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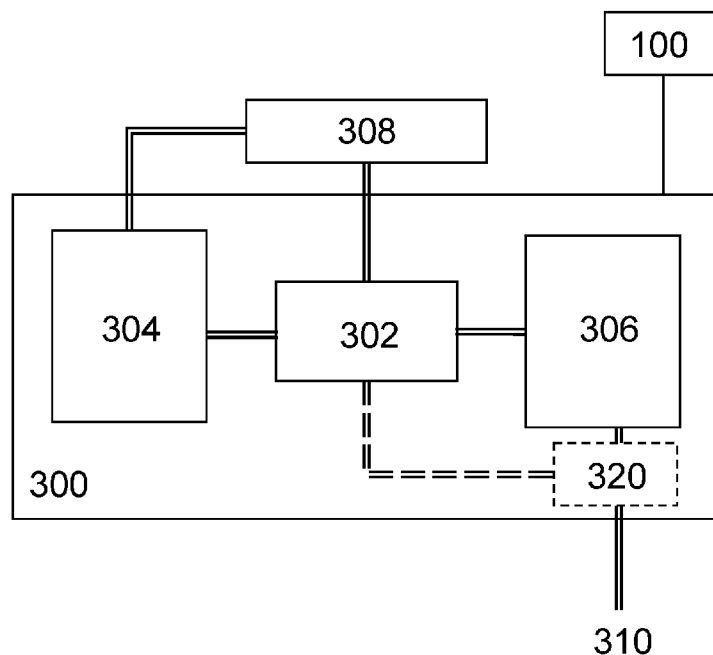


FIG. 2A

(57) **Abstract:** Disclosed herein is a control system (100) for controlling a power supply system (300) of a vehicle, the power supply system comprising a first electrical energy storage module (304) of the vehicle, a second electrical energy storage module (306) of the vehicle, and a power converter (302) configured to connect the second electrical energy storage module to an external power supply external to the vehicle, wherein during charging of the second electrical energy storage module by provision of electrical power from the external power supply. The control system (100) is configured to: receive an electrical power demand signal indicative of a load (308) demand of a load connected to the power supply system (300); receive a temperature signal indicative of a temperature of the power supply system (300); and output a power supply signal to control the power supply system to provide electrical power from: the first electrical energy storage module (304) to the load in dependence on the electrical power demand signal being below a power



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threshold; or the external power supply via the power converter (302) to the load in dependence on the electrical power demand signal being above the power threshold, wherein the power threshold is an adaptive power threshold dependent on the electrical power demand signal and the temperature signal.

Control System for Electrical Energy Source Management

TECHNICAL FIELD

The present disclosure relates to managing a power supply system for a vehicle. Aspects relate to a control system for controlling a power supply system of a vehicle, a power supply system, a vehicle, a method for controlling a power supply system of a vehicle, computer readable instructions and a non-transitory computer readable medium.

BACKGROUND

There has recently been increased interest in providing battery-powered vehicles. A typical charging protocol for a traction battery of an electrically powered vehicle is for the traction battery to be connected to a charging source (e.g. plugged into the grid) and then charging of the battery takes place once connected for charging. A battery powered vehicle may provide electrical power to various vehicle components. Some of these components may require powering while the vehicle is charging. Different power sources may power such components with different efficiencies dependent on the component power demand, and it is desirable to use an appropriate power source to power such components. Current systems may not provide power to such components in the most efficient way which may lead, for example, to wasted power or a reduction in battery life.

It is an aim of the present disclosure to address one or more of the disadvantages associated with the prior art.

SUMMARY OF THE INVENTION

Aspects and embodiments of the invention provide a control system for controlling a power supply system of a vehicle, a power supply system, a vehicle, a method for controlling a power supply system of a vehicle and computer readable instructions as claimed in the appended claims.

According to an aspect there is provided a control system for controlling a power supply system of a vehicle, the power supply system comprising a first electrical energy storage module of the vehicle, a second electrical energy storage module of the vehicle, and a power converter configured to connect the second electrical energy storage module to an external power supply external to the vehicle, wherein during charging of the second electrical energy storage module by provision of electrical power from the external power supply, the control system is configured to: determine to power a load using the first electrical energy storage module or the power converter in dependence on a received power demand from the load and an environmental factor of the power supply system; and output a power supply signal to control the provision of power to the load by the first electrical energy storage module or the power converter in dependence on the determination. The environmental factor of the power supply system may comprise a temperature, state of health, state of charge, humidity, fault state, and/or other environmental factor.

Advantageously, power is supplied to a load from an electrical energy supply module appropriately for the power demand from the load and the environment. For example, a very low power demand may be provided by a low voltage energy source and a higher power demand may be provided by a high voltage energy source. The determination of which energy source to use to power the load may depend on the load demand in combination with another environmental factor, both of which affect the efficiency with which power may be provided to the load and affect which source is the most appropriate to power the load.

According to an aspect there is provided a control system for controlling a power supply system of a vehicle, the power supply system comprising a first electrical energy storage module of the vehicle, a second electrical energy storage module of the vehicle, and a power converter configured to connect the second electrical energy storage module to an external power supply external to the vehicle, wherein during charging of the second electrical energy storage module by provision of electrical power from the external power supply, the control system is configured to: determine to power a load using the first electrical energy storage module or the power converter in dependence on a received power demand from the load and an electrical parameter of the power supply system; and output a power supply signal to

control the provision of power to the load by the first electrical energy storage module or the power converter in dependence on the determination.

Advantageously, power is supplied to a load from an electrical energy supply module appropriately for the electrical parameters of the system at that time. The efficiency of the power converter depends on the power drawn from it as well as the voltage over it, so the determination to power the load from the electrical energy storage module or via the power converter may be more appropriately made to increase efficient use of the power converter, and maintain desirable characteristics of the first electrical energy storage module such as longer battery life / slower battery aging, maintaining a desired minimum charge level, operating in a healthy temperature range, etc.

According to an aspect there is provided a control system for controlling a power supply system of a vehicle, the power supply system comprising a first electrical energy storage module of the vehicle, a second electrical energy storage module of the vehicle, and a power converter configured to connect the second electrical energy storage module to an external power supply external to the vehicle, wherein during charging of the second electrical energy storage module by provision of electrical power from the external power supply, the control system is configured to: receive an electrical power demand signal indicative of a load demand of a load connected to the power supply system; receive a temperature signal indicative of a temperature of the power supply system; and output a power supply signal to control the power supply system to provide electrical power from: the first electrical energy storage module to the load in dependence on the electrical power demand signal being below a power threshold; or the external power supply via the power converter to the load in dependence on the electrical power demand signal being above the power threshold, wherein the power threshold is an adaptive power threshold dependent on the electrical power demand signal and the temperature signal.

Advantageously, the threshold at which power supplied to a load is either from the first electrical energy storage module (e.g. 12V battery) or the external power supply via the power converter (e.g. a DCDC converter) is dependent on the power demand from the load (e.g. a 12V / LV load such as a cooling fan) and the temperature of at least a part of the power supply system, since both these factors affect how well the first electrical energy storage module, and the power converter, are able to provide the demanded power. Power from the power converter is most efficiently provided when the load demand is over a particular threshold level, and below this, the power converter operates more inefficiently. Power from the 12V battery can be used in low demand provided the 12V temperature is low enough to prevent premature aging of the 12V battery which detrimentally affects 12V battery efficiency / health.

Improved charging of the second electrical energy storage module may be facilitated, by being able to charge more quickly, by allowing the first electrical energy module to provide power to a load when suitable during charging of the second electrical energy storage module, leaving the power provided from the external power supply to be used to charge the second electrical energy storage medium rather than power the load. This ultimately allows the vehicle to require a shorter charging time and improves the driving range of the vehicle. The second electrical energy storage module is thus charged with consideration of the power demands of a load connected to the power supply system and the temperature of the power supply system (e.g. the temperature of the first electrical energy storage module). Accounting for the power demand from a load allows the most suitable electrical energy source to be used to power the load (the first electrical energy storage module if the demand is low and the module is cool enough to operate without detrimentally affecting the battery storage efficiency, and the second electrical energy storage module, via the converter and during charging of the second electrical energy storage module, if the demand is high).

By taking into account the temperature of the power supply system or a component thereof, the controller allows the health of the power supply system components, such as the first and second electrical energy storage modules, to be maintained for longer. The health reflects the ability of the storage modules to store electrical energy, and good health correlates with a high storage capacity, high electrical energy transfer efficiency and low electrical energy losses. The first electrical energy storage module will warm up as electrical energy is stored in it or drawn from it, and thus the first electrical energy storage module will age at a faster rate when the cells of the first electrical energy storage module are warmer (and similarly for the second electrical energy storage module). Therefore accounting for the temperature of the

power supply system during deciding how to power a load advantageously helps ensure that efficient charging of the second electrical energy storage module, prolonging good health of the module, can be performed, while mitigating against aging (i.e. health deterioration) of the first electrical energy storage module, for example.

5 The control system may comprise one or more controllers. The one or more controllers may collectively comprise: at least one electronic processor having an electrical input for receiving the electrical power demand signal indicative of a load demand of a load connected to the power supply system and for receiving the temperature signal indicative of a temperature of the power supply system; and at least one memory device electrically coupled to the at least one electronic processor and having instructions stored therein; and wherein the at least one electronic processor is arranged to access the at least one memory device and execute the instructions thereon so as to output the power supply signal to control the power supply system to provide electrical power from: the first electrical energy storage module to the load in dependence on the electrical power demand signal being below a power threshold; or the external power supply via the power converter to the load in dependence on the electrical power demand signal being above the power threshold, wherein the power threshold is an adaptive power threshold dependent on the electrical power demand signal and the temperature signal.

15 The power threshold dependent on the electrical power demand from the load connected the power supply system may be dependent on one or more of the voltage across the load and the current drawn by the load.

The temperature signal may be indicative of the temperature of one or more of: the first electrical energy storage module of the power supply system; the second electrical energy storage module of the power supply system; and the power converter the power supply system.

20 The power threshold may be further dependent on one or more of: a voltage across the power converter; a state of health of the first electrical energy storage module; a state of charge of the first electrical energy storage module; and a fault state of the first electrical energy storage module. These factors may also contribute to a determination of whether to power the load from the first electrical energy storage module or by the external power supply via the power converter.

25 Advantageously, by accounting for the voltage across the power converter as well as the power demand from the load, improved efficiency of charging may be achieved, since a determination of whether the load is better powered by the first electrical energy storage module or by the power converter can be made according to the voltage across the power converter. Accounting for the health of the first electrical energy storage module can help to prolong the health of the first electrical energy storage module by, as the health decreases with use and time, the preference for powering the load by the converter increases. Accounting for the state of charge of the first electrical energy storage module can help to prolong the health of the first electrical energy storage module by, for example, opting to power the load by the converter if the state of charge is below a state of charge threshold to avoid depleting the charge stored in the first electrical energy storage module when the charge stored is low.

35 The power threshold dependent on the voltage across the power converter may be dependent on one or more of an input voltage across input terminals of the power converter and an output voltage across output terminals of the power converter.

The control system may be configured to control the power supply system to provide electrical power from the external power supply via the power converter to the load when the temperature of the first electrical energy storage module is above a temperature threshold. For example, if the first electrical energy storage module is too hot, and using it at that temperature may cause premature aging and/or inefficient power provision, power may instead be provided to the load by the external power supply via the power converter until the first electrical energy storage module has cooled down. Advantageously, by accounting for the temperature of the first electrical energy storage module, the control system is able to adaptively switch between from powering the load by the first electrical energy storage module or by the external power supply to help prolong the health of the first electrical energy storage module.

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The control system may be configured to control the power supply system to provide electrical power from the external power supply via the power converter to the load when the power demand from the load is above a power demand threshold. The control system may be configured to control the power supply system to provide electrical power from the external power supply via the power converter to the load when the state of charge of the first electrical energy storage module is below a remaining charge threshold. Advantageously, efficiency of the power converter is improved by operating to power the load in the more efficient portion of the power converter demand – efficiency operating range.

There may be a range between 0% charge stored and 100% charge stored in which it is preferable to power the load using charge stored in the first electrical energy storage module and allow the second electrical energy storage module to receive energy for storage from the external power supply, and outside of that range, preferable to power the load using the power supplied from the external power supply. Advantageously, by accounting for the state of charge of the first electrical energy storage module, the control system is able to adaptively switch between from powering the load by the first electrical energy storage module or by the external power supply to help prolong the health of the second electrical energy storage modules and use the power converter to power the load in an efficient operating range for the power converter.

When the state of charge of the first electrical energy storage module is below a remaining charge threshold, the control system may be configured to control the power supply system to provide electrical power from the external power supply to the first electrical energy storage module to increase the state of charge of the first electrical energy storage module to reach a filled charge threshold. The control system may also provide electrical energy from the external power supply via the power converter to the load to power the load. Advantageously, the control system is able to control power provision to charge the first electrical energy storage module and provide power via the power converter to power the load when the first electrical energy storage module has low charge.

When the state of charge of the first electrical energy storage module has reached a filled charge threshold following supply of electrical power to the first electrical energy storage module, the control system may control the power supply system to provide electrical power from the external power supply to the second electrical energy storage module and provide electrical power to the load from the first electrical energy storage module. Advantageously, the control system is able to control power provision to charge the second electrical energy storage module and provide power via the first electrical energy storage module to power the load when the first electrical energy storage module has sufficient charge.

The control system may be configured to control the power supply system to provide electrical power from the external power supply via the power converter to the load when the state of health of the first electrical energy storage module is below a health threshold. Advantageously, by accounting for the state of health (e.g. age) of the first electrical energy storage module, the control system is able to adaptively switch between powering the load by the first electrical energy storage module or by the external power supply to help prolong the health of the first electrical energy storage module.

During provision of electrical power from the external power supply via the power converter to the load, the control system may be configured to control the power supply system to provide electrical power from the external power supply via the power converter to the second electrical energy storage module to increase the electrical energy stored in the second electrical energy storage module. Advantageously, the control system can allow for the second electrical energy storage means to receive electrical energy for storage from the external power supply as well as a portion of the received electrical energy from the external power supply going to powering the load.

The power threshold may be determined according to a predetermined mapping dependent on the temperature of the power supply system and the power demand from the load. The temperature of the power supply system may comprise a temperature of the first electrical energy storage module. The predetermined mapping may be further dependent on one or more of health of the first electrical energy storage module and a state of charge of the first electrical energy storage module. Advantageously, the control system can determine how to control power

provision in the power supply system according to a predetermined plot of the variables accounted for. The relationship between various parameters may be recorded as a 3D map of, e.g. power demand vs temperature of the first electrical energy storage module vs the voltage over the power converter.

5 The control system may be configured to: detect if the electrical power demand from the load connected to the power supply system changes from a value below the power threshold to a value above the power threshold; and in response to the detection: output a power request signal to the power converter to cause power to be supplied from the external power supply via the power converter to the load; and output a power inhibit signal to the first electrical energy storage module to prevent the provision of electrical power from the first electrical energy storage module to the load. In response to the detection, the control system may switch the power converter on prior to output of the power request signal. Advantageously, the control system is able to detect when (i.e. when demand increases from the load) to switch over from powering the load from the first electrical energy storage module to the external power supply.

15 The control system may be configured to: detect if the electrical power demand from the load connected to the power supply system changes from a value above the power threshold to a value below the power threshold; and in response to the detection: output a power inhibit signal to the power converter to inhibit the provision of electrical power from the external power supply via the power converter to the load; and output a power request signal to the first electrical energy storage module to cause power to be supplied from the first electrical energy storage module to the load. The control system may switch the power converter off if no charging of the second electrical energy storage module is required. Advantageously, the control system is able to detect when demand decreases from the load to switch over from powering the load from the external power supply to the first electrical energy storage module.

20 According to another aspect, there is provided a power supply system comprising any control system disclosed herein; the first electrical energy storage module; the second electrical energy storage module; and the power converter. The first electrical energy storage module may comprise a low voltage (e.g. 12V) battery. The second electrical energy storage module may comprise a high voltage (e.g. 48V) battery. The power converter may be a DCDC power converter.

25 According to another aspect, there is provided a vehicle comprising any system disclosed herein or any control system disclosed herein.

30 According to another aspect, there is provided a method for controlling a power supply system of a vehicle, the power supply system comprising a first electrical energy storage module of the vehicle, a second electrical energy storage module of the vehicle, and a power converter configured to connect the second electrical energy storage module to an external power supply external to the vehicle, wherein during charging of the second electrical energy storage module by provision of electrical power from the external power supply, the method comprises: receiving an electrical power demand signal indicative of a load demand of a load connected to the power supply system, receiving a temperature signal indicative of a temperature of the power supply system; and outputting a power supply signal to control the power supply system to provide electrical power from: the first electrical energy storage module to the load in dependence on the electrical power demand signal being below a power threshold; or the external power supply via the power converter to the load in dependence on the electrical power demand signal being above the power threshold; wherein the power threshold is an adaptive power threshold dependent on the electrical power demand signal and the temperature signal.

35 The method may comprise adapting the power threshold dependent on the electrical power demand signal and the temperature signal indicative of a temperature of the first electrical energy storage module. Advantageously, the claimed invention may be provided as computer code to be implemented in an existing vehicle power supply system.

40 According to a further aspect, there is provided computer software (i.e. computer readable instructions) that, when executed by a computer, is configured to perform any method disclosed herein. Optionally the computer software is stored on a computer readable medium.

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According to a further aspect, there is provided a non-transitory, computer-readable storage medium storing instructions thereon that, when executed by one or more electronic processors, causes the one or more electronic processors to carry out any method disclosed herein.

Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination. That is, all embodiments and/or features of any embodiment can be combined in any way and/or combination, unless such features are incompatible. The applicant reserves the right to change any originally filed claim or file any new claim accordingly, including the right to amend any originally filed claim to depend from and/or incorporate any feature of any other claim although not originally claimed in that manner.

BRIEF DESCRIPTION OF THE DRAWINGS

One or more examples will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 shows a control system for controlling a power supply system of a vehicle according to examples disclosed herein;

Figure 2A shows a control system and power supply system comprising first and second electrical energy storage modules according to examples disclosed herein;

Figure 2B shows an electrical energy storage module comprising plural energy storage elements according to examples disclosed herein;

Figure 3A shows the power supply system of Figure 2A providing power to a load via an external power supply, first and second electrical energy storage modules according to examples disclosed herein;

Figure 3B shows the power supply system of Figure 2A providing power to a load via a second electrical energy storage module while a first electrical energy storage module is charged by an external power supply according to examples disclosed herein;

Figure 3C is a version of the power supply system of Figure 3A further comprising an on board charger according to examples disclosed herein;

Figure 3D is a version of the power supply system of Figure 3B further comprising an on board charger according to examples disclosed herein;

Figure 4A shows an example of charging efficiency as a function of power demand, and Figure 4B shows an example of electrical parameter behaviour through a charging period according to examples disclosed herein;

Figure 5 shows an example method according to examples disclosed herein;

Figures 6A and 6B show example flow diagrams of control system operation according to examples disclosed herein; and

Figure 7 shows a vehicle according to examples disclosed herein.

DETAILED DESCRIPTION

There has recently been increased interest in providing battery-powered vehicles. A typical charging protocol for a traction battery of an electrically powered vehicle is for the traction battery to be connected to a charging source (e.g. plugged into the grid) and then charging of the battery takes place once connected for charging. A battery powered vehicle may provide electrical power to various vehicle components. Some of these components may require powering while the vehicle is charging. Different power sources may power such components with different efficiencies dependent on the component power demand, and it is desirable to use an appropriate power source to power such components. Current systems may not provide power to such components in the most efficient way which may lead, for example, to wasted power or a reduction in battery life.

Examples disclosed herein may provide an improved way to control a vehicle power supply system by controlling the provision of power to a load in a way which accounts for the power demand of the load and one or more other factors, such as temperature, state of charge, or an electrical parameter of the power supply system. By selecting a most appropriate electrical energy storage module of the power supply to power the load, improvements may be made to the operation of the power supply system for example, by improving charging efficiency, power supply efficiency to the load, and battery aging of the electrical energy storage modules of the power supply system.

For example, a vehicle may comprise a first (low voltage) electrical energy supply and a second (high voltage) electrical energy supply for powering the vehicle powertrain. During AC charging of the high voltage electrical energy storage module, a low voltage (e.g. 12V) load such as a cooling fan may request electrical power at a low level, for example as low as 15A. For a low output power demand such as a 15A / 12V demand, the efficiency of a power converter converting power from the high voltage supply (e.g. from a traction battery or on board charger unit) to a low voltage supply for powering the load may be low (for example, below 90%), whereas at higher output power demands, for example above 100A, the power converter efficiency may be much higher, at around 98%. The power converter may be a DCDC converter. A DCDC converter is an electromechanical or electronic device which converts electrical power from one voltage to another. The power converter, if used to power the low power load, would operate at a poor efficiency during parts of the charging cycle. Other factors than load power demand can also affect efficiency, such as temperature of electrical energy storage module, stored charge levels, and battery health. Examples of the present disclosure aim to mitigate against detrimental operation of the power supply system (e.g. accelerated aging or poor efficiency) by accounting for operational factors of the charging process to provide power by a most appropriate electrical energy power supply of the vehicle.

Figure 1 shows a control system 100 for controlling a power supply system of a vehicle according to examples disclosed herein. The control system 100 comprises one or more controllers 110. The control system 100 as illustrated in Figure 1 comprises one controller 110, although it will be appreciated that this is merely illustrative. The controller 110 comprises processing means 120 and memory means 130. The processing means 120 may be one or more electronic processing device 120 which operably executes computer-readable instructions. The memory means 130 may be one or more memory device 130. The memory means 130 is electrically coupled to the processing means 120. The memory means 130 is configured to store instructions, and the processing means 120 is configured to access the memory means 130 and execute the instructions stored thereon.

The controller 110 comprises an input means 140 and an output means 150. The input means 140 may comprise an electrical input 140 of the controller 110. The output means 150 may comprise an electrical output 150 of the control system 100. The input 140 is configured to receive one or more input signals 165, for example from a load indicative of a power demand, a temperature sensor to provide a temperature indication, a moisture sensor to provide humidity levels, a charge meter to provide a level of remaining charge of an electrical energy storage element, a voltmeter, an ammeter, etc. The inputs may be either physical and/or may be from a vehicle communication bus. There may be one or more sensors which provide information to the controller input 140. The output 150 is configured to provide one or more output signals 155.

The controller 100 is for controlling a power supply system of a vehicle, and the power supply system itself may comprise a first electrical energy storage module of the vehicle, a second electrical energy storage module of the vehicle, and a power converter configured to connect the second electrical energy storage module to an external power supply external to the vehicle.

In some examples, during charging of the second electrical energy storage module by provision of electrical power from the external power supply, the control system 100 may be configured to determine to power a load using the first electrical energy storage module or the second electrical energy storage module in dependence on a received power demand from the load and an electrical parameter of the power supply system (e.g. the first electrical energy storage module, the second electrical energy storage module, and /or the power converter). The electrical parameter may be a current or a voltage, for example. The control system 100 may output a power supply signal to control the provision of power to the load by the determined first or second electrical energy storage module. In such an example, the input 140 may therefore be arranged to receive the power demand and one or more electrical parameter values as input signals. The output 150 may therefore be arranged to output the power supply signal as an output signal 155. The electrical parameter in some examples may be a voltage over the power converter, which is related to the efficiency at which the power converter can operate and efficiently convert electrical energy to a different voltage.

In some examples, during charging of the second electrical energy storage module by provision of electrical power from the external power supply, the control system 100 may be configured to determine to power a load using the first electrical energy storage module or the second electrical energy storage module in dependence on a received power demand from the load and an environmental factor of the power supply system. The control system 100 may output a power supply signal to control the provision of power to the load by the determined first or second electrical energy storage module. In such an example, the input 140 may therefore be arranged to receive the power demand and one or more environmental parameter values as input signals. The output 150 may therefore be arranged to output the power supply signal as an output signal 155. The environmental factor of the power supply system may comprise a temperature, state of health (SoH; e.g. battery age), state of charge (SoC; e.g. charge level as a % of capacity), and/or other environmental factor.

In some examples, during charging of the second electrical energy storage module by provision of electrical power from the external power supply, the control system 100 may be configured to: receive an electrical power demand signal as an input signal 165 indicative of a load demand of a load connected to the power supply system; receive a temperature signal as an input signal 165 indicative of a temperature of the power supply system; and output a power supply signal 155 to control the power supply system to provide electrical power. The electrical power is supplied from the first electrical energy storage module to the load in dependence on the electrical power demand signal being below a power threshold; or supplied from the external power supply via the power converter to the load in dependence on the electrical power demand signal being above the power threshold. The power threshold is an adaptive power threshold dependent on the electrical power demand signal and the temperature signal. In such an example, the input 140 may therefore be arranged to receive the electrical power demand signal and the temperature signal as input signals 165. The electrical power demand input signal 165 may be received from the load 160. The temperature input signal 165 may be received from a temperature sensor 160, for example configured to detect the temperature of a component or portion of the power supply system such as the first electrical energy storage module, the second electrical energy storage module, the power converter, or other component. The output 150 may therefore be arranged to output the power supply signal as an output signal 155 to an output element 170 such as a switch to control the electrical current pathways in the power supply system.

Figure 2A shows a control system 100 and power supply system 300 comprising first and second electrical energy storage modules 304, 306. The control system 100 is configured to control the power supply system 300 which forms part of a vehicle. The power supply system 300 comprises a first electrical energy storage module 304 of the vehicle, a second electrical energy storage module 306 of the vehicle, and a power converter 302 configured to connect the second electrical energy storage module 306 to an external power supply 310 external to the vehicle. The power converter 302 is configured to convert the electrical power from the second electrical energy storage module 306 from high voltage to low voltage in order to charge the first electrical energy storage module 304 and/or to supply the low voltage power demand of the load 308. The first electrical energy storage module 304 may comprise a low voltage (e.g. 12V) battery. The second electrical energy storage module 306 may comprise a high voltage (e.g. 400V or 800V) battery. The power converter 302 may be a DCDC power converter. In some examples there may be an on board charger (OBC) 320 present as part of the control system 320. In examples with an OBC 320, the OBC 320 may be located as shown connected between the external power supply 310, the second electrical energy storage module 306 and the power converter 302. In some examples the OBC 320 may be outside the control system 320 rather than part of the control system 300. The OBC 320 may supply power to the power converter 302 directly in some examples by bypassing the second electrical energy storage module 306 (see Figures 3C and 3D).

Figure 2B shows an electrical energy storage module 314 comprising plural energy storage elements 314a, 314b. An electrical energy storage element 314a, 314b contributes a portion of the electrical energy storage capacity of the electrical energy storage module 314. The example shows two electrical energy storage elements 314a,b but in other examples there may be more than two. The electrical energy storage module 314 may be a first electrical energy storage module 304, and/or a second electrical energy storage module 306. A junction box 312 is electrically connected to the electrical energy storage elements 314a,b and a connection to the electrical energy storage module 314 may connect to the junction box 312 to be connected therefrom to the electrical energy storage elements 314a,b.

Figures 3A and 3B illustrate operation of the power supply system 300 of Figure 2A in different ways according to different modes of operation selected according to a power threshold. The power threshold is an adaptive power threshold dependent on an electrical power demand signal received by the control system 100 and in dependence on a further parameter signal (e.g. a temperature signal) received by the control system 100 in this example. The arrows indicate the provision of electrical power.

During charging of the second electrical energy storage module 306 by provision of electrical power from the external power supply 310, the control system 100 is configured to receive an electrical power demand signal indicative of a load demand of a load 308 connected to the power supply system 300. The load may be, for example, part of an electrically powered on-board system such as a cooling system, security system, sensor system, or other vehicle system.

The control system 100 is also configured to receive a further parameter signal, e.g. a temperature signal indicative of a temperature of the power supply system 300. For example, the temperature signal may indicate the temperature of the first electrical energy storage module 304, the second electrical energy storage module 306, the power converter 302, a housing of the power supply system 300, or other element of the power supply system 300.

Figure 3A shows the power supply system 300 providing power to the load 308 via the external power supply 310, second electrical energy storage module 306, and power converter 302. The control system 100 is configured to output a power supply signal to control the power supply system 300 to provide electrical power from the external power supply 310 via the power converter 302 to the load 308 in dependence on the electrical power demand signal being above the power threshold. As shown, electrical power is provided from the external power supply 310 to the power converter 302 via the second electrical energy storage module 306, and from the power converter 302 to the load 308. That is, if the power demand exceeds a threshold power, power is supplied via the external power supply 310 to the load 308. Power may also be supplied from the power converter 302 to the first electrical energy storage module 304 to charge the first electrical energy storage module 304. Thus, during provision of electrical power from the external power supply 310 via the power converter 302 to the load 308, the control system 100 may be configured to control the power supply system 300 to provide electrical power from the external power supply 310 to the first electrical energy storage module 304 via the power converter 302 to increase the electrical energy stored in the first electrical energy storage module 304.

Figure 3B shows the power supply system 300 providing power to the load 308 via the first electrical energy storage module 304 while the second electrical energy storage module 306 is charged by the external power supply 310. The control system 100 is configured to output a power supply signal to control the power supply system 300 to provide electrical power from the first electrical energy storage module 304 to the load 308 in dependence on the electrical power demand signal being below a power threshold. That is, if the power demand is below a threshold power, power is supplied to the load 308 from stored electrical energy stored at the first electrical energy storage module 304 without the first electrical energy storage module 304 also receiving electrical power from the external power supply 310. For example, in this scenario, the power converter 302 located between the first electrical energy storage module 304 and the external power supply 310 may be switched off or disconnected from the first electrical energy storage module 304 so the first electrical energy storage module 304 is electrically isolated from the power converter 302 and thus from the external energy supply 310.

Therefore, in typical operation, the load 308 gets power from either the power converter 302 as in Figure 3A or from the first electrical energy storage module 304 as in Figure 3B. In some examples, if the power demand from the load 308 exceeds the capability of the power converter 302 (e.g. 5000W demand or more), the first electrical energy storage module 304 may also supply additional power as well as the power converter 302.

In some examples there may be an on board charger (OBC) 320 connected between the external power supply 310, the second electrical energy storage module 306 and the power converter 302 as shown in Figures 3C and 3D.

Figure 3C is the same as Figure 3A except for the presence of the OBC 320. Figure 3C shows the power supply system 300 providing power to the load 308 via the external power supply 310, OBC 320, second electrical energy storage module 306, and power converter 302. There is an option in this example of supplying power from the external power supply 310 to the OBC 320, from the OBC 320 to the power converter 302, and from the power converter 302 to the load. That is, power may be supplied from the external power supply 310 to the OBC 320 to the power converter 302 onwards to the load 308, as well as power being supplied from the external power supply 310 to the OBC 320 to the second electrical energy storage module 306.

Figure 3D is the same as Figure 3B except for the presence of the OBC 320. Figure 3D shows the power supply system 300 providing power to the load 308 via the first electrical energy storage module 304 while the second electrical energy storage module 306 is charged by the external power supply 310 via the OBC 320.

Control systems as discussed herein allow for electrical power to be provided to the load in an efficient way. For example, the first electrical energy storage module 304 may be a low voltage (e.g. 12V) battery typically for powering low power vehicle apparatus such as lights, cabin climate controls, cooling fans etc., and the second electrical energy storage module 306 may be a high voltage (e.g. 400V or 800V) battery typically for powering high power apparatus including the powertrain. Considering the magnitude of the power demand from the load in determining how to provide power to the load, using electrical energy from the first low voltage module when the power demand is low (for example, <35A), and using electrical energy from the external power supply via the power converter 302 when the power demand is high (e.g. >35A) means the power converter is operational to provide electrical energy in an efficient operating range, as shown in Figure 4A. Therefore, the overall electrical energy consumption from the external power source is reduced compared with more inefficient external electrical power usage by powering the load at a low power in the inefficient range of operation of the power converter.

Figure 4A shows a schematic graph of efficiency (in % of electrical energy transferred from the power converter to the load) on the vertical axis, plotted against power demand in Watts on the horizontal axis. In this example, below a power demand of around 1000W and as power demand decreases, the efficiency of charge transfer decreases rapidly. Above a power demand of around 1450W the efficiency of charge transfer remains steadily high at around 97.8% efficiency. It is therefore desirable to operate the power converter to provide electrical energy from the external power supply to the load above a power demand of a threshold power level of e.g. 1000W or 1400W (whatever level is considered to provide an acceptably high efficiency, e.g. of 97% or 96%), and to not operate the power converter to provide electrical energy from the external power supply to the load below that threshold power level and instead to power the load using charge stored in the first electrical energy storage module, to avoid providing charge inefficiently using the power converter.

As an example, during AC charging, the loads (e.g. 12V / low voltage loads) may require low power provision (as low as 15A). For a "low" output like 15A, the power converter efficiency may be as low as around 90%, while at "high" outputs e.g. above 108A, the power converter efficiency can be much higher at around 97% or 98%. Therefore, the power converter may potentially operate at its worst efficiency to provide power to the load during low load parts of the charging cycle (i.e. during provision of charge from the external power supply to the second electrical energy storage module). Examples disclosed herein may address this problem by using the first electrical energy storage module (e.g. a 12V battery) to supply power to the load of the vehicle when the demand is low ("low" power demand may be, for example, <35A / <1500W) and using the power converter to provide power to the load only when the demand is high ("high" demand maybe, for example, >35A / >1500W), or when the 12V battery needs to be charged. This helps to ensure that the power converter operates at high efficiency (e.g. >95% efficiency), therefore reducing the overall consumption required from the external power supply / grid.

Therefore, the control system 100 may be configured to control the power supply system 300 to provide electrical power from the external power supply 310 via the power converter 302 to the load 308 when the power demand from the load is above a power demand threshold. Conversely, the control system 100 may be configured to control the power supply system 300 to provide electrical power from the first electrical energy storage module 304 to the load 308 when the power demand from the load 308 is below the power demand threshold.

Advantageously, the power converter 302 is used in its more efficient range of operating to power the load; otherwise power is supplied by the first electrical energy storage module 304.

The example of Figure 4A illustrates how efficiency of charge provision by the power converter is dependent on the size of the power demand by the load only. Examples disclosed herein realise that other parameters also affect how best to provide power to the load, whether that is with consideration of the efficiency with which charge can be provided by the power converter, and/or the effect of using the first (low voltage) storage module to provide power. For example, providing electrical energy using the low voltage storage module when the low voltage storage module is too hot can cause the charge storage capability of the low voltage storage module to be detrimentally reduced and negatively affect future capacity of that module, so that is to be avoided where possible. Similarly, the threshold power demand above which the power converter is considered to operate suitably efficiently may be temperature dependent, and so deciding to provide electrical energy using the power converter or the first storage module when the power converter is very cold may be different than in a situation when the power converter is warmer.

As another example of further considerations to make in determining how best to power the load, if the first low voltage module requires re-charging (i.e. it stores lower than a threshold level of remaining electrical charge, such as 15% of total charge storage capacity), the load may be powered by the external power supply via the power converter, even if this means operating the power converter in an inefficiency power supply range, since the first low voltage module does not hold sufficient charge to power the load and maintain a threshold minimum stored charge. In this scenario electrical energy from the external power supply may be used to power the load and also re-charge the first low voltage module.

Powering the load with consideration of both operating the power converter at a suitably high efficiency (that is, when the load demand is above a power demand threshold) and operating the first (low voltage) electrical energy storage module when the charge stored by that module is above a threshold value in practice may result in powering the load in a cyclic process of discharging the first electrical energy storage module as it provides power to the load, and recharging the first electrical energy storage module when the threshold remaining charge is reached and powering the load via the power converter during the recharging. This process may be known as cycling, charge cycling, or low voltage cycling when the first electrical energy storage module is a low voltage module (e.g. a 12V battery).

Figure 4B shows an example of charge cycling by which a low power demand from a load is supplied by the power supply system (cyclically, by the first (low voltage) electrical energy storage module and by the power converter via the external power supply) during high voltage charging of the second (high voltage) electrical energy storage module. The graph of Figure 4B shows a plot of time in minutes on the horizontal axis, high voltage (HV) battery charging power in kW and external supply (plug) power in kW on the left vertical axis, and low voltage (12V) battery capacity Wh and power converter power in W on the right vertical axis. The external supply (plug) power is shown as a constant value of 11 kW power supplied to the power supply system. The HV battery charging power is shown as a constant value of around 10.8 kW during provision of power to the load 308 from the first low voltage (e.g. 12V) battery, and shown as a lower value of around 9.2 kW during supply to the load 304 and charging of the first electrical energy storage module 304 from the power converter 302.

The capacity of the low voltage battery at the start of a cycle is around 320Wh and linearly decreases as power from the low voltage battery is provided to power the load until a threshold remaining charge of around 50Wh remains at which point the load is instead powered via the power converter receiving power from the external power supply, and the low voltage battery is re-charged by power from the external power supply until it reaches a full charge of 320Wh again. In other examples the behaviour may not necessarily be linear. The power converter output power to the load is shown as 0W (zero W) while the low voltage battery is powering the load, and during recharging of the low voltage battery (when the low voltage battery is not powering the load) the power converter output power is increased to around 1450W to power the load. Thus while the low voltage electrical energy storage device is able (has sufficient stored charge) to power the low power demand load, it powers the load rather than the power converter powering the load with low efficiency.

Thus the control system 100 may be configured to control the power supply system 300 to provide electrical power from the external power supply 310 via the power converter 302 to the load 308 when the SoC of the first electrical energy storage module 304 is below a remaining charge threshold. When the SoC of the first electrical energy storage module 304 is below a remaining charge threshold, the control system 100 may be configured to control the power supply system 300 to provide electrical power from the external power supply 310 to the first electrical energy storage module 304 to increase the SoC of the first electrical energy storage module 304 to reach a filled charge threshold. The control system 100 may also control the power supply system 300 to provide electrical energy from the external power supply 310 via the power converter 302 to the load 308 to power the load 308. When the SoC of the first electrical energy storage module 304 has reached a filled charge threshold following supply of electrical power to the first electrical energy storage module 304, the control system 100 may control the power supply system 300 to provide electrical power from the external power supply 310 to the second electrical energy storage module 306 and provide electrical power to the load 308 from the first electrical energy storage module 304.

Improved charging of the second electrical energy storage module (which may be used to power the powertrain of the vehicle) may be achieved, by being able to charge more quickly and avoid operating inefficiently, by allowing the first electrical energy module (e.g. a low voltage battery) to provide power to a load when suitable during charging of the second electrical energy storage module. This in turn allows the vehicle to require a shorter overall charging time of the second electrical energy storage module (HV module) and improves the driving range of the vehicle.

As mentioned above, there may be other environmental conditions in determining whether to power the load from the first low voltage module or the external power supply via the power converter. The examples of Figures 4A and 4B show a simple example of considering the power demand from the load, and the remaining SoC of the first (low voltage) electrical energy storage module in determining to power the load from the first electrical energy storage module or from the external power supply via the power converter and the threshold for switching between one or the other power source is a fixed amount.

In other examples, the threshold at which the determination is made to switch from using one or the other source of electrical power to charge the load may vary dependent on one or more factors; such a threshold may be considered to be an adaptive threshold. The control system 100 in such examples may be configured to receive an electrical power demand signal indicative of a load demand of a load connected to the power supply system and receive a temperature signal indicative of a temperature of the power supply system. The control system 100 is configured to output a power supply signal to control the power supply system to provide electrical power from: the first electrical energy storage module to the load in dependence on the electrical power demand signal being below a power threshold; or the external power supply via the power converter to the load in dependence on the electrical power demand signal being above the power threshold, wherein the power threshold is an adaptive power threshold dependent on the electrical power demand signal and the temperature signal.

Thus, the threshold to determine how to power the load depends on the power demand from the load and a temperature of the power supply system, because the efficiency of the power converter as illustrated in Figure 4A, in reality, depends not only on the load demand but one or more other factors including e.g. a temperature of the power supply system. Accounting for the load demand and one or more other factors affecting the efficiency of the power converter provides an improved charging system which adapts more accurately to the true efficiency of the power converter for improved charging efficiency and to help prevent premature aging of first electrical energy power supply. Accounting for power supply system component temperature, such as the temperature of the first electrical energy storage module and associated components is determine how to power the load allows, for example, for the first electrical energy storage module to be used when it is cool enough to operate without detrimentally affecting the battery storage efficiency, or for the power converter to be used when at a temperature which does not detrimentally affect the efficiency of power provision by the converter.

The control system 100 may be configured to control the power supply system 300 to provide electrical power from the external power supply 310 via the power converter 302 to the load 308 when the temperature of the first electrical energy storage module 304 is above a

temperature threshold. By accounting for the temperature of the first electrical energy storage module 304, the control system 100 is able to adaptively switch between from powering the load 308 by the first electrical energy storage module 304 or by the external power supply 310 via the power converter 302 to help prolong the health of the first electrical energy storage module 304. By taking into account the temperature of the first electrical energy storage module 304, the control system 100 allows the health of the first electrical energy storage module 304 to be maintained for longer. The health reflects the ability of the storage module to store electrical energy, and good health correlates with a high storage capacity, high electrical energy transfer efficiency and low electrical energy losses. The first electrical energy storage module 304 will warm up as electrical energy is stored in it or drawn from it, and thus the first electrical energy storage module 304 will age at a faster rate when the cells of the first electrical energy storage module 304 are warmer. Therefore accounting for the temperature of the first electrical energy storage module 304 during deciding how to power a load 308 advantageously helps ensure efficient charging of the second electrical energy storage module 306 and prolong good health of the module 306, while mitigating against aging (i.e. health deterioration) of the first electrical energy storage module 304.

The power threshold, which is dependent on the electrical power demand from the load connected the power supply system, may be dependent on one or more of the voltage across the load and the current drawn by the load. That is, the efficiency at which the power converter can provide power to the load is dependent on the electrical parameters of the load, and this can be recognised and used to inform how to power the load.

The power threshold may be dependent on one or more other electrical factors of the power supply system; for example, on one or more of: a voltage across the power converter; a state of health (SoH) of the first electrical energy storage module; and a state of charge (SoC) of the first electrical energy storage module (as indicated in Figure 4B). The power threshold dependent on the voltage across the power converter may be dependent on one or more of an input voltage across input terminals of the power converter and an output voltage across output terminals of the power converter. By accounting for the voltage across the power converter as well as the power demand from the load, improved efficiency of charging may be achieved since the efficiency of power provision by the power converter is dependent on the voltage across the power converter. Accounting for the health of the first electrical energy storage module can help to prolong its health since, as the health decreases with use and time, the preference for powering the load by the converter increases.

The power threshold may be dependent on a fault state of the first electrical energy storage module; that is, if there is a fault with the first electrical energy storage module then the load may be powered by the power converter to ensure the load is powered. A fault indication may be indicated, for example by illumination of a fault light on the vehicle console or by transmitting an error message to a user's electronic device linked to the vehicle, to indicate there is a fault.

The control system 100 may be configured to control the power supply system 300 to provide electrical power from the external power supply 310 via the power converter 302 to the load 308 when the state of health of the first electrical energy storage module 304 is below a health threshold. The state of health may be qualified as, for example, the ability of the battery to charge to at least a threshold capacity (e.g. 98%) of the full capacity (the full capacity of 100% may be, for example, the ideal capacity or the capacity of a new battery before use). For example, being able to charge to 98% of the ideal/full capacity of the battery may be considered to be good battery health. For example, being able to charge to no more than 75% of the ideal/full capacity of the battery may be considered to be poor battery health. By accounting for the state of health (e.g. age) of the first electrical energy storage module 304, the control system 100 is able to adaptively switch from powering the load 308 by the first electrical energy storage module 304 or by the external power supply 310 to help prolong the health of the first electrical energy storage module 304.

As discussed above, there may be plural factors taken into account in determining how to power the load, and consideration of these factors, including power demand by the load and a temperature of the power supply system, are accounted for in determining an adaptive power threshold above which the load is powered in one way, and below which the load is powered in another way. Such a power threshold may be determined according to a predetermined mapping which is dependent on the temperature of the power supply system 300 and the

power demand from the load 308. The temperature of the power supply system 300 may comprise a temperature of the first electrical energy storage module 304. The predetermined mapping may be further dependent on one or more other factors, such as the health of the first electrical energy storage module 304 and a SoC of the first electrical energy storage module 304, for example. Such a mapping would be a multi-dimensional mapping. Therefore, the control system 100 can determine how to control power provision in the power supply system 300 according to a predetermined plot of the variables accounted for.

The control system 100 may be configured to detect if the electrical power demand from the load 308 connected to the power supply system 300 changes from a value below the power threshold to a value above the power threshold. In response to the detection the control system 100 may output a power request signal to the power converter 302 to cause power to be supplied from the external power supply 310 via the power converter 302 to the load 308, and output a power inhibit signal to the first electrical energy storage module 304 to prevent the provision of electrical power from the first electrical energy storage module 304 to the load 308. In response to the detection, the control system 100 may switch the power converter 302 on prior to output of the power request signal. Thus the control system 100 is able to detect when (i.e. when demand increases from the load 308) to switch over from powering the load 308 from the first electrical energy storage module 304 to the external power supply 310.

The control system 100 may be configured to detect if the electrical power demand from the load 308 connected to the power supply system 300 changes from a value above the power threshold to a value below the power threshold. In response to the detection the control system 100 may output a power inhibit signal to the power converter 302 to inhibit the provision of electrical power from the external power supply 310 via the power converter 302 to the load 308, and output a power request signal to the first electrical energy storage module 304 to cause power to be supplied from the first electrical energy storage module 304 to the load 308. The control system 100 may switch the power converter 302 off if no charging of the first electrical energy storage module 304 is required. Thus the control system 100 is able to detect when demand decreases from the load 308 to switch over from powering the load from the external power supply 310 via the power converter 302 to the first electrical energy storage module 304.

In some examples, the control system 100 may determine to power the load using the first electrical energy storage module 304 or the external power supply 310 via the power converter 302 in dependence on a predicted vehicle usage pattern. For example, historically a drive cycle may start at 8am on a weekday morning (say, by a user travelling to work) and it may be desirable to ensure the first electrical energy supply module is fully charged (or at least charged to a threshold fill charge level e.g. 80%, 90% or 95%). The control system 100 may control the provision of power to the load 308 in dependence on this historical vehicle usage so that at 8am on the next weekday morning, the first electrical energy storage module 304 is charged to a level at least meeting the threshold fill charge level. As another example, a user may be able to enter a one-off planned drive time (e.g. 2pm on Saturday to travel on holiday, which is not a repeated drive time) and the control system 100 may operate to ensure a minimum charge level in the first electrical energy storage module 304 for this planned time. In other words, the control system 100 may predictively modify the adaptive power threshold, and/or modify the power source used to power the load, to ensure the first electrical energy storage module 304 is charged to a level at least meeting the threshold fill charge level.

Figure 5 shows an example method 500 for controlling a power supply system of a vehicle. The power supply system comprises a first electrical energy storage module of the vehicle, a second electrical energy storage module of the vehicle, and a power converter configured to connect the second electrical energy storage module to an external power supply external to the vehicle, as in Figure 3A for example.

The method 500 comprises, during charging of the second electrical energy storage module by provision of electrical power from the external power supply: receiving an electrical power demand signal 502 indicative of a load demand of a load connected to the power supply system; receiving a temperature signal 504 indicative of a temperature of the power supply system (e.g. of the first electrical energy storage module of the power supply system); and outputting a power supply signal 506 to control the power supply system to provide electrical power from: the first electrical energy storage module to the load in dependence on the electrical power demand signal being below a power threshold

508; or the external power supply via the power converter to the load in dependence on the electrical power demand signal being above the power threshold 510; wherein the power threshold is an adaptive power threshold dependent on the electrical power demand signal and the temperature signal. Step 506 may be considered to comprise the step of determining the power supply signal to output, to either perform step 508 or stop 510.

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The method 500 may comprise adapting the power threshold 512 dependent on the electrical power demand signal and the temperature signal indicative of a temperature of the first electrical energy storage module. The method 500 may comprise a feedback loop 514 to re-determine how to power the load, for example based on updated load power demand, temperature, and/or other parameter values of the power supply system or load.

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Figures 6A and 6B show example flow diagrams of control system operation. Figure 6B is a specific example scenario of the operation shown in Figure 6A. . The process flow shown as solid lines may be considered to relate to general operation of the low voltage battery (first electrical energy storage module) and the power converter. The process flow shown as dashed lines may be considered to relate to power efficiency variance calculations based on load power demand and power converter electrical parameters (input and output voltages).

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The high voltage battery 602 (a second electrical energy storage module) is in communication with a supervisory controller 604 which determines in step 606 whether the current operation conditions mean the efficiency threshold for powering the load 610 are met for the power converter 612. If so the load 610 is powered via the power converter 612 and if not the load 610 is powered by the low voltage battery (a first electrical energy storage module). The operation of the power converter 612 is fed back by way of the input voltage of the power converter at the high voltage side 614 (connected to the high voltage battery 602) and the output voltage of the power converter at the low voltage side 618 (connected to the low voltage battery 608). Based on the input and output voltages 614, 618 of the power converter 612, a calculation of power converter threshold efficiency 616 can be made and fed into the determination of whether or not the efficiency threshold is met 606. Variations of this method may include the use of plural low voltage batteries (as in Figure 2B) which may increase the operating window of low voltage battery discharge; that is, the power converter may be switched off, and the load powered by the low voltage batteries, for more of the duration of the load power demand, and when used, powering the load by the power converter may be more efficient as the threshold power demand requiring powering from the power converter would be higher than if only one low voltage battery is available for powering the loads (i.e. the low voltage batteries can provide a higher power to power the load than only one low voltage battery). Where a supervisory controller is described, it is envisaged that other equivalent control topologies are appropriate, such as a supervisory controller.

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Other factors may be accounted for in determining how to power the load as shown in Figure 6B such as the thermal impact on low voltage battery operation and battery aging (SoH) of the low voltage battery. In Figure 6B the elements with the same reference numbers as in Figure 6A represent the same elements/steps. Additionally shown steps in Figure 6B illustrate the consideration of one or more additional factors as well as power demand from the load. In step 620, the control system considers the low voltage battery operating temperature, in step 622 the control system considers the low voltage power supply State of Health (SoH), and in step 624 the control system considers the low voltage SoC. In this example, the efficiency threshold 606 must be met, the low voltage battery must be in a predetermined operating temperature range 620, the low voltage battery must have a sufficiently good SoH 622 and must have a sufficiently high SoC in order for the low voltage battery to power the load 610; otherwise the load is powered via the power converter 612. Mapping between these various parameters may be stored in a predefined mapping and referred to in the method to determine how to power the load.

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Figure 7 shows a vehicle according to examples disclosed herein comprising the systems or control system discussed above. It will be appreciated that various changes and modifications can be made to the present invention without departing from the scope of the present application.

CLAIMS

1. A control system (100) for controlling a power supply system (300) of a vehicle, the power supply system comprising a first electrical energy storage module (304) of the vehicle, a second electrical energy storage module (306) of the vehicle, and a power converter (302) configured to connect the second electrical energy storage module to an external power supply (310) external to the vehicle, wherein during charging of the second electrical energy storage module by provision of electrical power from the external power supply, the control system is configured to:

receive an electrical power demand signal indicative of a load demand of a load (308) connected to the power supply system;

receive a temperature signal indicative of a temperature of the power supply system; and

output a power supply signal to control the power supply system to provide electrical power from:

the first electrical energy storage module to the load in dependence on the electrical power demand signal being below a power threshold; or

the external power supply via the power converter to the load in dependence on the electrical power demand signal being above the power threshold,

wherein the power threshold is an adaptive power threshold dependent on the electrical power demand signal and the temperature signal.

2. The control system (100) of claim 1, wherein the power threshold is further dependent on one or more of:

a voltage across the power converter (302);

a state of health of the first electrical energy storage module (304);

a state of charge of the first electrical energy storage module; and

a fault state of the first electrical energy storage module.

3. The control system (100) of any preceding claim, wherein the control system is configured to control the power supply system (300) to provide electrical power from the external power supply (310) via the power converter (302) to the load (308) when the temperature of the first electrical energy storage module (304) is above a temperature threshold.

4. The control system (100) of any preceding claim, wherein the control system is configured to control the power supply system (300) to provide electrical power from the external power supply (310) via the power converter (302) to the load (308) when the power demand from the load is above a power demand threshold.

5. The control system (100) of any preceding claim, wherein, when the state of charge of the first electrical energy storage module (304) is below a remaining charge threshold, the control system is configured to control the power supply system (300) to provide electrical power from the external power supply (310) to the first electrical energy storage module to increase the state of charge of the first electrical energy storage module to reach a filled charge threshold.

6. The control system (100) of any preceding claim, wherein, when the state of charge of the first electrical energy storage module (304) has reached a filled charge threshold following supply of electrical power to the first electrical energy storage module, control the power supply system (300) to provide electrical power from the external power supply (310) to the second electrical energy storage module (306) and provide electrical power to the load (308) from the first electrical energy storage module.

7. The control system (100) of any preceding claim, wherein the control system is configured to control the power supply system (300) to provide electrical power from the external power supply (310) via the power converter (302) to the load (308) when the state of health of the first electrical energy storage module (304) is below a health threshold.

8. The control system (100) of any preceding claim, wherein, during provision of electrical power from the external power supply (310) via the power converter (302) to the load, the control system is configured to control the power supply system (300) to provide electrical power from the external power supply via the power converter to the second electrical energy storage module (306) to increase the electrical energy stored in the second electrical energy storage module.

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9. The control system (100) of any preceding claim, wherein the power threshold is determined according to a predetermined mapping dependent on the temperature of the power supply system (300) and the power demand from the load.

10. The control system (100) of any preceding claim, wherein the control system is configured to:
detect if the electrical power demand from the load (308) connected to the power supply system (300) changes from a value below the power threshold to a value above the power threshold; and in response to the detection:

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output a power request signal to the power converter (302) to cause power to be supplied from the external power supply (310) via the power converter to the load; and

output a power inhibit signal to the first electrical energy storage module (304) to prevent the provision of electrical power from the first electrical energy storage module to the load.

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11. The control system (100) of any preceding claim, wherein the control system is configured to:
detect if the electrical power demand from the load (308) connected to the power supply system (300) changes from a value above the power threshold to a value below the power threshold; and in response to the detection:

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output a power inhibit signal to the power converter (302) to inhibit the provision of electrical power from the external power supply (310) via the power converter to the load; and

output a power request signal to the first electrical energy storage module (304) to cause power to be supplied from the first electrical energy storage module to the load.

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12. A power supply system (300) comprising
the control system (100) of any of claims 1 to 11;
the first electrical energy storage module (304);
the second electrical energy storage module (306); and
the power converter (302).

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13. A vehicle (700) comprising the power supply system (300) of claim 12 or the control system (100) of any of claims 1 to 11.

14. A method for controlling a power supply system (300) of a vehicle, the power supply system comprising a first electrical energy storage module (304) of the vehicle, a second electrical energy storage module (306) of the vehicle, and a power converter (302) configured to connect the second electrical energy storage module to an external power supply (310) external to the vehicle, wherein during charging of the second electrical energy storage module by provision of electrical power from the external power supply, the method comprises:

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receiving an electrical power demand signal (502) indicative of a load demand of a load (308) connected to the power supply system,

receiving a temperature signal (504) indicative of a temperature of the power supply system; and

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outputting a power supply signal (506) to control the power supply system to provide electrical power from:
the first electrical energy storage module to the load in dependence on the electrical power demand signal being below a power threshold (508); or

the external power supply via the power converter to the load in dependence on the electrical power demand signal being above the power threshold (510);

wherein the power threshold is an adaptive power threshold dependent on the electrical power demand signal and the temperature signal.

15. Computer readable instructions which, when executed by a computer, are arranged to perform a method (500) according to claim 14.

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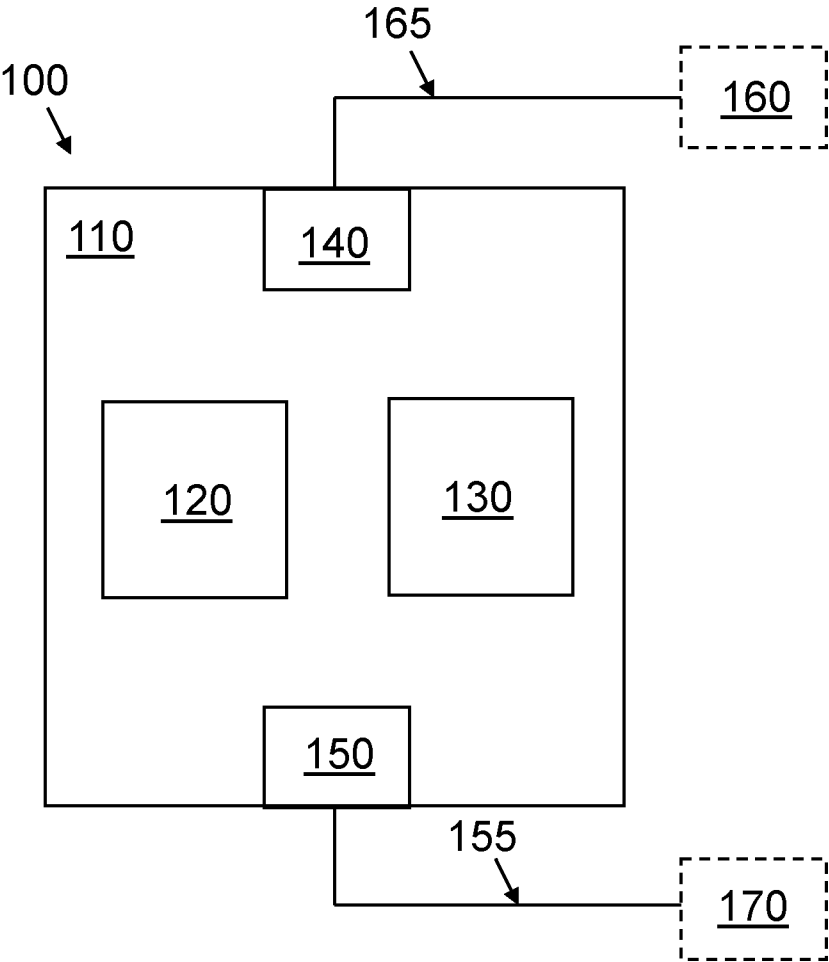


FIG. 1

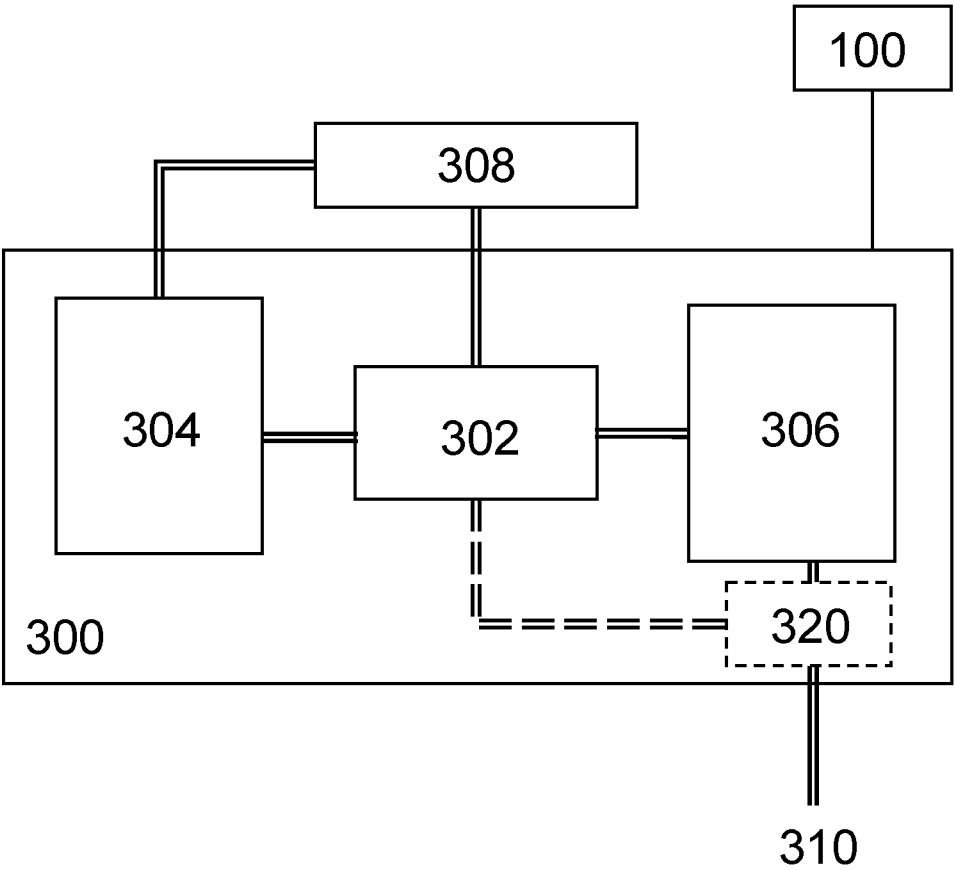


FIG. 2A

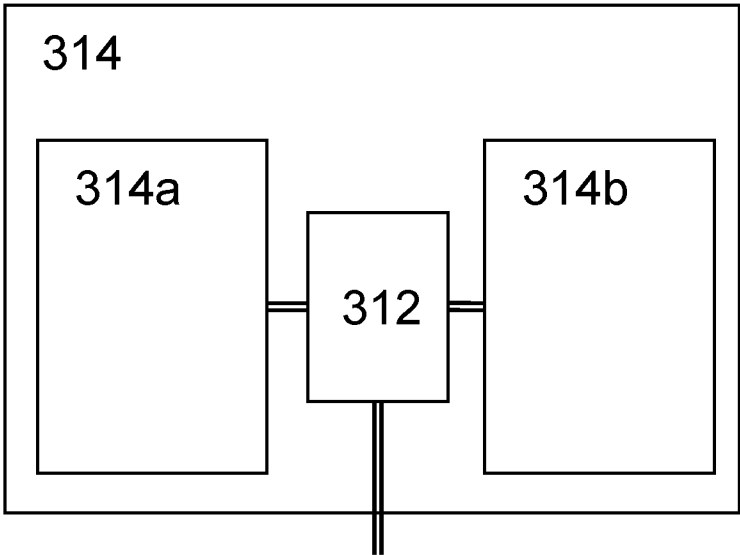


FIG. 2B

3 / 9

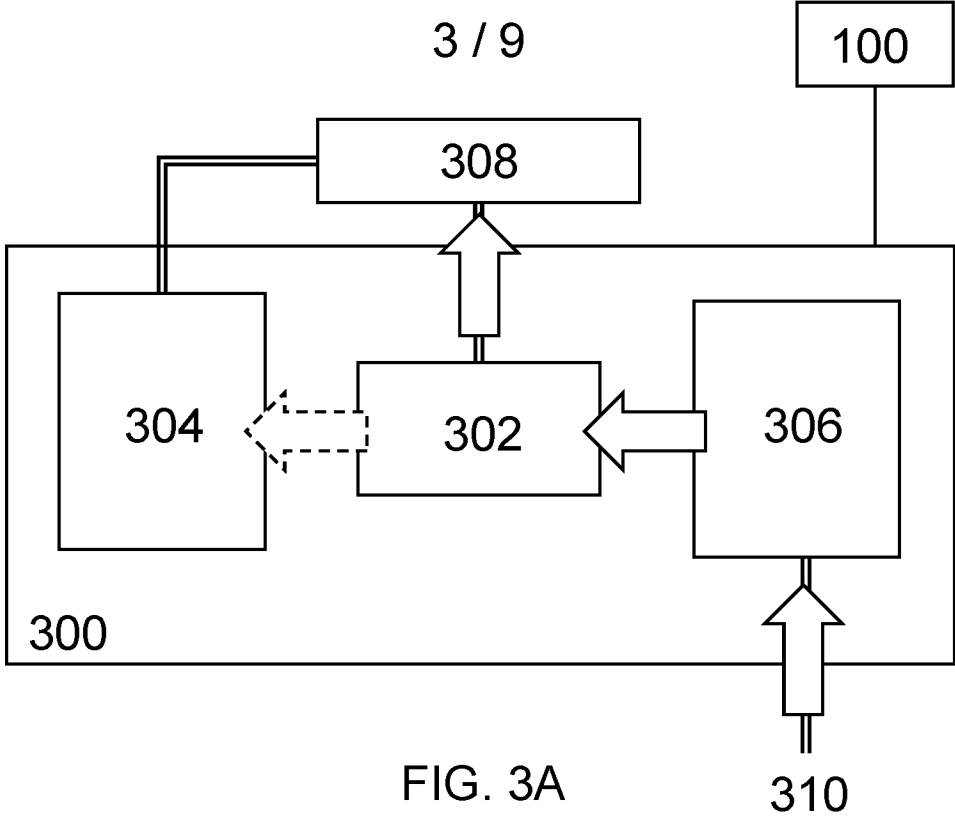


FIG. 3A

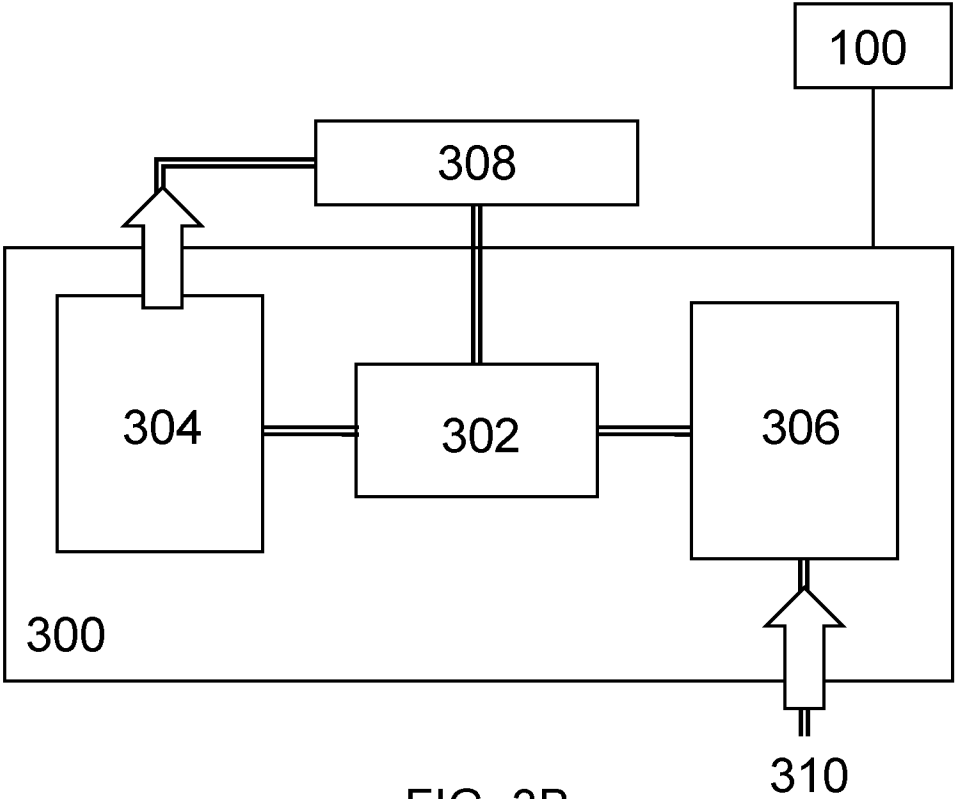


FIG. 3B

4 / 9

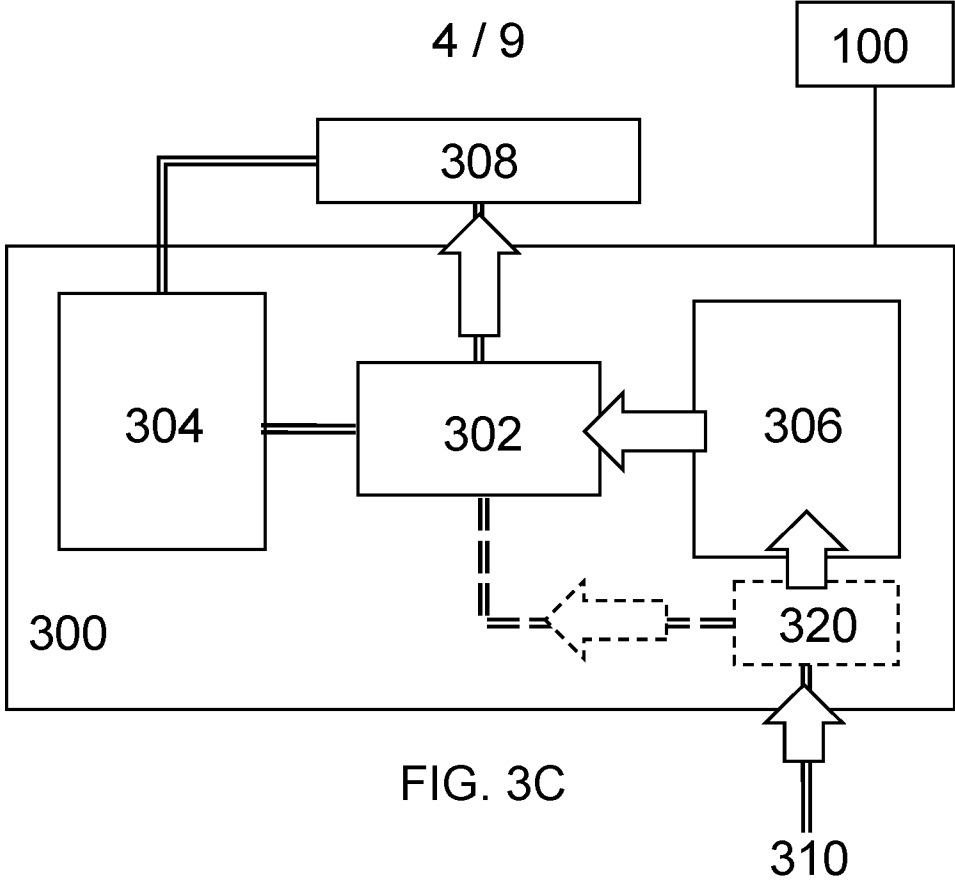


FIG. 3C

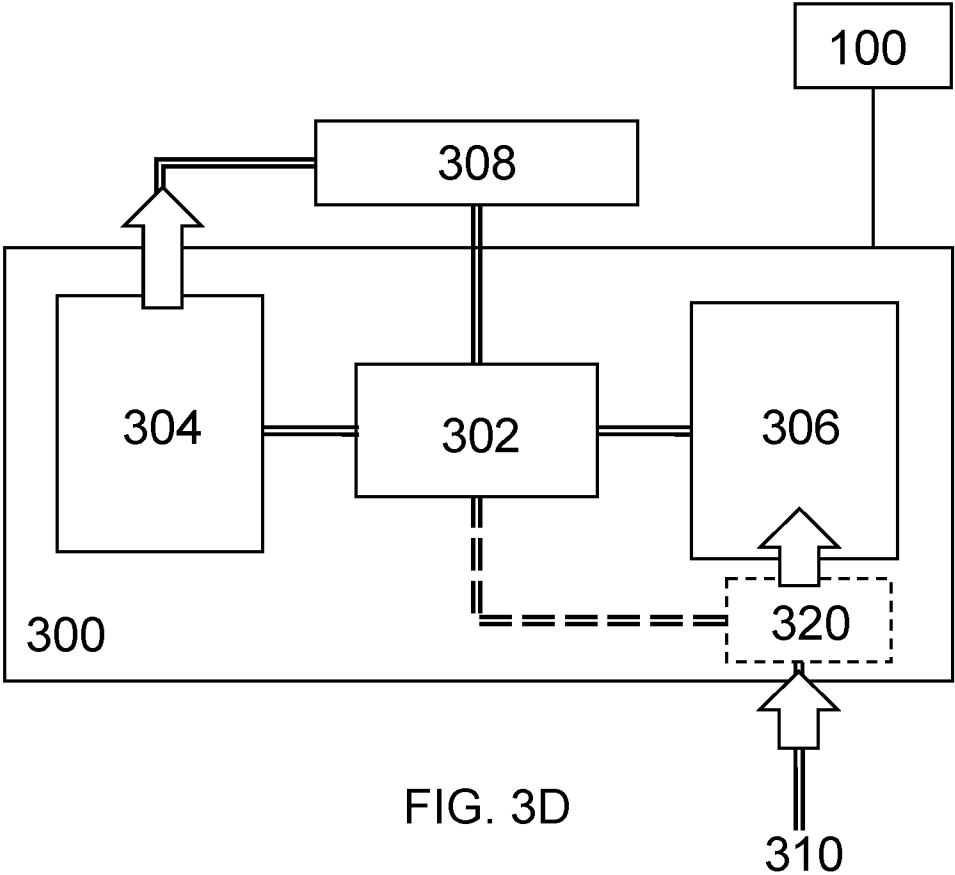


FIG. 3D

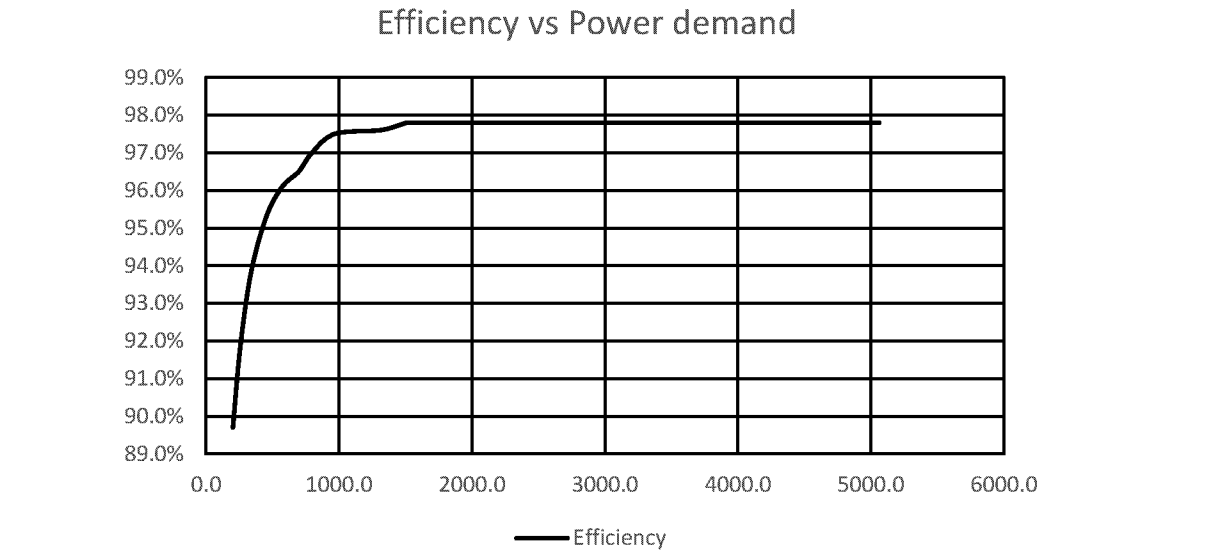


FIG. 4A

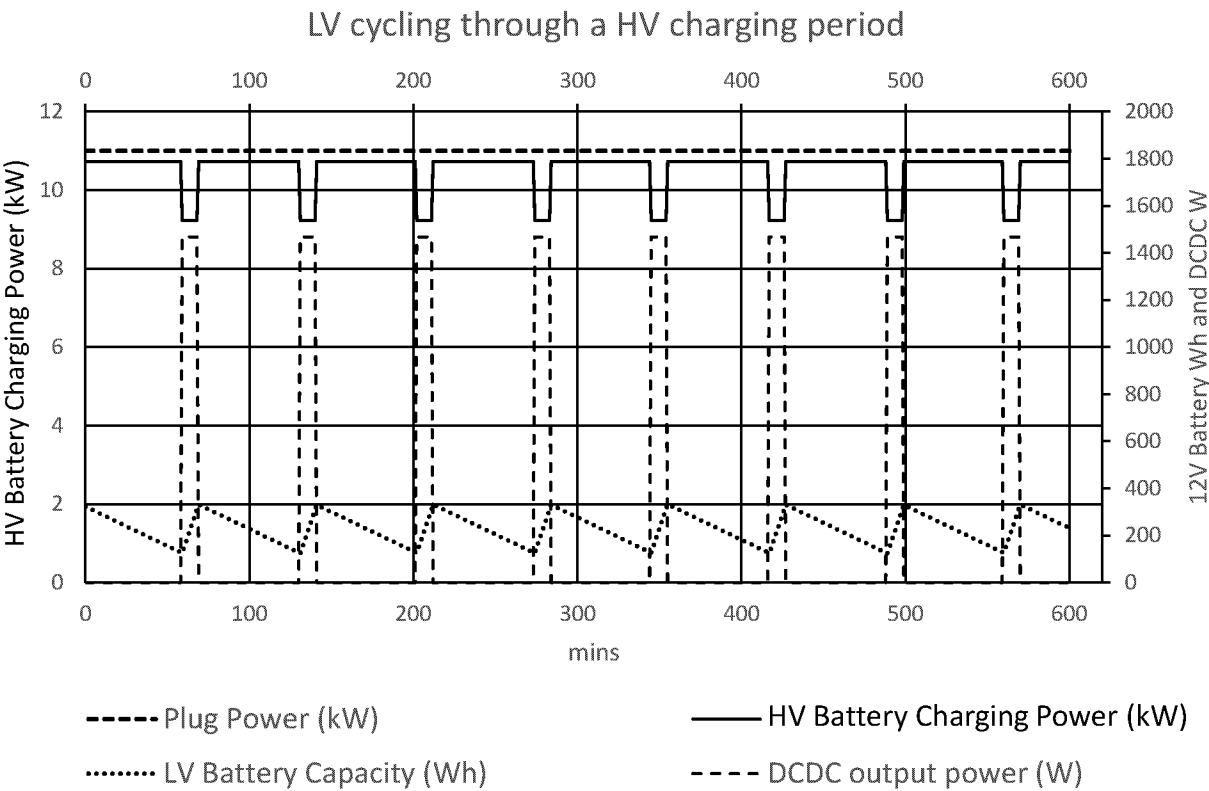


FIG. 4B

6 / 9

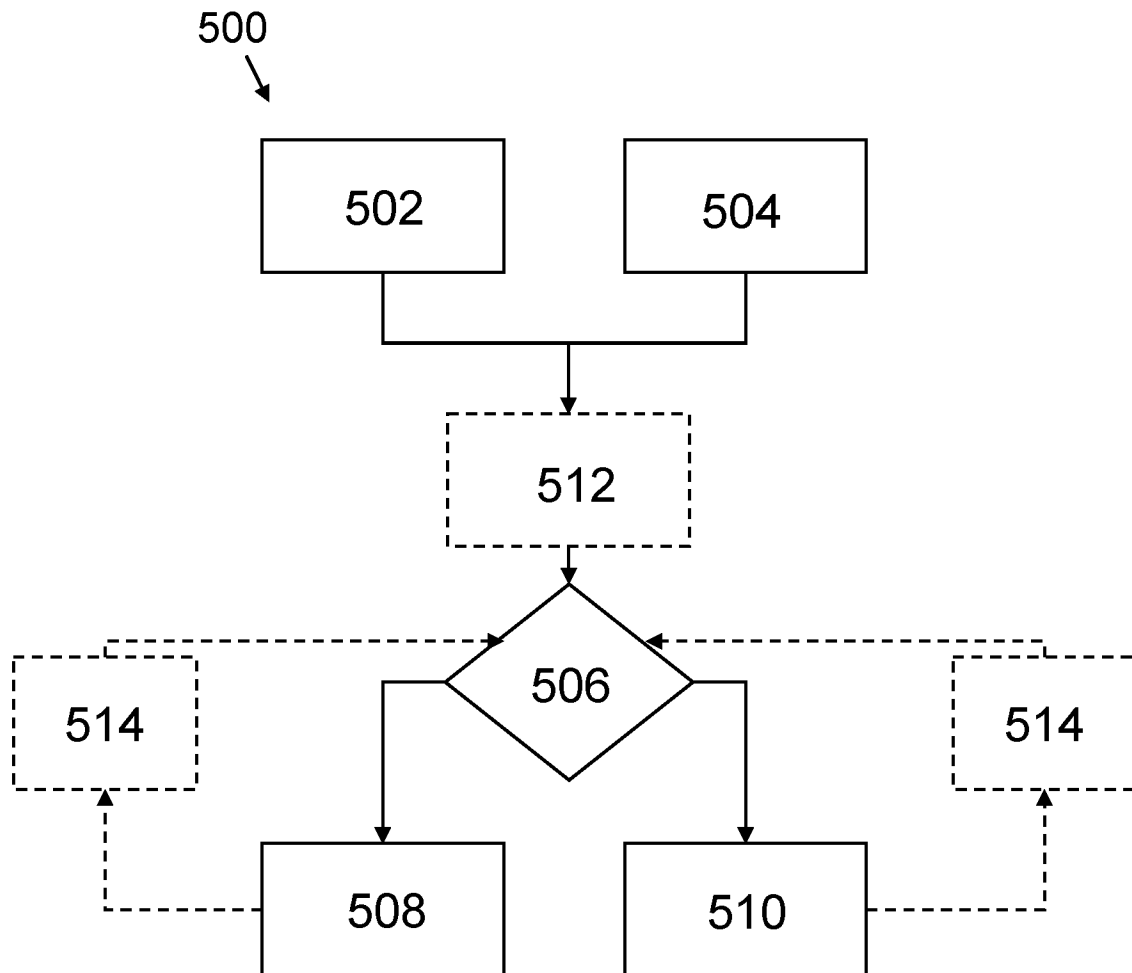


FIG. 5

7 / 9

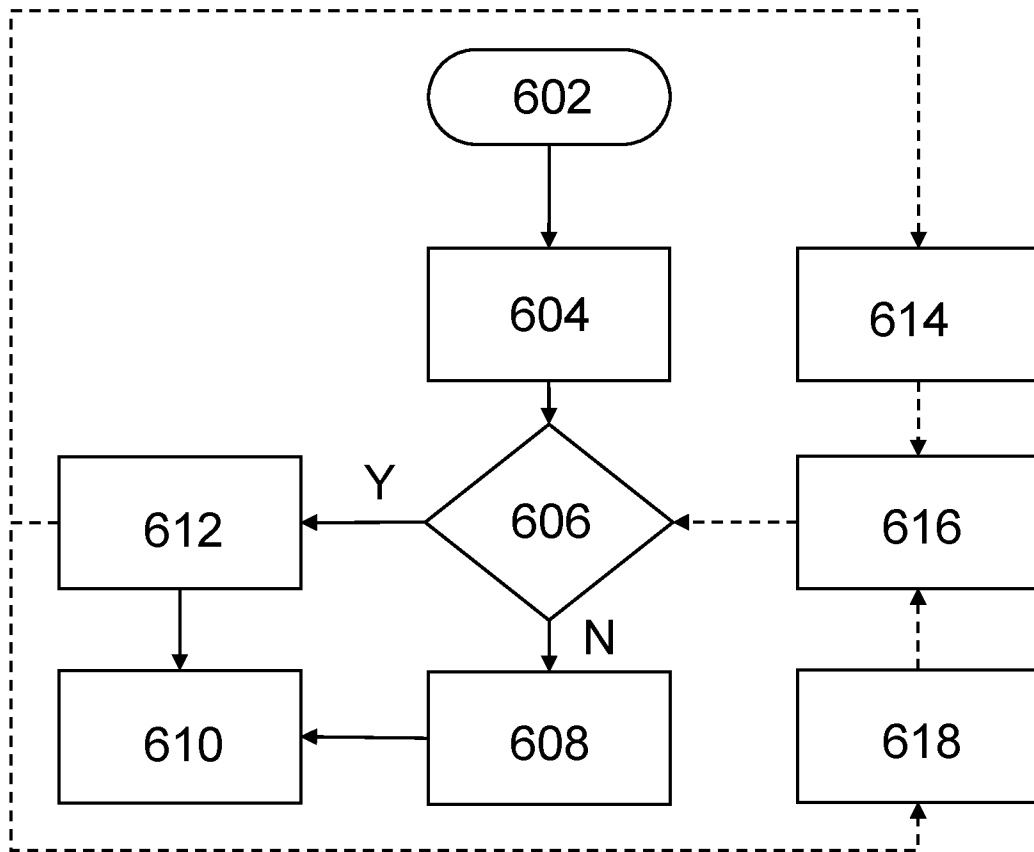


FIG. 6A

8 / 9

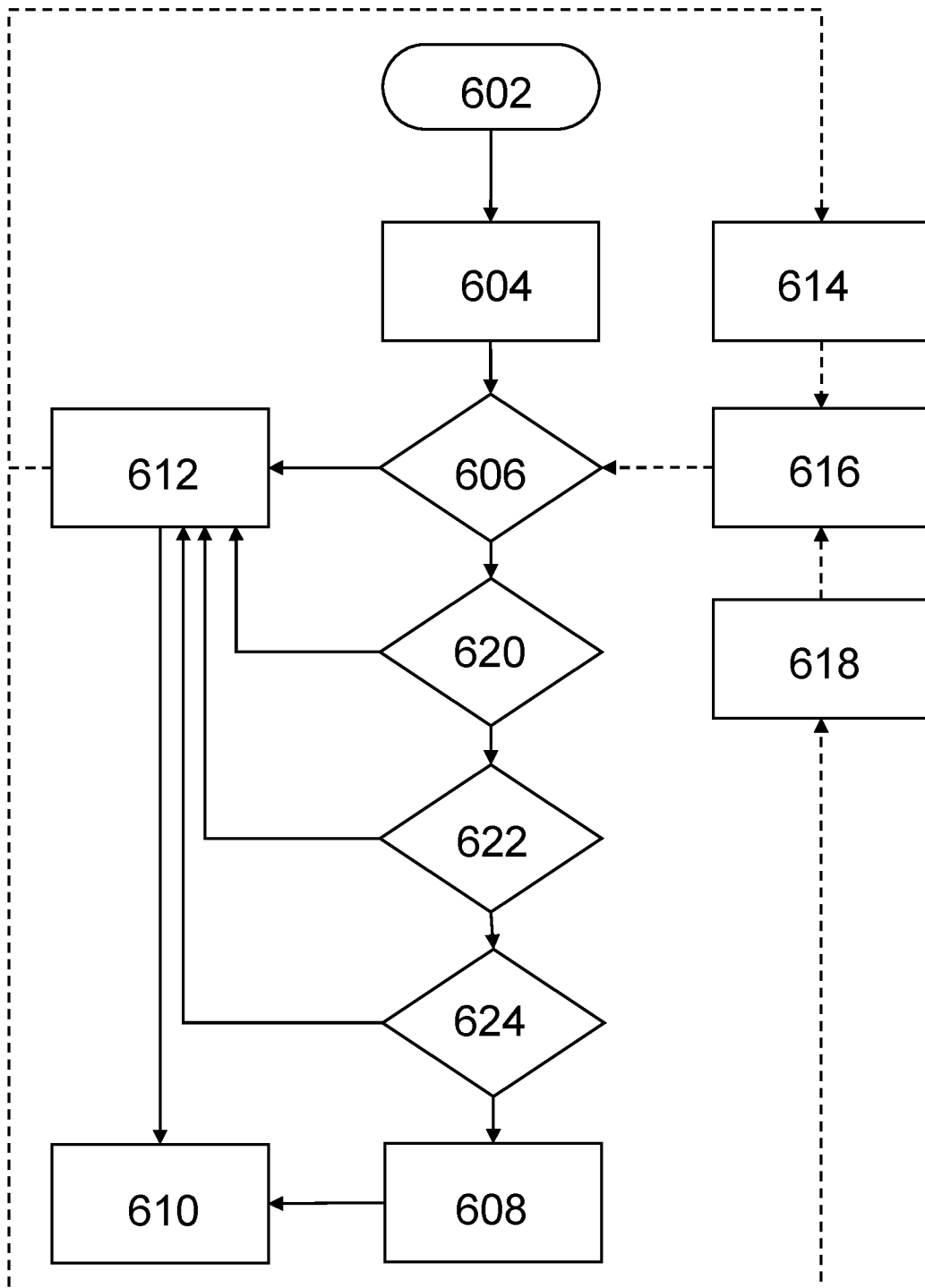


FIG. 6B

9 / 9

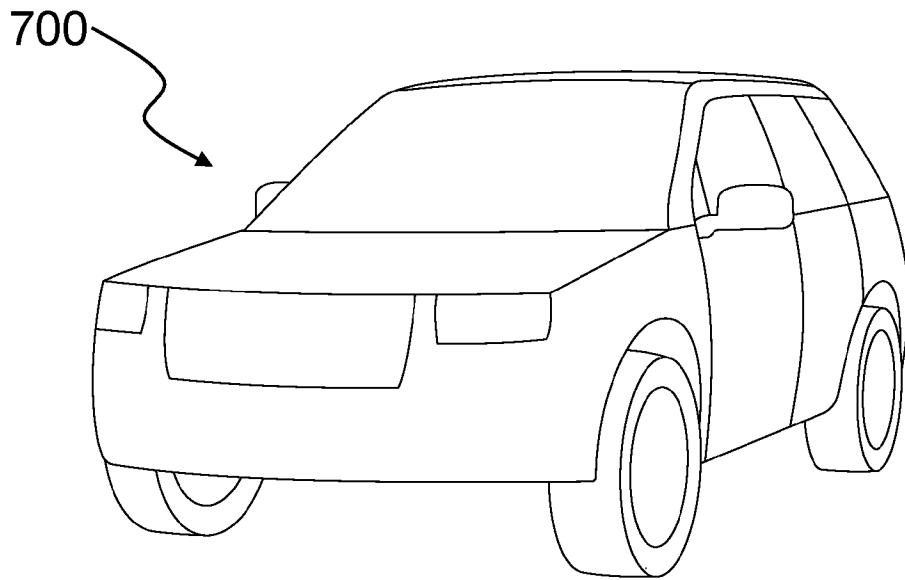


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/067821

A. CLASSIFICATION OF SUBJECT MATTER INV. B60L1/00 B60L53/22 B60L58/12 B60L58/16 B60L58/20 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) B60L Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2015/063556 A1 (TOYOTA MOTOR CO LTD [JP]) 7 May 2015 (2015-05-07) abstract; figures 1,4,5 -----	1 - 6,8 - 15
Y	US 2020/287390 A1 (LEE HO JOONG [KR] ET AL) 10 September 2020 (2020-09-10) abstract; figures 1-3 -----	1 - 6,8 - 15
A	EP 2 631 105 B1 (TOYOTA MOTOR CO LTD [JP]) 22 March 2017 (2017-03-22) abstract; figures 1,4 -----	1 - 15
A	WO 2015/019144 A2 (TOYOTA MOTOR CO LTD [JP]) 12 February 2015 (2015-02-12) abstract; figures 1,2,5 -----	1 - 15
A	US 2013/175858 A1 (SAKURAI TAKESHI [JP] ET AL) 11 July 2013 (2013-07-11) abstract; figures 1,2 -----	1 - 15
☐ 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 "E" earlier application or patent but published on or after the international filing date "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) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "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 "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 "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 "&" document member of the same patent family		
Date of the actual completion of the international search 20 September 2024		Date of mailing of the international search report 08/10/2024
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 Arias Pérez, Jagoba

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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