW2-, SW3, SW4, SW5, SW6) of the connecting arrangement (40) for providing the selected operating mode, and

- an inverter control module for controlling the inverter (20) for providing a transfer of electrical energy according to the provided operating mode.

15. A control method for controlling an electric drive system (1) according to any one of the preceding claims, comprising:

- receiving information representative of an operating mode of the drive system (1) to be controlled,
- selecting an operating mode of the drive system (1) to be controlled according to the received information,
- controlling the controllable switches (SW1+, SW1-, SWs, SW2+, SW2-, SW3, SW4, SW5, SW6) of the connecting arrangement (40) for providing the selected operating mode, and
- controlling the inverter (20) for providing a transfer of electrical energy according to the provided operating mode.

16. A computer program comprising instructions which, when the program is executed by a computer cause the computer to perform the method according to claim 15.

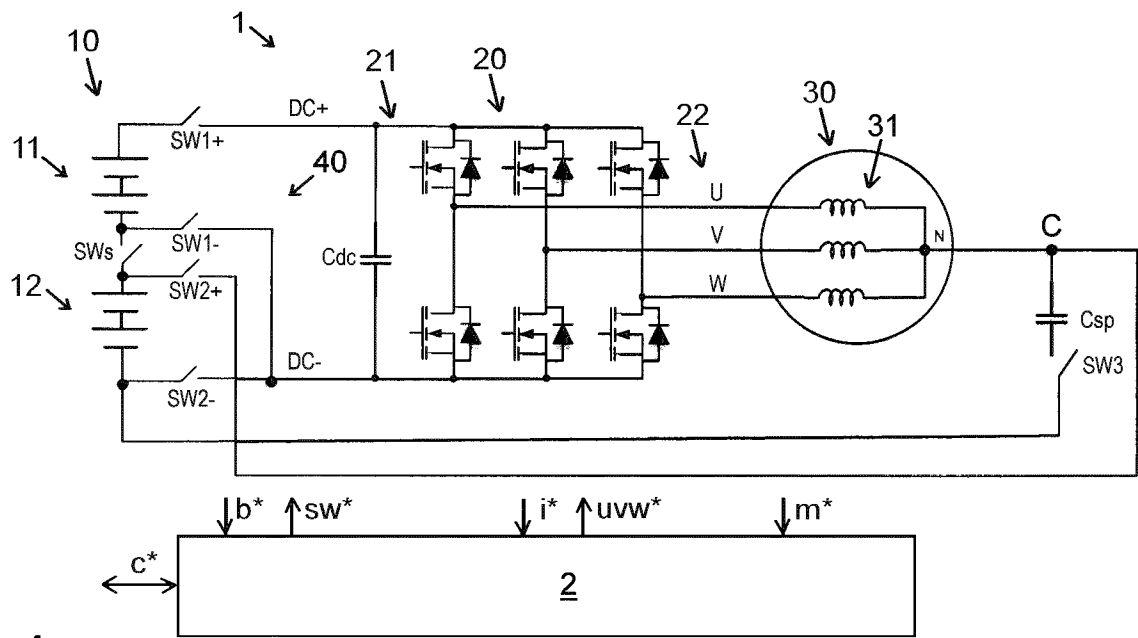


Fig. 1

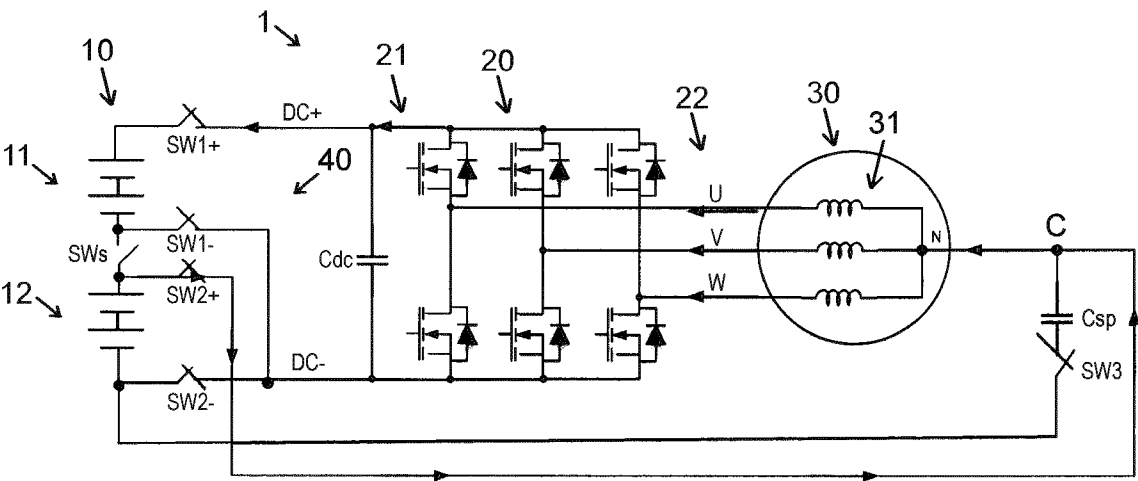


Fig. 2

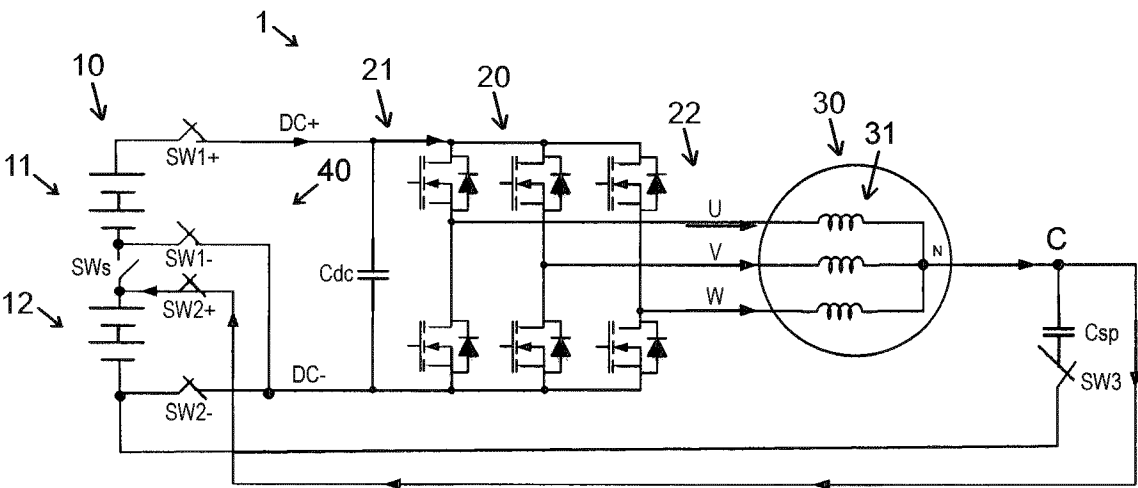


Fig. 3

FIG 4

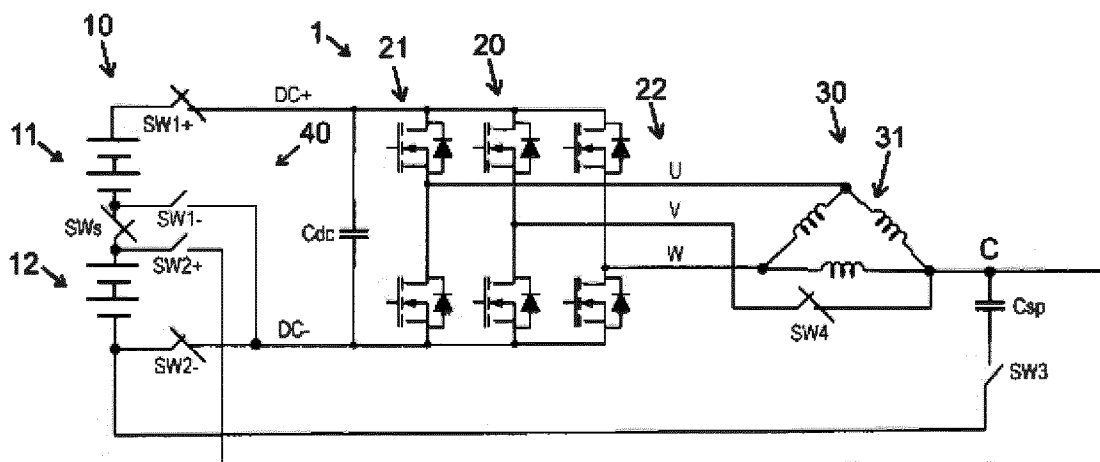
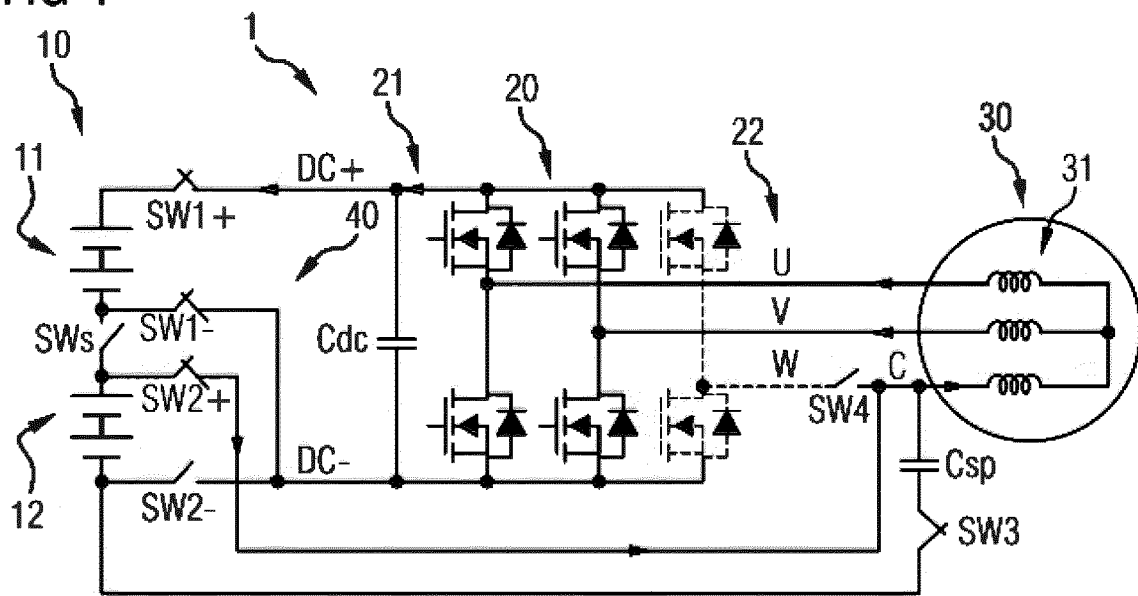
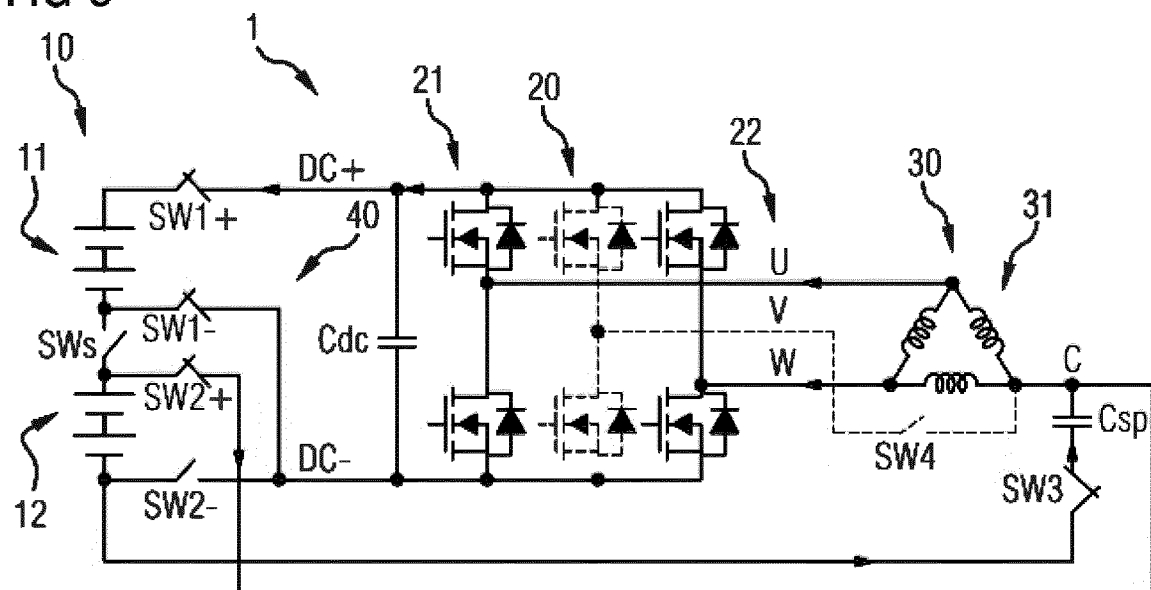


Fig. 5

FIG 6



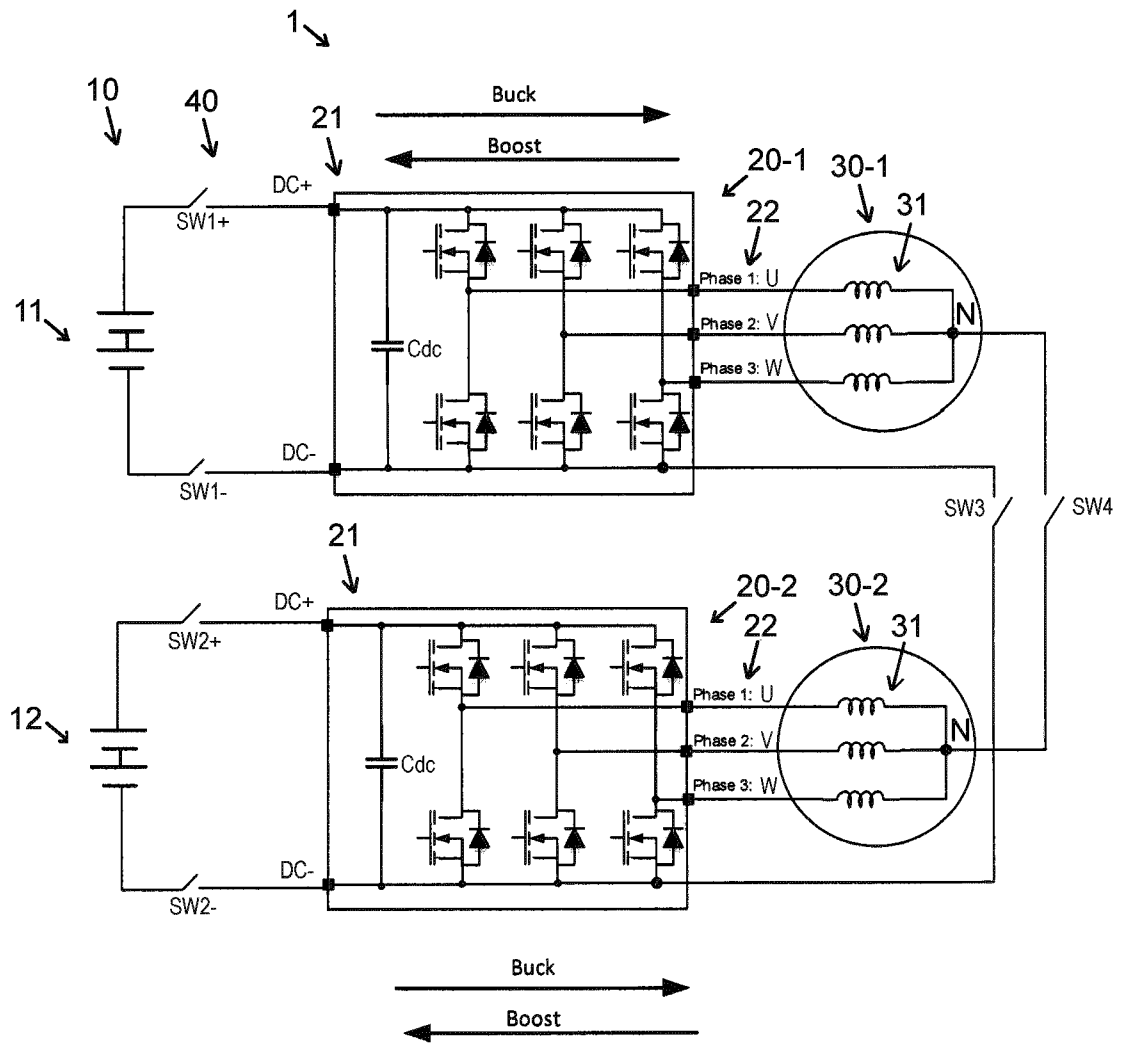


Fig. 7

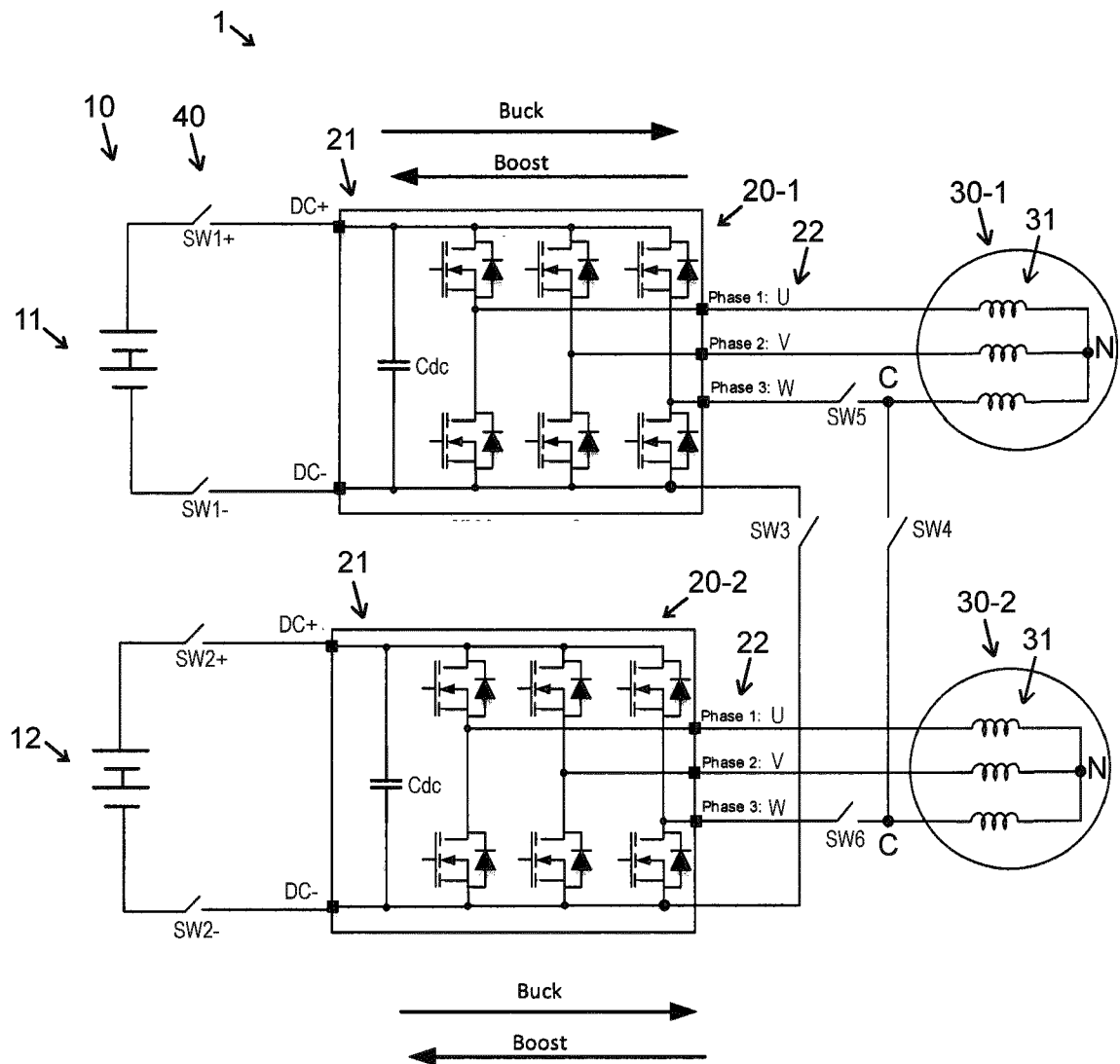


Fig. 8

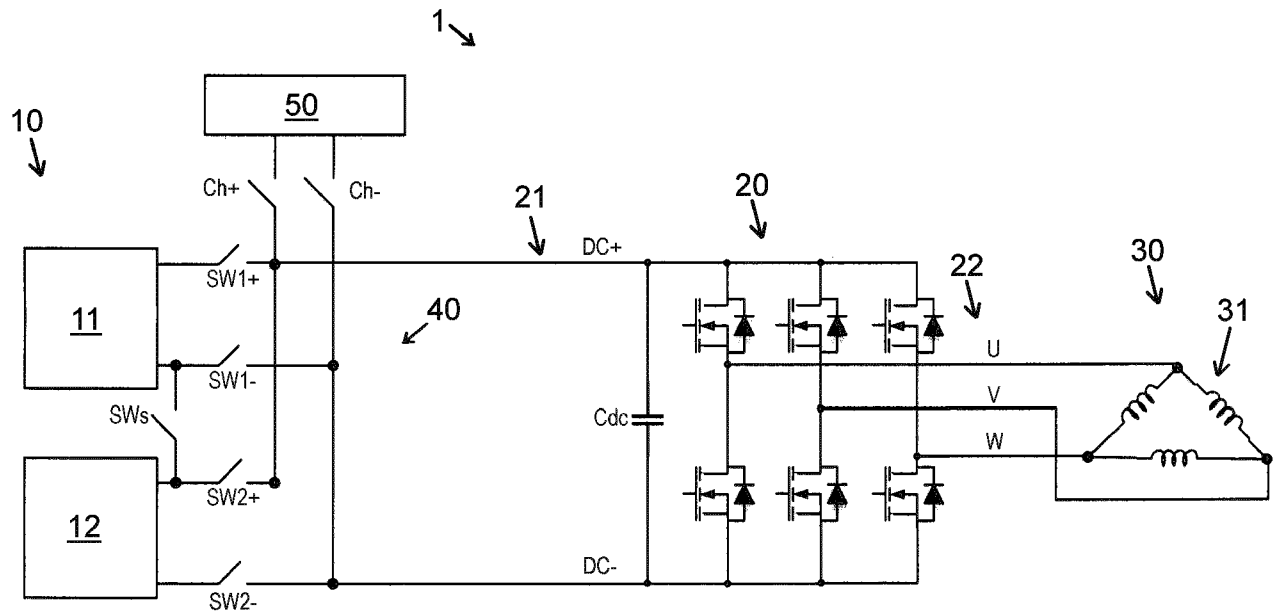


Fig. 9

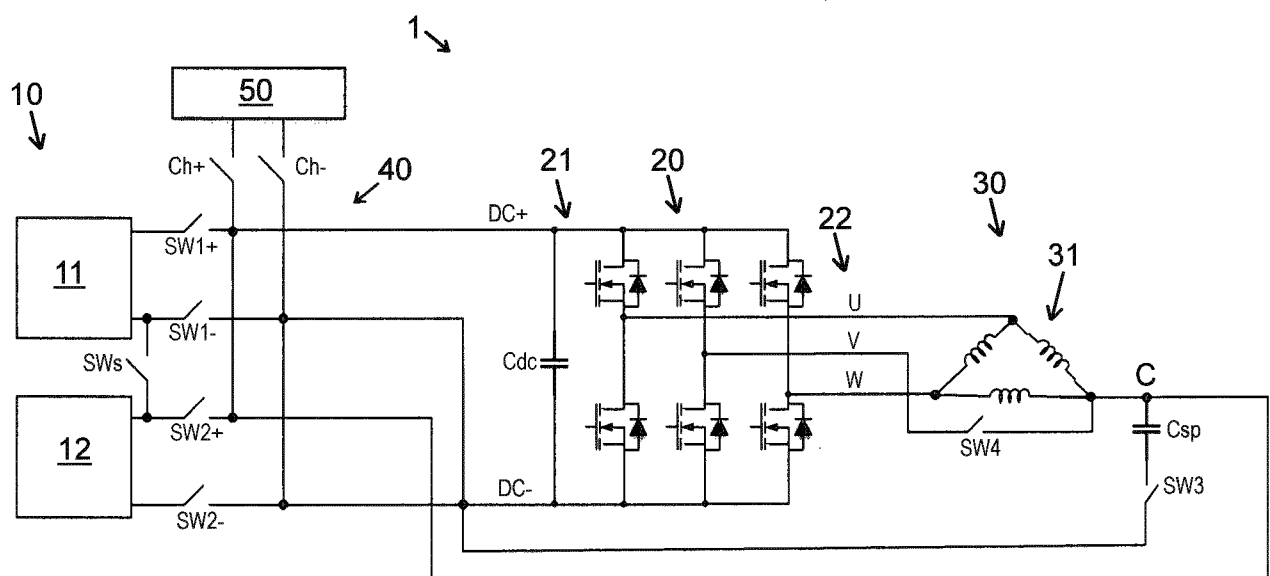


Fig. 10

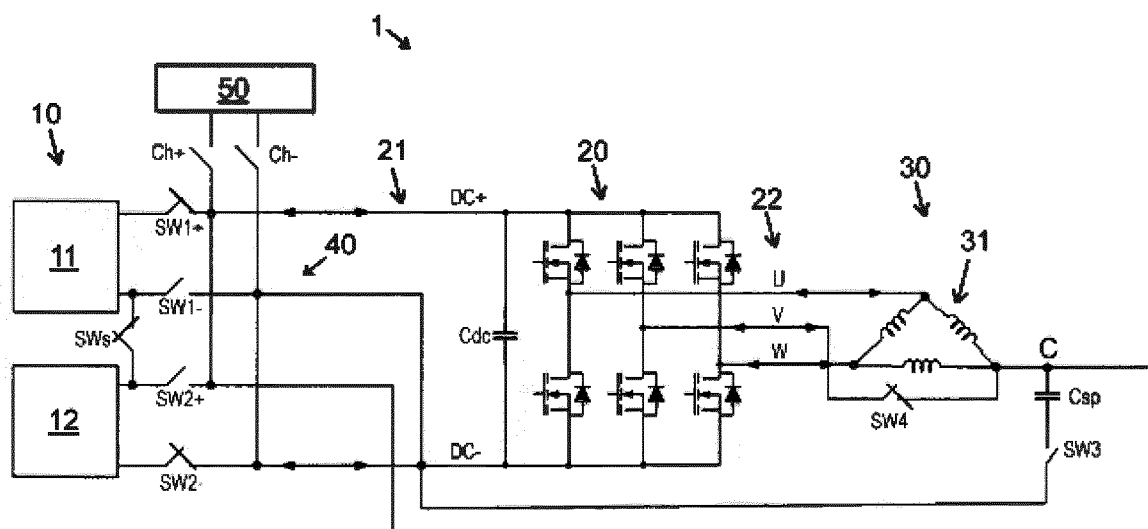
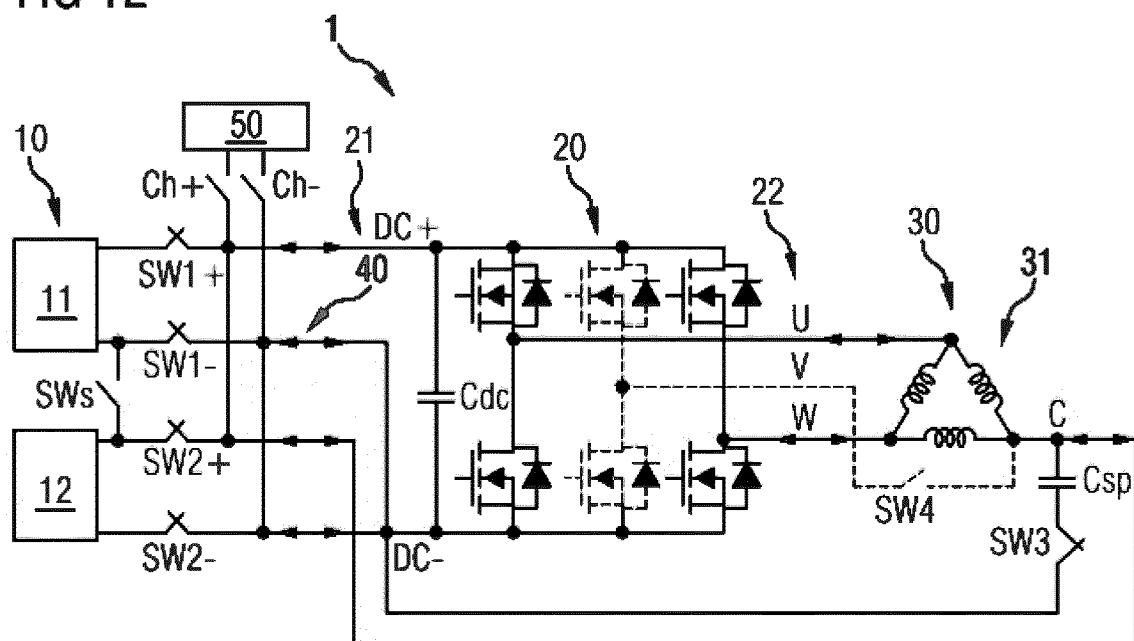


Fig. 11



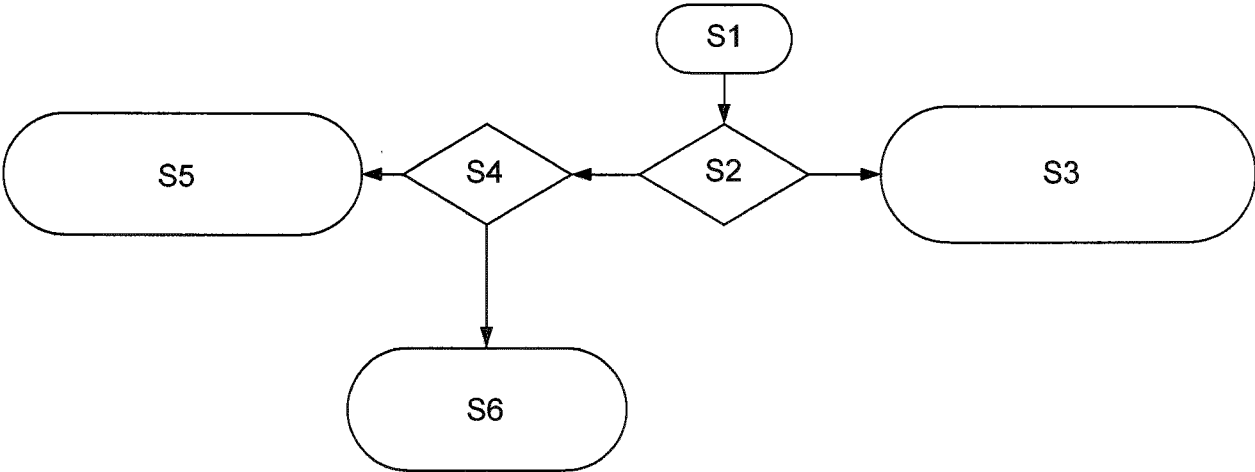


Fig. 13

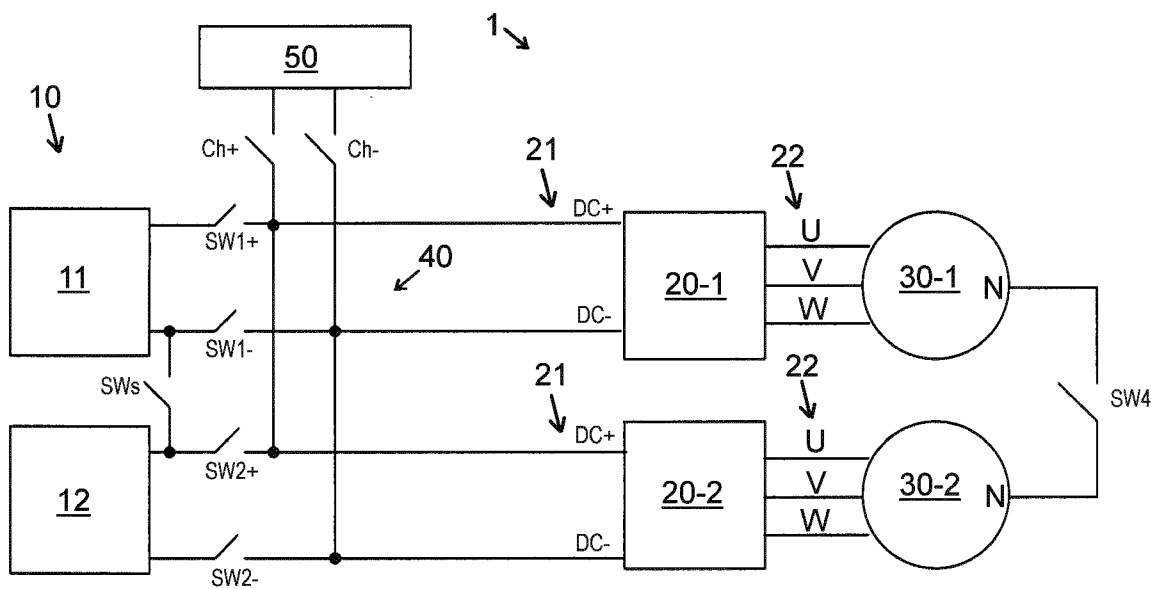


Fig. 14

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/067905

A. CLASSIFICATION OF SUBJECT MATTER					
INV.	B60L3/00	B60L3/04	B60L15/00	B60L50/51	B60L53/10
	B60L58/21	B60L58/22	B60L58/27	B60L58/19	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					
C. DOCUMENTS CONSIDERED TO BE RELEVANT					
Category*	Citation of document, with indication, where appropriate, of the relevant passages				Relevant to claim No.
X	GB 2 592 242 A (DYSON TECHNOLOGY LTD [GB]) 25 August 2021 (2021-08-25)				1-3, 14-16
Y	page 5 - page 14; claims 1-4; figures 1-11				12,13
A					4-11

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A	page 3 - page 5; claims 1-14; figures 2-7				4-7

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	column 5 - column 16; claims 1-11; figures 1-10				

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	column 4 - column 17; claims 1-13; figures 1-6				

	-/-				
☒ Further documents are listed in the continuation of Box C.					
☒ See patent family annex.					
* Special categories of cited documents :					
"A" document defining the general state of the art which is not considered to be of particular relevance			"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention		
"E" earlier application or patent but published on or after the international filing date			"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone		
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)			"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art		
"O" document referring to an oral disclosure, use, exhibition or other means			"&" document member of the same patent family		
"P" document published prior to the international filing date but later than the priority date claimed					
Date of the actual completion of the international search			Date of mailing of the international search report		
10 September 2024			24/09/2024		
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016			Authorized officer Koutsorodis, Dafni		

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/067905

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2020/091853 A1 (YOSHIDA SHOGO [JP] ET AL) 19 March 2020 (2020-03-19) the whole document -----	1 - 16

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Information on patent family members

International application No

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