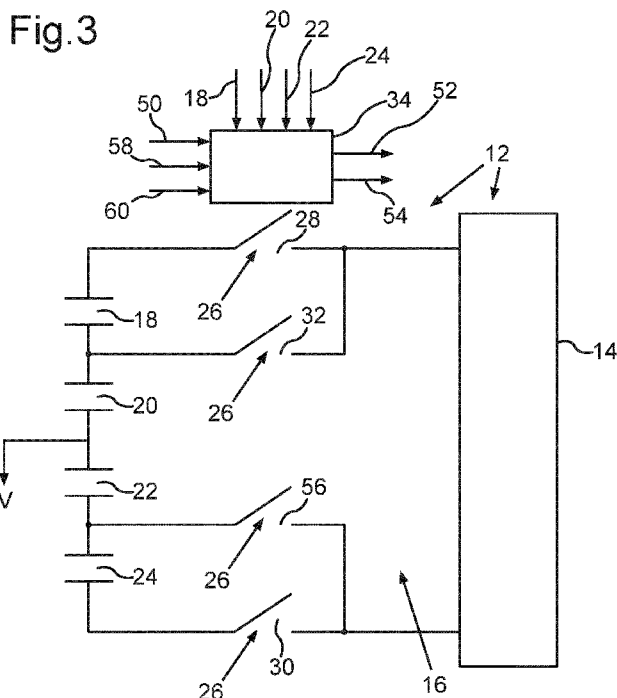




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| <b>(71) Applicant:</b> <b>MERCEDES-BENZ GROUP AG</b> [DE/DE]; Mercedesstraße 120, 70372 Stuttgart (DE). |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |

**(54) Title:** A METHOD FOR OPERATING AN ELECTRIC DRIVE UNIT OF AN AXIAL FLUX MOTOR OF A MOTOR VEHICLE BY A SWITCHING DEVICE, A COMPUTER PROGRAM PRODUCT, A NON-TRANSITORY COMPUTER-READABLE STORAGE MEDIUM, AN ELECTRIC POWER SUPPLY NETWORK SWITCHING DEVICE, AND A CORRESPONDING ELECTRIC POWER SUPPLY NETWORK



**(57) Abstract:** The present invention relates to a method for operating an electric drive unit (14) including an axial flux motor (36) of an at least in part electrically operated motor vehicle (10) by a switching device (26) of an electric power supply network (16) of the motor vehicle (10), including the steps of providing the switching device (26) with at least a first high side switch (28) of the switching device (26), which is connected to a first connector (38) of a first battery module (18) and a second connector (40) of the electric drive unit (14), a first middle switch (32) of the switching device (26), which is connected to a third connector (42) of the first battery module (18) and a fourth connector (44) of a second battery module (20) and to the second connector (40), and a second high side switch (30)

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of the switching device (26), which is connected to a fifth connector (46) of the second battery module (20) and a sixth connector (48) of the electric drive unit (14); receiving a current speed signal (50) of the motor vehicle (10) by an electronic computing device (34) of the switching device (26); and generating switching signals (52, 54) for the switches (28, 30, 32) depending on the received speed signal (50) by the electronic computing device (34), wherein the at least two battery modules (18, 20) are switched in such a way that at a first speed lower than a defined threshold a first voltage (V) lower than a second voltage (V), which is provided at a second speed, which is higher than the threshold, is provided for the electric drive unit (14). Furthermore, the invention relates to a computer program product, a non-transitory computer-readable storage medium, a switching device (26) and an electric power supply network (16).

Mercedes-Benz Group AG

Felton

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**A method for operating an electric drive unit of an axial flux motor of a motor vehicle by a switching device, a computer program product, a non-transitory computer-readable storage medium, an electric power supply network switching device, and a corresponding electric power supply network**

#### FIELD OF THE INVENTION

**[0001]** The present invention relates to the field of automobiles. More specifically, the invention relates to a method for operating an electric drive unit of an axial flux motor of an at least in part electrically operated motor vehicle by a switching device of an electric power supply network of the motor vehicle. Furthermore, the present invention relates to a corresponding computer program product, a corresponding non-transitory computer-readable storage medium, a corresponding switching device, as well as to a corresponding electric power supply network.

#### BACKGROUND INFORMATION

**[0002]** An axial flux motor includes the highest power density among electric motors and the highest efficiency at the operating range of motor vehicles. Therefore, the axial flux motor may be used in a plurality of motor vehicles. The system efficiency of the axial flux motor and the corresponding electric power supply network, which may be regarded as a powertrain system, may dramatically drop at low speeds. For example, the motor efficiency for the axial flux motor may be approximately the same at 1000 rpm/100 Nm/95% and 3000rpm/100Nm/96%. However, the shown system efficiency may reflect a difference, for example 84 % at 1000rpm/100 Nm versus 98 % at 3000 rpm/100 Nm. The difference between the system efficiencies may be more significant at lower speeds, for example the motor efficiency may be 93 % at 500 rpm/100 Nm while the system efficiency may be, for example, 78 % at 500 rpm/100 Nm.

**[0003]** A high DC link voltage may be one of the causes for the system efficiency drop at lower speeds. To operate at higher speeds, the electric drive unit (EDU) may utilize a high

DC link voltage to overcome the so-called counter-electromotive force (back-EMF) of the axial flux motor. To operate at lower speeds, the electric drive unit may not utilize the high DC link voltage to overcome the back-EMF of the axial flux motor. In fact, the high DC link voltage at the electric drive unit may increase the switching and conduction losses of the electric drive unit when driving the axial flux motor at lower speeds.

#### SUMMARY OF THE INVENTION

**[0004]** Therefore, it is an object of the present invention to provide a method, a computer program product, a computer-readable storage medium, a switching device, as well as a corresponding electric power supply network, by which the axial flux motor may be operated in a more efficient way.

**[0005]** This object is solved by a method, a computer program product, a non-transitory computer-readable storage medium, a corresponding switching device, as well as a corresponding electric power supply network. Advantageous forms of the embodiments are presented in the dependent claims.

**[0006]** One aspect of the present invention relates to a method for operating an electric drive unit of an axial flux motor of an at least in part electrically operated motor vehicle by a switching device of an electric power supply network of the motor vehicle. The switching device may be provided with at least a first high side switch of the switching device, which is connected to a first connector of a first battery module and a second connector of the electric drive unit, a first middle switch of the switching device, which is connected to a third connector of the first battery module and a fourth connector of a second battery module, and a second high side switch of the switching device, which is connected to a fifth connector of the second battery module and a sixth connector of the electric drive unit. A current speed signal of the motor vehicle may be received by an electronic computing device of the switching device. Switching signals may be generated for the switches depending on the received speed signal by the electronic computing device, wherein the at least two battery modules are switched in such a way that at a first speed lower than a defined threshold a first voltage lower than a second voltage, which is provided at a second speed, which is higher than the threshold, may be provided for the electric drive unit.

**[0007]** Therefore, an efficient way for operating the axial flux motor is provided. In particular, at a lower speed, a lower voltage such as a lower DC link voltage may be

provided for the electric drive unit, and therefore switching and conduction losses of the electric drive unit may be minimized. On the other side, at high speeds, the electric drive unit may be provided with a high DC link voltage, and therefore the axial flux motor may be provided with a high energy and therefore high speeds of the motor vehicle may be provided.

**[0008]** In particular, a variable DC link voltage with battery configuration of the at least in part electrically operated motor vehicle may be provided to improve the system efficiency at lower speeds. The so-called powertrain system is in particular provided with the electric drive unit as well as the electric power supply network. The electric power supply network may include at least the two battery modules as well as the switching devices. By proposing at least two battery module connections and switching schemes, the DC link voltage supplied to the electric drive unit may be varied.

**[0009]** In particular, this may reduce switching and conduction losses of the electric drive unit. The proposed solution may reduce the switching and conduction losses of the axial flux motor at lower speeds. Additionally, the proposed solution may reduce the thermal stress of a power module and increase the lifetime of power modules.

**[0010]** In particular, the electric drive unit may include at least the power electronics, the gearbox as well as the axial flux motor.

**[0011]** It is obvious for a person skilled in the art that the electric power supply network may include more than two battery modules. Therefore, also the switching device may include more than three switches. In particular, according to the provided battery modules, and also according to the provided connection between the battery modules, the switches may be connected to different parts of the electric power supply network. For example, the first middle switch may be connected to different connectors of the plurality of battery modules, as well as to the electric drive unit.

**[0012]** Furthermore, the battery modules may be connected in different ways. For example, the battery modules may be connected in parallel or in series, in particular at higher speeds. It is also obvious for a person skilled in the art that, if the electric power supply network includes more than two battery modules, different ways of connecting the battery modules may be provided. For example, some of the battery modules may be connected in series and some of the battery modules may be connected in parallel to each other. In particular, the connection provided may depend on a predefined voltage in

the electric power supply network and/or a predefined current in the electric power supply network.

**[0013]** According to an embodiment, the switching signals may be generated in such a way that at the first speed at least the first middle switch and one of the high side switches are closed and one of the high side switches is open. Therefore, for example the voltage of one of the battery modules may be provided for the electric drive unit, wherein switching and conduction losses at a low speed may be minimized.

**[0014]** In another embodiment the switching signals may be generated in such a way that at the second speed at least the first high side switch and the second high side switch are closed and the middle switch is open. Therefore, for example the two battery modules may be connected in series, and thus the voltages of each battery module may be added to each other and therefore a high voltage for the electric drive unit may be provided.

**[0015]** In another embodiment, additionally the switching process may be controlled depending on a received torque command signal and/or a received driving mode signal of the motor vehicle. Therefore, the switching process may be efficiently controlled, in particular not just depending on the current speed but also on the received torque command signal, for example if a user of the motor vehicle wants to accelerate, or the driving mode signal, for example if the user wants to drive in a more, sporty mode.

**[0016]** In particular, the method may be a computer-implemented method. Therefore, another aspect of the present invention relates to a computer program product including program code means for performing a method according to the preceding aspect.

**[0017]** A still further aspect of the present invention relates to a non-transitory computer-readable storage medium including at least the computer program product according to the preceding aspect.

**[0018]** A still further aspect of the present invention relates to a switching device for operating an electric drive unit of an axial flux motor of an at least in part electrically operated motor vehicle, including at least a first high side switch, a second high side switch, a first middle switch, and one electronic computing device, wherein the switching device may be configured for performing a method according to the preceding aspect. In particular, the method is performed by the switching device.

**[0019]** The electronic computing device may include electronic means, for example processors, circuits, in particular integrated circuits, and further electronic means for performing a method according to the preceding aspect.

**[0020]** Furthermore, the present invention relates to an electric power supply network for providing electric power for an electric drive unit for an axial flux motor of an at least in part electrically operated motor vehicle, including at least a first battery module, a second battery module, and a switching device according to the preceding aspect.

**[0021]** According to an embodiment, at least a third battery module and a fourth battery module may be provided, wherein the battery modules may be connected in series, and wherein at least a second middle switch may be connected to the battery modules for operating the electric drive unit. In particular, the serial connection may be provided for higher speeds. Therefore, a high voltage at a high speed may be provided for the electric drive unit. On the other hand, if the motor vehicle is driving at lower speed, also a switching of the at least four battery modules may be provided, by which at the lower speed the implemented voltage may be reduced in order to reduce or minimize the electrical losses in the electric power supply network.

**[0022]** According to an alternative form, at least a third battery module and a fourth battery module may be provided, wherein at least two of the battery modules are connected in series to a first battery network part and the other two of the battery modules are connected in series to a second battery network part, wherein the first battery network part and the second battery network part are connected parallel to each other, and wherein at least a second middle switch and a third middle switch are connected to the battery modules for operating the electric drive unit. In particular, the parallel connection may be provided at higher speeds. Therefore, depending on a predefined network definition, the battery modules may be connected in parallel and in series to each other.

**[0023]** It is obvious for a person skilled in the art that the method according to the first aspect of the present invention may be adapted for the electric power supply network including at least the four battery modules. Furthermore, it is obvious for a person skilled in the art, that the electric power supply network may include further battery modules, wherein then the switching device may include further switches, in particular further high side switches and further middle switches, for providing different levels of electric power for the electric drive unit.

**[0024]** A still further aspect of the present invention relates to a powertrain system including the electric power supply network as well as the electronic driving unit. Furthermore, the present invention also relates to a motor vehicle including at least the system according to the preceding aspect. The motor vehicle may be configured as an at least in part electrically operated motor vehicle or a fully electrically operated motor vehicle.

**[0025]** Further advantages, features, and details of the present invention derive from the following description of preferred embodiments as well as from the drawings. The features and feature combinations previously mentioned in the description as well as the features and feature combinations mentioned in the following description of the figures and/or shown in the figures alone can be employed not only in the respectively indicated combination but also in any other combination or taken alone without leaving the scope of the present invention.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0026]** The novel features and characteristic of the present disclosure are set forth in the appended claims. The accompanying drawings, which are incorporated in and constitute a part of this disclosure, illustrate exemplary embodiments and together with the description, serve to explain the disclosed principles. The same numbers are used throughout the figures to reference like features and components. Some embodiments of system and/or methods in accordance with embodiments of the present subject matter are now described below, by way of example only, and with reference to the accompanying figures.

**[0027]** The drawings show in:

**[0028]** Fig. 1 a schematic side view according to an embodiment of a motor vehicle including an embodiment of a powertrain system including an embodiment of an electric power supply network;

**[0029]** Fig. 2 a schematic block diagram according to an embodiment of the powertrain system;

**[0030]** Fig. 3 another schematic block diagram according to an embodiment of the powertrain system;

**[0031]** Fig. 4 another schematic block diagram according to an embodiment of the powertrain system; and

**[0032]** Fig. 5 a schematic flow chart according to an embodiment of the method.

**[0033]** In the figures the same elements or elements having the same function are indicated by the same reference signs.

#### DETAILED DESCRIPTION

**[0034]** In the present document, the word "exemplary" is used herein to mean "serving as an example, instance, or illustration". Any embodiment or implementation of the present subject matter described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments.

**[0035]** While the present disclosure is susceptible to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and will be described in detail below. It should be understood, however, that it is not intended to limit the disclosure to the particular forms disclosed, but on the contrary, the disclosure is to cover all modifications, equivalents, and alternatives falling within the scope of the disclosure.

**[0036]** The terms "comprises", "comprising", or any other variations thereof, are intended to cover a non-exclusive inclusion so that a setup, device or method that comprises a list of components or steps does not include only those components or steps but may include other components or steps not expressly listed or inherent to such setup or device or method. In other words, one or more elements in a system or apparatus preceded by "comprises" or "comprise" does not or do not, without more constraints, preclude the existence of other elements or additional elements in the system or method.

**[0037]** In the following detailed description of the embodiment of the present disclosure, reference is made to the accompanying drawing that forms part hereof, and in which is shown by way of illustration a specific embodiment in which the disclosure may be practiced. This embodiment is described in sufficient detail to enable those skilled in the art to practice the disclosure, and it is to be understood that other embodiments may be utilized and that changes may be made without departing from the scope of the present disclosure. The following description is, therefore, not to be taken in a limiting sense.

**[0038]** Fig. 1 shows a schematic side view according to an embodiment of a motor vehicle 10. The motor vehicle 10 is at least in part electrically operated. The motor vehicle 10 may be also fully electrically operated. The motor vehicle 10 therefore includes at least a powertrain system 12. The powertrain system 12 may include at least an electric drive unit 14 as well as an electric power supply network 16. The electric drive unit 14 includes at least an axial flux motor 36, and for example also (not shown) power electronics and a gearbox.

**[0039]** Fig. 2 shows an embodiment of the powertrain system 12 including at least the electric drive unit 14 as well as the electric power supply network 16. The electric power supply network 16 includes at least a first battery module 18 as well as a second battery module 20. As shown in Fig. 3 and 4 also a third battery module 22 as well as a fourth battery module 24 may be provided.

**[0040]** The electric power supply network 16 may further include at least a switching device 26. The switching device 26 according to the shown embodiment may include at least a first high side switch 28, a second high side switch 30 as well as a first middle switch 32. Furthermore, the switching device 26 may include at least an electronic computing device 34.

**[0041]** According to the shown embodiment of Fig. 2, a method for operating the electric drive unit 14 for the axial flux motor 36 is provided. The switching device 26 includes at least the first high side switch 28 of the switching device 26, which is connected to a first connector 38 of the first battery module 18 and a second connector 40 of the electric drive unit 14. The first middle switch 32 is connected to a third connector 42 of the first battery module 18 and a fourth connector 44 of the second battery module 20 as well as to the second connector 40. The second high side switch 30 is connected to a fifth connector 46 of the second battery 20 and a sixth connector 48 of the electric drive unit 14. At least a current speed signal 50 of the motor vehicle 10 may be received by the electronic computing device 34. Switching signals 52, 54 for the switches 28, 30, 32 may be generated by the electronic computing device 34 depending on the speed signal 50, wherein at least two battery modules 18, 20 are switched in such a way that a first speed lower than a defined threshold a first voltage  $V$  lower than a second voltage  $V$ , which is provided at a second speed, which is higher than the threshold, is provided for the electric drive unit 14.

**[0042]** Fig. 3 shows another schematic block diagram according to an embodiment of the powertrain system 12. In particular, Fig. 3 shows that the electric power supply network 16 may include the third battery module 22 as well as the fourth battery module 24. In particular it is shown that the battery modules 18, 20, 22, 24 are connected in series.

**[0043]** Fig. 3 shows that a second middle switch 56 may be provided. For example, each of the battery modules 18, 20, 22, 24 may provide a voltage of 200 V. When the middle switches 32 and 56 are closed and the high side switches 28, 30 are open, the second battery module 20 and the third battery module 22 are connected in series to the electronic driving unit 14. For example, the input voltage V of the electric drive unit 14 may be for example 400 V when the two middle switches 32, 56 are closed and the high side switches 28, 30 are open. When the middle switches 32, 56 are open and the high side switches 28, 30 are closed, the input voltage V of the electric drive unit 14 may be 800 V because all four battery modules 18, 20, 22, 24 are connected in series.

**[0044]** Furthermore, Fig. 3 shows that the electronic computing device 34 for controlling the switching process may additionally receive a torque command signal 58 as well as a driving mode signal 60. Characteristics of the battery modules 18, 20, 22, 24 such as the module voltage may be provided to the electronic computing device 34. Furthermore, Fig. 3 shows that for example an output signal of the electronic computing device 34, in particular the switching signals 52, 54 may be switching signals 52 for the high side switches 28, 30 as well as switching signals 54 for the middle switches 32, 56.

**[0045]** Fig. 4 shows a schematic block diagram according to an embodiment of the powertrain system 12. In particular, according to Fig. 4, the first battery module 18 and the fourth battery module 24 are connected in series as a first battery network part 62, and the second battery module 20 and the third battery module 22 are connected in series to a second battery network part 64. The first battery network part 62 and the second battery network part 64 are connected in parallel to each other. Fig. 4 shows that a third middle switch 66 as well as a fourth middle switch 68 are provided. According to the shown embodiment, if all middle switches 32, 56, 66, 68 are closed and the high side switches 28, 30 are open, an input voltage V of the electric drive unit 14 may be for example 400 V. If the middle switches 32, 56, 66, 68 are open and the high side switches 28, 30 are closed, an input voltage V of the electric drive unit 14 may be for example 800 V.

**[0046]** Fig. 5 shows a schematic block diagram according to an embodiment of the method. For example in a first step S1, all middle switches 32, 56, 66, 68 are closed and the high side switches 28, 30 are opened. In a second step S2, all middle switches 32, 56, 66, 68 are opened and also all high side switches 28, 30 are opened. In a third step S3, all middle switches 32, 56, 66, 68 are opened and all high side switches 28, 30 are closed. In a fourth step S4, all middle switches 32, 56, 66, 68 are opened and all high side switches 28, 30 are opened. In a fifth step S5, all middle switches 32, 56, 66, 68 are closed and all high side switches 28, 30 are opened.

**[0047]** Furthermore, Fig. 4 shows that the electronic computing device 34 for controlling the switching process may additionally receive a torque command signal 58 as well as a driving mode signal 60. Characteristics of the battery modules 18, 20, 22, 24 such as the module voltage may be provided to the electronic computing device 34. Furthermore, Fig. 4 shows that for example an output signal of the electronic computing device 34, in particular the switching signals 52, 54 may be switching signals 52 for the high side switches 28, 30 as well as switching signals 54 for the middle switches 32, 56, 66, 68.

**[0048]** Fig. 5 shows a schematic flow chart according to an embodiment of the method. Therefore, for example according to Fig. 3, in the first step S1 a low voltage V may be provided. Accordingly, in the first step S1, the motor vehicle 10 may drive with a low speed. Therefore the middle switches 32, 56 are closed and the high side switches 28, 30 are opened and the first voltage V is provided. In the second step S2, all switches may be opened when, for example, the motor vehicle 10 is accelerating. In the third step S3, the motor vehicle 10 may be driving at a higher speeds and the four battery modules 18, 20, 22, 24 are connected in series and the second voltage V is provided. In an alternative embodiment, the four battery modules 18, 20, 22, 24 may be connected in parallel according to Fig. 4. In the fourth step S4, the motor vehicle 10 may brake and all switches are opened. In the fifth step S5, the motor vehicle 10 is driving at a lower speed and again a low voltage V may be provided by the electric power supply network 16.

## Reference Signs

|         |                                 |
|---------|---------------------------------|
| 10      | motor vehicle                   |
| 12      | powertrain system               |
| 14      | electric drive unit             |
| 16      | electronic power supply network |
| 18      | first battery module            |
| 20      | second battery module           |
| 22      | third battery module            |
| 24      | fourth battery module           |
| 26      | switching device                |
| 28      | first high side switch          |
| 30      | second high side switch         |
| 32      | first middle switch             |
| 34      | electronic computing device     |
| 36      | axial flux motor                |
| 38      | first connector                 |
| 40      | second connector                |
| 42      | third connector                 |
| 44      | fourth connector                |
| 46      | fifth connector                 |
| 48      | sixth connector                 |
| 50      | speed signal                    |
| 52      | switching signal                |
| 54      | switching signal                |
| 56      | second middle switch            |
| 58      | torque command signal           |
| 60      | driving mode signal             |
| 62      | first battery network part      |
| 64      | second battery network part     |
| 66      | third middle switch             |
| 68      | fourth middle switch            |
| S1 – S5 | steps of the method             |
| V       | voltage                         |

CLAIMS

1. A method for operating an electric drive unit (14) comprising an axial flux motor (36) of an at least in part electrically operated motor vehicle (10) by a switching device (26) of an electric power supply network (16) of the motor vehicle (10), comprising the steps of:
  - providing the switching device (26) with at least a first high side switch (28) of the switching device (26), which is connected to a first connector (38) of a first battery module (18) and a second connector (40) of the electric drive unit (14), a first middle switch (32) of the switching device (26), which is connected to a third connector (42) of the first battery module (18) and a fourth connector (44) of a second battery module (20) and to the second connector (40), and a second high side switch (30) of the switching device (26), which is connected to a fifth connector (46) of the second battery module (20) and a sixth connector (48) of the electric drive unit (14);
  - receiving a current speed signal (50) of the motor vehicle (10) by an electronic computing device (34) of the switching device (26); and
  - generating switching signals (52, 54) for the switches (28, 30, 32) depending on the received speed signal (50) by the electronic computing device (34), wherein the at least two battery modules (18, 20) are switched in such a way that at a first speed lower than a defined threshold a first voltage (V) lower than a second voltage (V), which is provided at a second speed, which is higher than the threshold, is provided for the electric drive unit (14).
2. The method according to claim 1,  
characterized in that  
the switching signals (52, 54) are generated in such a way that at the first speed, at

least the first middle switch (32) and second high side switch (30) are closed and the first high side switch (28) are opened.

3. The method according to claim 1 or 2, characterized in that the switching signals (52, 54) are generated in such a way that at the second speed at least the first high side switch (28) and the second high side switch (30) are closed and the first middle switch (32) is opened.
4. The method according to any one of claims 1 to 3, characterized in that additionally the switching process is controlled depending on a received torque command signal (58) and/or a received driving mode signal (60) of the motor vehicle (10).
5. A computer program product comprising program code means for performing a method according to any one of claims 1 to 4.
6. A non-transitory computer-readable storage medium comprising at least the computer program product according to claim 5.
7. A switching device (26) for operating an electric drive unit (14) comprising an axial flux motor (36) of an at least in part electrically operated motor vehicle (10), comprising at least a first high side switch (28), a second high side switch (30), a first middle switch (32), and an electronic computing device (34), wherein the switching device (26) is configured for performing a method according to any one of claims 1 to 4.
8. An electric power supply network (16) for providing electric power for an electric drive unit (14) comprising an axial flux motor (36) of an at least in part electrically operated motor vehicle (10), comprising at least a first battery module (18), a second battery module (20), and a switching device (16) according to claim 7.
9. The electric power supply network (16) according to claim 8, characterized in that

at least a third battery module (22) and a fourth battery module (24) are provided, wherein the battery modules (18, 20, 22, 24) are connected in series, and wherein at least a second middle switch (56) is connected to the battery modules (18, 20, 22, 24) for operating the electric drive unit (14).

10. The electric power supply network according to claim 8, characterized in that

at least a third battery module (22) and a fourth battery module (24) are provided, wherein at least two of the battery modules (18, 20, 22, 24) are connected in series to a first battery network part (62) and the other two of the battery modules (18, 20, 22, 24) are connected in series to a second battery network part (64), wherein the first battery network part (62) and the second battery network part (64) are connected parallel to each other, and wherein at least a second middle switch (56), a third middle switch (66), and a fourth middle switch (68) are connected to the battery modules (18, 20, 22, 24) for operating the electric drive unit (14).

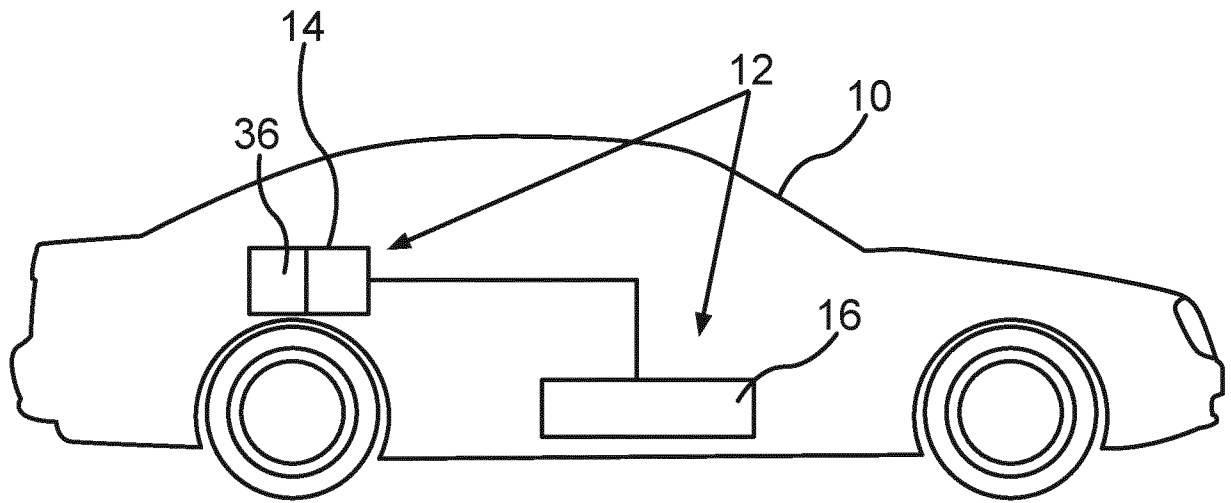


Fig.1

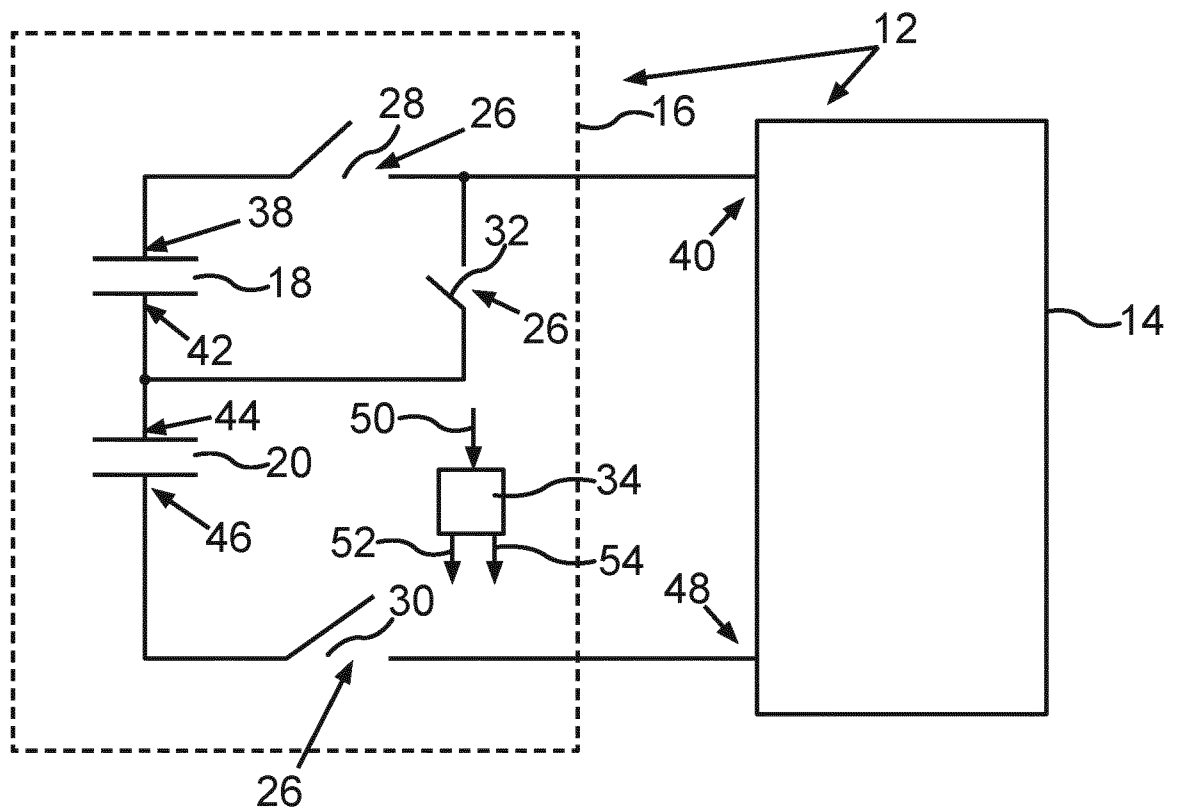


Fig.2

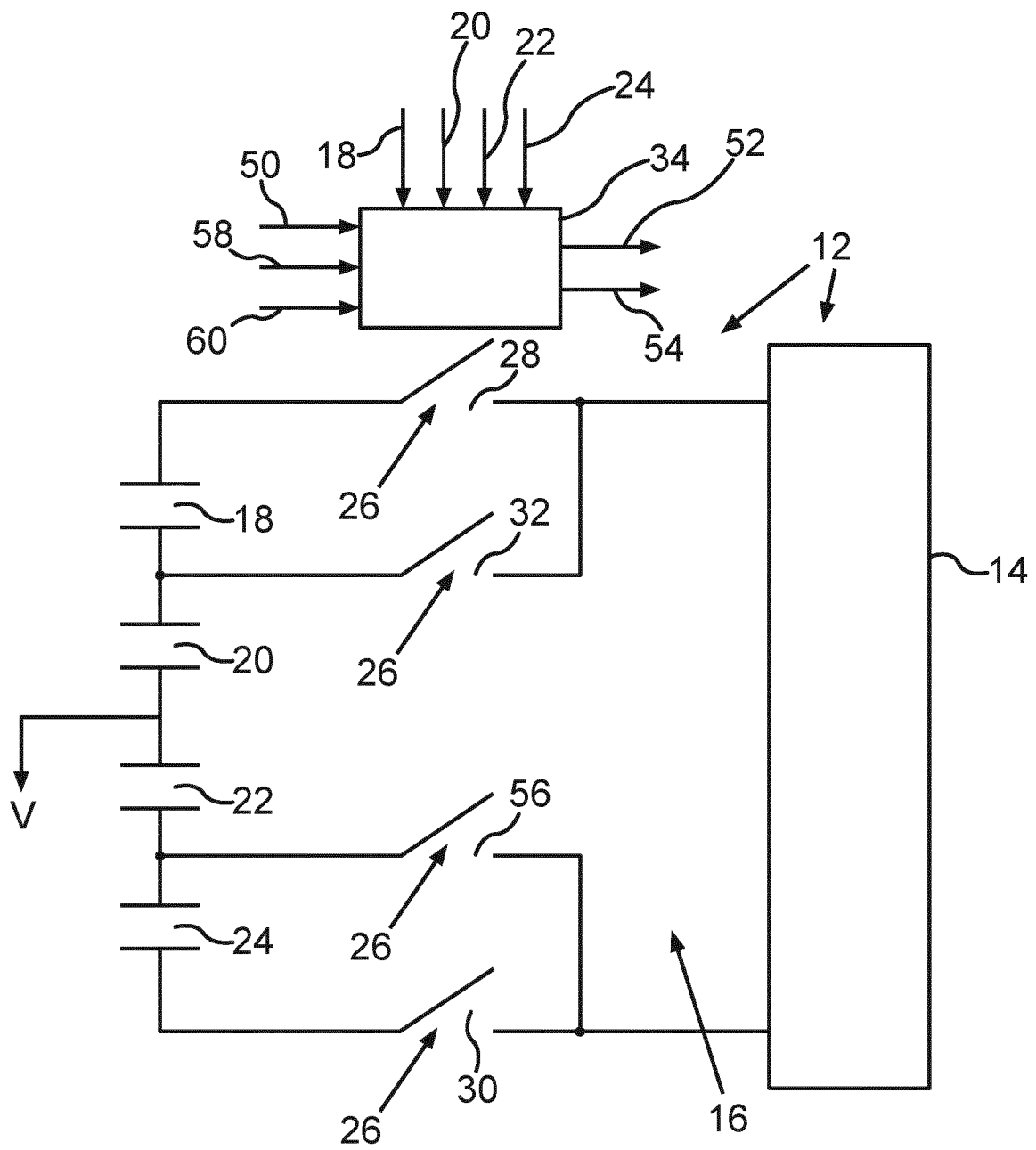


Fig.3

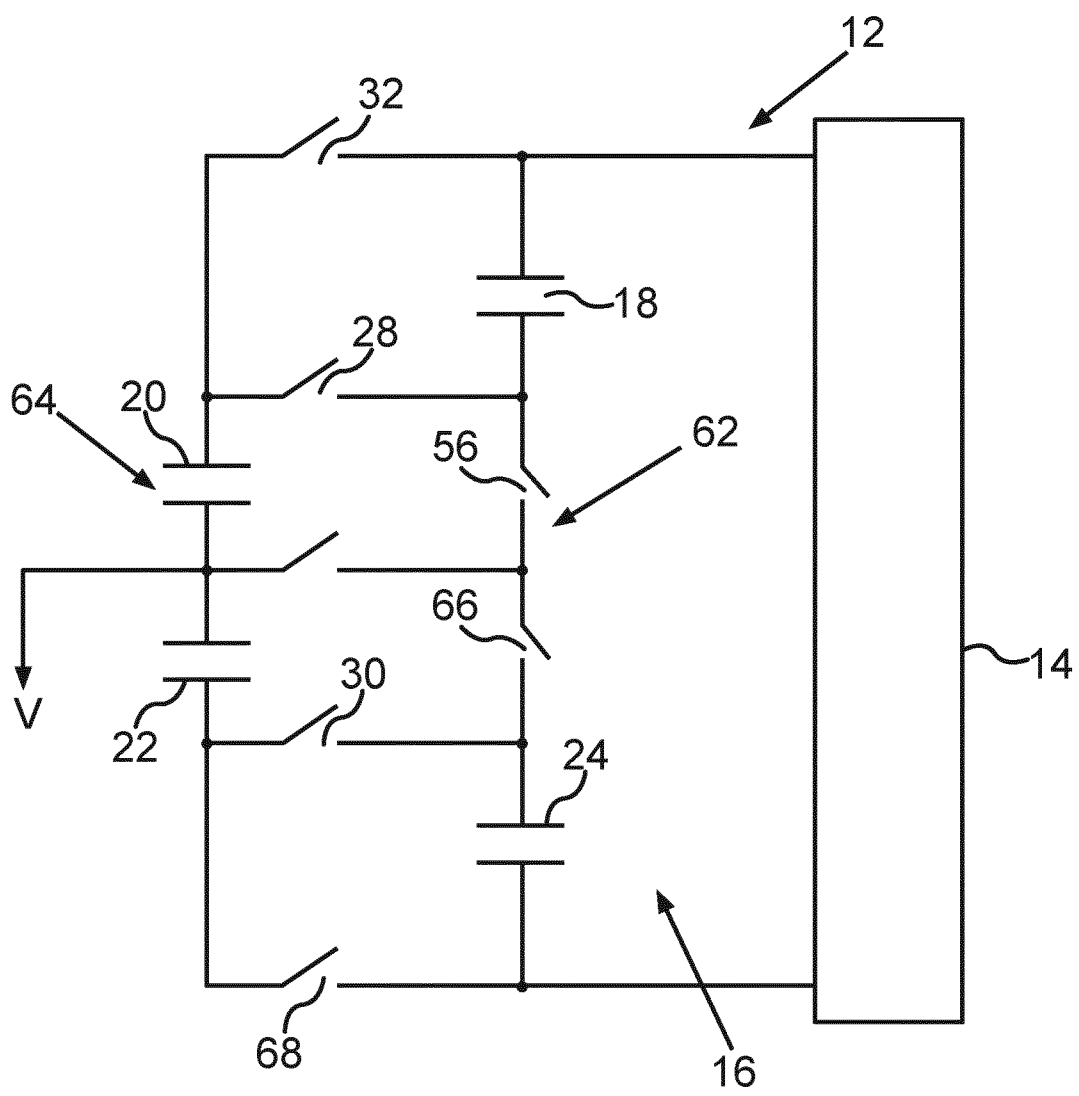


Fig.4

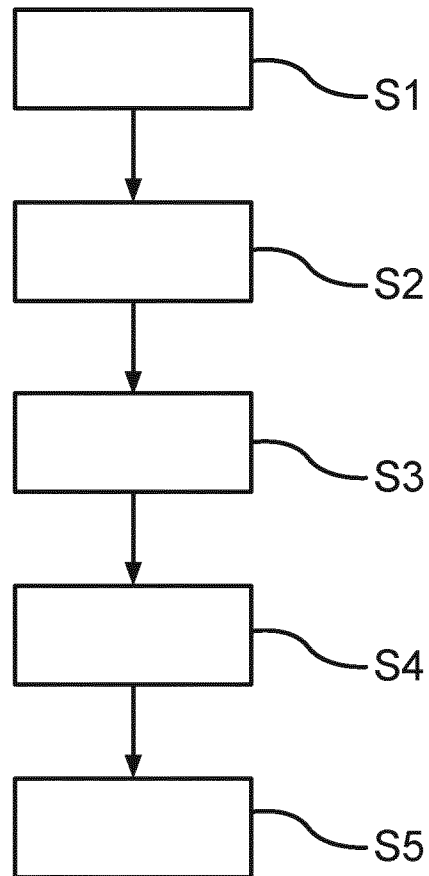


Fig.5

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|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                       |                                                                             |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|
| <b>A. CLASSIFICATION OF SUBJECT MATTER</b><br><b>INV. B60L15/02</b><br><b>ADD.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                       |                                                                             |
| According to International Patent Classification (IPC) or to both national classification and IPC                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                       |                                                                             |
| <b>B. FIELDS SEARCHED</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                       |                                                                             |
| Minimum documentation searched (classification system followed by classification symbols)<br><b>H02P H02J B60L B60K B60W H02K</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                       |                                                                             |
| 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)<br><b>EPO-Internal, WPI Data</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                       |                                                                             |
| <b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                       |                                                                             |
| Category*                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Citation of document, with indication, where appropriate, of the relevant passages                                                                                                                                                                    | Relevant to claim No.                                                       |
| <b>X</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | <b>US 2022/169349 A1 (JESEWITZ RAYMOND L [US] ET AL) 2 June 2022 (2022-06-02)</b><br><b>abstract</b><br><b>paragraphs [0003] - [0010], [0014] - [0030]</b><br><b>paragraphs [0056] - [0083], [0100] - [0126]</b><br><b>figures 1A-12</b><br><br>----- | <b>1-10</b>                                                                 |
| <b>X</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | <b>US 2008/024035 A1 (AYDIN METIN [TR] ET AL) 31 January 2008 (2008-01-31)</b><br><b>abstract</b><br><b>paragraphs [0001] - [0008], [0012] - [0040]</b><br><b>figures 1-3</b><br><br>-----<br><br>-/--                                                | <b>1-10</b>                                                                 |
| <input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                       |                                                                             |
| <p>* Special categories of cited documents :</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier application or patent but published on or after the international filing date</p> <p>"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)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> <p>"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</p> <p>"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</p> <p>"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</p> <p>"&amp;" document member of the same patent family</p> |                                                                                                                                                                                                                                                       |                                                                             |
| Date of the actual completion of the international search<br><br><b>9 April 2024</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                       | Date of mailing of the international search report<br><br><b>02/05/2024</b> |
| Name and mailing address of the ISA/<br>European Patent Office, P.B. 5818 Patentlaan 2<br>NL - 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040,<br>Fax: (+31-70) 340-3016                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                       | Authorized officer<br><br><b>Hagan, Colm</b>                                |

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International application No

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| C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                       |
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