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(73) Patenthaver: **ALSTOM Holdings, 48 rue Albert Dhalenne, 93400 Saint-Ouen-sur-Seine, Frankrig**

(72) Opfinder: **ROUILLE, Bruno, , 65200 ORDIZAN, Frankrig**

(74) Fuldmægtig i Danmark: **Novagraaf Brevets, Bâtiment O2, 2 rue Sarah Bernhardt CS90017, F-92665 Asnières-sur-Seine cedex, Frankrig**

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POWER SUPPLY SYSTEM AND METHOD FOR CONTROLLING SUCH A POWER SUPPLY SYSTEM

DESCRIPTION

The present invention relates to power supply systems and methods for controlling such power supply systems.

The invention is particularly applicable to power supply systems used in electric vehicles.

Electric vehicles, and more particularly electrically-powered rail vehicles, generally feature an electricity storage system comprising, for example, one or more electrochemical storage batteries.

It is now common practice to add a fuel cell to the electrical storage system to provide a power supply to supplement the battery and extend the vehicle's range.

Thus, the vehicle's drive train can be powered when the vehicle is not supplied with electricity from an external source, for example when the vehicle is traveling in an area where there is no catenary or power rail.

In practice, however, fuel cell autonomy is limited by technical constraints on on-board hydrogen storage.

The hydrogen needed to operate the fuel cell is stored in a special tank on board the vehicle. However, the hydrogen storage techniques currently available require the use of large, heavy tanks, which are further particularly costly. For example, storing one kilogram of hydrogen requires a 25-kilogram tank.

In many applications, such as rail or passenger transport, traction equipment must be kept to a reasonable size and weight, so it is not possible to increase the amount of hydrogen stored on board the vehicle at will.

However, the fuel cell must have sufficient energy autonomy to help power the vehicle.

US 2013/065089 A1 discloses a system for managing a fuel cell in a motor vehicle, wherein the fuel cell is coupled to a battery within an electric drive train of the vehicle, this battery being used inter alia to temporarily store electrical energy during regenerative braking of the vehicle.

US 2019/229357 A1 discloses a vehicle that comprises a fuel cell configured to provide electrical energy, in particular to power an engine of the vehicle, the latter including an energy storage device, such as a battery, which can be recharged with excess power from the fuel cell.

US 2019/160963 A1 discloses a method for driving a fuel cell in an electric vehicle, wherein an engine and auxiliary devices are powered by a supply device comprising a fuel cell and an electric battery.

US 2002/162694 A1 discloses a road vehicle with an electric motor powered by a power system comprising a fuel cell. A controller calculates the electrical load required to operate the vehicle.

These drawbacks are more particularly addressed by the invention, which proposes an improved power supply system, in particular for an electric vehicle, comprising a battery and a fuel cell, wherein hydrogen consumption is optimized.

To this end, the invention relates to a method of controlling an electric power supply system for an electric vehicle, an electric power supply system for an electric vehicle, and an electric vehicle according to the attached claims.

Owing to the invention, optimized fuel cell operation makes it possible to reduce hydrogen consumption, without degrading fuel cell operation or its ability to supply power when the vehicle needs it. Thus, for a given volume of hydrogen stored in the vehicle, the vehicle's range is increased without the need to install a larger tank, which would be more expensive, bulkier and more cumbersome.

The invention will be better understood and other advantages thereof will become clearer in the light of the following description of an embodiment of a system for supplying power given by way of example only and made with reference to the appended drawings, in which:

[Fig. 1] Figure 1 is a block diagram of a power supply system for a rail vehicle in accordance with one embodiment of the invention comprising a fuel cell;

[Fig. 2] Figure 2 is an efficiency curve of the fuel cell of Figure 1;

[Fig. 3] Figure 3 is a diagram depicting the steps of an example of a method for controlling the power supply system of Figure 1 in accordance with an embodiment of the invention.

Figure 1 shows an electric vehicle 2 with a power supply system.

The electric vehicle 2 can be an electrically-powered rail vehicle.

According to non-limiting examples, the rail vehicle can be a passenger train, or a high-speed train, or a locomotive, or a service vehicle such as a railcar or a jitney, or an urban transport vehicle such as a metro or a tramway.

Alternatively, the vehicle 2 can be an electric road vehicle, such as an electric bus or an electric truck.

According to examples, the vehicle 2 comprises an electric drive train comprising one or more electric motors 4 preferably configured to move the vehicle along a track.

In the example shown, the or each motor 4 is mechanically coupled to a load, such as one or more wheels of a bogie or drive axle. Alternatively, the traction chain can include one or more loads of different types.

The power supply system is also configured to supply power to one or more auxiliary equipment items of the vehicle 2.

For example, the auxiliary equipment items include at least one or even several auxiliary apparatuses for the vehicle 2, such as a ventilation, heating or air conditioning system, or one or more motors for opening or closing automatic vehicle doors, or a lighting system, or a passenger information system, or any other equivalent apparatus, these examples being non-exhaustive.

As shown in Figure 1, the power supply system includes a first energy storage device comprising a hydrogen tank 6 and a fuel cell 8, both on board the vehicle 2.

A power conversion device 10 is connected to the fuel cell 8 and is configured to transform the electrical voltage delivered by the fuel cell 8 to electrically power the motor 4 and auxiliary equipment items.

The conversion device 10 comprises a first power converter 12 and a second power converter 14.

The first converter 12 is connected to the output of the fuel cell 8.

For example, the first converter 12 is a DC-DC step-up voltage converter, such as a chopper.

The second converter 14 is connected to the motor 4. For example, this involves an inverter that converts the DC voltage delivered by the first converter 12 into an AC voltage used to power the motor 4.

According to a non-limiting example, the electrical voltage at the terminals of the fuel cell 8 can vary based on the electrical power required from the fuel cell 8 when in operation. In practice, this electrical voltage is lower than the electrical voltage present between the conductors of the internal DC supply bus (here between the converters 12 and 14).

The power supply system includes a second energy storage device comprising a battery 16.

Advantageously, the battery 16 can comprise an electrochemical storage battery. Alternatively, the battery 16 may comprise a capacitor or supercapacitor array, or any suitable electricity storage technology. In some cases, such as with capacitors or super-capacitors, it may be necessary to add a DC/DC output converter, such as a step-up chopper.

According to a non-limiting example, the battery 16 has a voltage greater than or equal to 750V DC across its terminals when charged.

Advantageously, the battery 16 is connected to the converter 10 to supply power to the motor 4 and the auxiliary equipment items. For example, the battery 16 is connected to the input of the second converter 14. Alternatively, the power supply system can include a second DC/DC conversion stage to step up the output voltage to a voltage of 1500V, for example to be compatible with the voltage required by the traction motor.

The battery 16 can also be recharged by the fuel cell 8 or by electrical energy collected by a collection device on the vehicle 2, such as a pantograph or current collector shoe or any equivalent system.

The auxiliary equipment items are supplied by an additional power converter 18, which can be powered by the battery 16 and/or the fuel cell 8 via the conversion device 10.

In the example shown, the input of the additional converter 18 is connected to the output of the battery 16 and to the output of the first converter 12.

Advantageously, the additional converter 18 has a first output 20 which delivers a DC voltage and a second output 22 which delivers a second AC voltage, which may be a three-phase electrical voltage.

According to a non-limiting example, the DC voltage is equal to 24 V DC and the AC voltage is equal to 400 V AC.

According to some embodiments, the battery 16 and the fuel cell 8 are designed to store energy for at least partial electrical powering of the vehicle 2, in particular for powering the engine 4 and/or auxiliary equipment items, when the vehicle 2 is not powered by an external power source. This is the case, for example, when the vehicle 2 is traveling on a section of track where there is no catenary or feeder rail.

The supervision and regulation of the power supply system, and in particular of the first storage device, which is the primary energy source, and the second storage device, which is the energy storage system, are performed automatically by one or more electronic control devices, which may belong to the power supply system.

In some embodiments, the fuel cell 8 is preferentially used in addition to the battery 16.

Indeed, the battery 16 is preferentially used in such a way that its state of charge remains within a predetermined range, for example between 20 % and 90 % of its maximum capacity, in order to avoid premature wear of the battery or degradation of its performance.

The fuel cell 8 is therefore preferentially activated when the electrical power demanded from the battery would cause its state of charge to vary outside the predetermined range.

Furthermore, the battery 16, by its very nature, has a shorter response time than the fuel cell 8 and is better able to withstand repeated power variations than the fuel cell 8.

The fuel cell 8 is therefore preferentially used to respond to power demands over long periods of time, rather than to respond quickly to power demands that can vary rapidly and with a high amplitude of variation.

For example, an electronic controller associated with the battery 16 is programmed to calculate a target value for the state of charge, which is recalculated over time based on changes in the charge of the battery 16 and the loads imposed on the power system by the drive train and auxiliary equipment items.

Based on the calculated state of charge target value, the electronic controller determines a first setpoint value for the electrical power to be supplied by the battery 16.

Energy management of the fuel cell 8 is carried out by an electronic control device 24, which is able to define a second power setpoint to be supplied by the fuel cell 8 so that the power supply system responds to its demands while allowing the battery 16 to reach the calculated first setpoint.

In particular, the control device 24 is programmed to control the fuel cell 8 so that the latter delivers an electrical power of optimized value, for a given moment, so that the fuel cell 8 operates with maximum efficiency and in accordance with the demands of the power supply system.

To do this, the control device 24 is able to automatically control the power system based on this second calculated power setpoint, for example by modifying the quantity of air and/or the quantity of hydrogen supplied to the input of the fuel cell 8, in order to modify the power supplied by the fuel cell 8. The control device 24 can also be configured to modify the operation of the conversion device 10, for example by modifying the current setpoint of the first converter 12.

The control device 24 can also control an electrical switching device for connecting or disconnecting the fuel cell 8 from the rest of the power system.

In many embodiments, the control device 24 is implemented by an electronic circuit, for example mounted on an electronic board.

For example, the control device 24 comprises a processor, such as a programmable microcontroller, and a computer memory coupled to the processor and forming a computer-readable data storage medium.

According to examples, the memory is a ROM, or a RAM, or a non-volatile memory of the EPROM, or EEPROM, or Flash type, or any suitable memory technology, or any possible combination of these memory technologies.

The memory includes executable instructions and/or software code, in particular for implementing a method in accordance with the embodiments of the invention when these instructions and/or software code are executed by the processor.

Alternatively, the control device 24 comprises a programmable logic device (FPGA) or a dedicated integrated circuit configured to implement such methods.

According to embodiments, the control device 24 comprises a first calculation module 26, or energy management module, programmed to determine a value or range of values indicating the electrical power to be delivered by the fuel cell 8.

For example, the module 26 can measure and/or determine the following electrical quantities at a given time:

- the power required by the drive train, for example in response to an acceleration or braking command from a driver,

- the power required by the auxiliary equipment items,

- the state of charge of the battery 16,

- the maximum electrical power that can be supplied by the battery 16 when in a state of charge or a state of discharge.

In the example shown, the module 26 is then programmed to calculate the electrical power that the fuel cell should theoretically deliver, based on the electrical quantities determined, but also based on the battery power setpoint.

The module 26 calculates a minimum and maximum value for the power to be supplied by the fuel cell 8. The electrical power to be delivered by the fuel cell lies between said minimum and maximum values.

According to one example, the minimum value is equal to the sum of the power required by the drive train and the power required by the auxiliary components, minus the maximum power that can be delivered by the battery 16, particularly when discharging. The minimum value is zero if the above quantity is less than zero.

According to one example, the maximum value is equal to the sum of the power required by the drive train and the power required by the auxiliary components, minus the minimum power that can be delivered by the battery 16, particularly when discharging. The maximum value is zero if the above quantity is less than zero.

Thus, the power required from the fuel cell to supplement the power supplied by the battery 16 is equal to the power required for the battery to reach the target state of charge, minus the power required by the drive train and the power required by the auxiliary apparatuses.

According to some embodiments, the control device 24 also comprises a second calculation module 28, or optimization module, configured to calculate a target power value to be supplied by the fuel cell 8.

This calculation is made here based on power values determined by the first module 26, and according to a predetermined efficiency curve expressing the efficiency of the fuel cell 8. Such a curve is stored, for example, in a memory of the control device 24.

Figure 2 shows a graph 40 exemplifying an example of operation of the power supply system for the vehicle 2.

On this graph, the x-axis indicates the total current I_tot, expressed in amperes, delivered by the fuel cell 8. On the y-axis, the left-hand axis corresponds either to the electrical voltage delivered by the power supply (curve 44), expressed in volts, or to the power delivered by the power supply (curve 46), expressed in kW. The right-hand axis shows the energy efficiency FCC_eff of the fuel cell 8 (curve 42).

On this graph 40, curves 44, 46 indicate, respectively, the electrical voltage of the power supply system and the total power delivered by the power supply system.

Point 50 represents the maximum power output of the fuel cell, corresponding here to a voltage of 379 V DC for a power of 50 kW.

The first point 51 represents a first power limit, corresponding here to a voltage of 390 V DC for a power of 20 kW.

The second point 52 represents a second power limit, associated with a second limit value, corresponding here to a voltage of 315 V DC for a power of 200 kW.

Area 54 designates an operating range of the fuel cell 8 where it has maximum or optimum efficiency. Area 54 corresponds to a set of operating points of the fuel cell 8 for which the values lie between the first limit 51 and the second limit 52, and whose upper values are bounded by the energy efficiency curve 42 of the fuel cell 8.

Preferably, to define the second power setpoint, the module 28 selects an operating point within area 54, preferably corresponding to the maximum of the efficiency curve 42 within area 54 (point 50).

From this efficiency curve 42, the module 28 selects a setpoint value between the minimum and maximum values calculated by the module 26, which satisfies at least several of the following criteria:

- the power supplied by the battery 16 can, owing to the additional power supplied by the fuel cell 8, converge toward the first setpoint value;

- driver control commands, such as acceleration or braking, are complied with as much as possible;

- at least some, if not all, of the auxiliary equipment items can be correctly powered;

- variations in the power required from the fuel cell 8 over time are preferably slow.

For example, the fuel cell operates at a level equal to the maximum efficiency point as determined by the efficiency curve 42, or at a level close to this maximum efficiency point, for example within plus or minus 10 % of the maximum efficiency point.

The efficiency curve 42 can be predefined in advance, for example at the factory from the specifications of the fuel cell 8. Alternatively, the efficiency curve 42 can be calculated by the device 24 and updated over time based on the operation of the power system and/or based on wear and tear on the fuel cell 8.

In some implementations, if the power required from the fuel cell 8 is low, for example below its minimum operating threshold, then the fuel cell 8 is not used so as not to overcharge the battery 16. In this case, the control device 24 commands the disconnection of the fuel cell 8 or does not start the chopper 12.

In other implementations, the traction or braking setpoint that causes the required variation in electrical power may have to be limited by the control device 24 in the extreme case where the power required is too great and the electrical supply system cannot meet the demand, for example because neither the fuel cell 8 nor the battery 16 can supply the required power. The control device 24 can also instruct the auxiliary equipment items to reduce power consumption.

An operating example is now described with reference to the example shown in Figure 3.

The method begins in step 100, for example in response to a control command issued by a train driver, such as an acceleration or braking command issued by means of a traction manipulator, which has the effect of modifying the power consumption of the motor 4 and/or auxiliary equipment items.

Alternatively, step 100 can be performed regularly, for example at predefined intervals.

According to other alternatives, step 100 can be performed when the vehicle 2 reaches a specific geographical position, for example when the vehicle 2 passes specific points on a predefined trajectory during its journey.

In step 100, the control device 24 receives information, namely a first setpoint value corresponding to the electrical power that the battery must provide so that the power system can supply the drive train and auxiliary equipment items.

In step 102, the module 26 determines the electrical power required by the drive train, and more specifically by the motor(s) 4, as well as the electrical power required by the auxiliary equipment items.

In step 104, the module 26 determines the state of the battery, in particular the state of charge of the battery and the maximum power available for charging or the maximum power available for discharging.

In step 106, the module 26 calculates the maximum and minimum values of electrical power to be delivered by the fuel cell 8, based on the state of the power system and the demands that it must handle, as determined in steps 102 and 104.

In step 108, the second module 28 calculates the optimized value of electrical power to be supplied by the fuel cell from the maximum and minimum values of electrical power calculated by the module 26 and based on the efficiency curve 42.

Finally, in step 110, the control device 24 uses the optimized electrical power value calculated in this way as a setpoint to control the power supply system accordingly, so that the fuel cell 8 supplies the corresponding electrical power or, if necessary, is disconnected from the rest of the power supply system.

Owing to the invention, optimized fuel cell operation makes it possible to reduce hydrogen consumption, without degrading fuel cell operation or its ability to supply power when the vehicle needs it. Thus, for a given volume of hydrogen stored in the vehicle, the vehicle's range is increased without the need to install a larger tank, which would be more expensive, bulkier and more cumbersome.

Any feature of one of the above-described embodiments can be implemented in the other embodiments and variants described.

PATENTKRAV

1. Fremgangsmåde til at styre et strømforsyningssystem for et elkøretøj (2), der omfatter et batteri (16), en brændstofcelle (8) og en energikonverteringsanordning (10), der er forbundet til batteriet (16) og brændstofcellen (8), idet strømforsyningssystemet er konfigureret til at strømforsyne en elektrisk drivlinje (4) i køretøjet og mindst en hjælpeanordning, **kendetegnet ved, at** fremgangsmåden omfatter trinene med:

- hentning (100) af en første strømreferenceværdi, der svarer til den strøm, der skal forsynes af batteriet (16), idet den første strømreferenceværdi bestemmes ud fra en målværdi for en ladetilstand for batteriet (16),

- bestemmelse (102) af den strøm, der kræves af drivlinjen, og den strøm, der kæves af den mindst ene hjælpeanordning,

- bestemmelse (104) af tilstanden af batteriet, især ladetilstanden af batteriet samt den maksimalt tilgængelige strøm, som batteriet kan levere,

- beregning (106) af mindst én strømværdi, der skal leveres af brændstofcellen (8), afhængigt af tilstanden af batteriet og den strøm, som kræves af drivlinjen og den mindst ene hjælpeanordning,

- beregning (108), ud fra den beregnede strømværdi, af en anden referenceværdi for den strøm, som skal leveres af brændstofcellen (8), idet denne værdi optimeres, så brændstofcellen (8) fungerer ved eller tæt på dens maksimale effektivitetsværdi,

- styring (100) af strømforsyningssystemet i henhold til den anden beregnede strømreferenceværdi,

kendetegnet ved, at beregning (106) af mindst én værdi for strøm, der skal leveres af brændstofcellen (8) omfatter beregningen af en minimums- og maksimumsværdi for strøm, der skal leveres af brændstofcellen, idet den anden strømreferenceværdi er mellem nævnte minimums- og maksimumsværdi,

ved, at den beregnede strømværdi svarer til den strøm, der kræves af brændstofcellen for at supplere den strøm, der leveres af batteriet, idet den beregnede strømværdi er lig med den strøm, der kræves for, at batteriet kan nå den nævnte målværdi for ladetilstanden minus den strøm, der kræves af drivlinjen, og den strøm, der kræves af den nævnte mindst ene hjælpeanordning,

og **ved, at** beregningen af den anden strømreferenceværdi udføres på grundlag af en foruddefineret effektivitetskurve (42) for brændstofcellen (8), ved at vælge et arbejdspunkt (50) for brændstofcellen, der svarer til maksimumsværdien på effektivitetskurven (42) inden for et arbejdsområde (54), der er omfattet mellem minimumsværdien og den tidligere beregnede maksimumsværdi, og ved at opfylde mindst en flerhed af følgende kriterier:

- at den strøm, der leveres af batteriet (16), samles mod den første referenceværdi,

- at de styringskommandoer, som en fører afgiver, overholdes,

- at mindst én hjælpeanordning strømforsynes, og

- at udsvingene i den strøm, der kræves fra brændstofcellen (8), over tid er langsomme.

2. Fremgangsmåde ifølge krav 1, hvor minimumsværdien er lig med summen af den strøm, der kræves af drivlinjen, og den strøm, der kræves af den nævnte mindst ene hjælpeanordning, minus den maksimale strøm, der kan leveres af batteriet (16).

3. Fremgangsmåde ifølge krav 1 eller krav 2, hvor maksimumsværdien er lig med summen af den strøm, der kræves af drivlinjen, og den strøm, der kræves af den nævnte mindst ene hjælpeanordning, minus den minimumsstrøm, der kan leveres af batteriet.

4. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor den første strømreferenceværdi er beregnet tidligere på grundlag af den nævnte målværdi for ladetilstanden af batteriet.

5. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor fremgangsmåden implementeres som svar på en styrekommando fra en fører af køretøjet, for eksempel en accelerations- eller bremsningskommando, der har den virkning, at den ændrer strømforbruget for drivlinjen og/eller den nævnte mindst ene hjælpeanordning.

6. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor den anden strømreferenceværdi udvælges, så når brændstofcellen leverer strøm, der svarer til den anden strømreferenceværdi, batteriet (16) leverer strøm, der svarer til den beregnede første referenceværdi.

7. Strømforsyningssystem for et elkøretøj (2), der omfatter et batteri (16), en brændstofcelle (8) og en energikonverteringsanordning (10), der er forbundet til batteriet (16) og brændstofcellen (8), idet strømforsyningssystemet er konfigureret til at strømforsyne en elektrisk drivlinje (4) i køretøjet og mindst en hjælpeanordning, **kendetegnet ved, at** strømforsyningssystemet omfatter en elektronisk styreanordning (24), der er programmeret til at implementere trinene med:

- hentning (100) af en første strømreferenceværdi, der svarer til den strøm, der skal forsynes af batteriet (16), idet den første strømreferenceværdi bestemmes ud fra en målværdi for en ladetilstand for batteriet (16),

- bestemmelse (102) af den strøm, der kræves af drivlinjen, og den strøm, der kæves af den mindst ene hjælpeanordning,

- bestemmelse (104) af tilstanden af batteriet, især ladetilstanden af batteriet samt den maksimalt tilgængelige strøm, som batteriet kan levere,

- beregning (106) af mindst én strømværdi, der skal leveres af brændstofcellen (8), afhængigt af tilstanden af batteriet og den strøm, som kræves af drivlinjen og den mindst ene hjælpeanordning,

- beregning (108), ud fra den beregnede strømværdi, af en anden referenceværdi for den strøm, som skal leveres af brændstofcellen (8), så brændstofcellen (8) fungerer ved eller tæt på dens maksimale effektivitetsværdi,

- styring (100) af strømforsyningssystemet i henhold til den anden beregnede strømreferenceværdi,

kendetegnet ved, at beregning (106) af mindst én værdi for strøm, der skal leveres af brændstofcellen (8) omfatter beregningen af en minimums- og maksimumsværdi for strøm, der skal leveres af brændstofcellen, idet den anden strømreferenceværdi er mellem nævnte minimums- og maksimumsværdi,

ved, at den beregnede strømværdi svarer til den strøm, der kræves af brændstofcellen for at supplere den strøm, der leveres af batteriet, idet den beregnede strømværdi er lig med den strøm, der kræves for, at batteriet kan nå den nævnte målværdi for ladetilstanden minus den strøm, der kræves af drivlinjen, og den strøm, der kræves af den nævnte mindst ene hjælpeanordning,

og **ved, at** beregningen af den anden strømreferenceværdi udføres på grundlag af en foruddefineret effektivitetskurve (42) for brændstofcellen (8), ved at vælge et arbejdspunkt for brændstofcellen, der svarer til maksimumsværdien på effektivitetskurven (42) inden for et arbejdsområde, der er omfattet mellem minimumsværdien og den tidligere beregnede maksimumsværdi, og ved at opfylde mindst en flerhed af følgende kriterier:

- at den strøm, der leveres af batteriet (16), samles mod den første referenceværdi,

- at de styringskommandoer, som en fører afgiver, overholdes,

- at mindst én hjælpeanordning strømforsynes, og

- at udsvingene i den strøm, der kræves fra brændstofcellen (8), over tid er langsomme.

8. Elkøretøj (2), der omfatter et strømforsyningssystem ifølge krav 7.

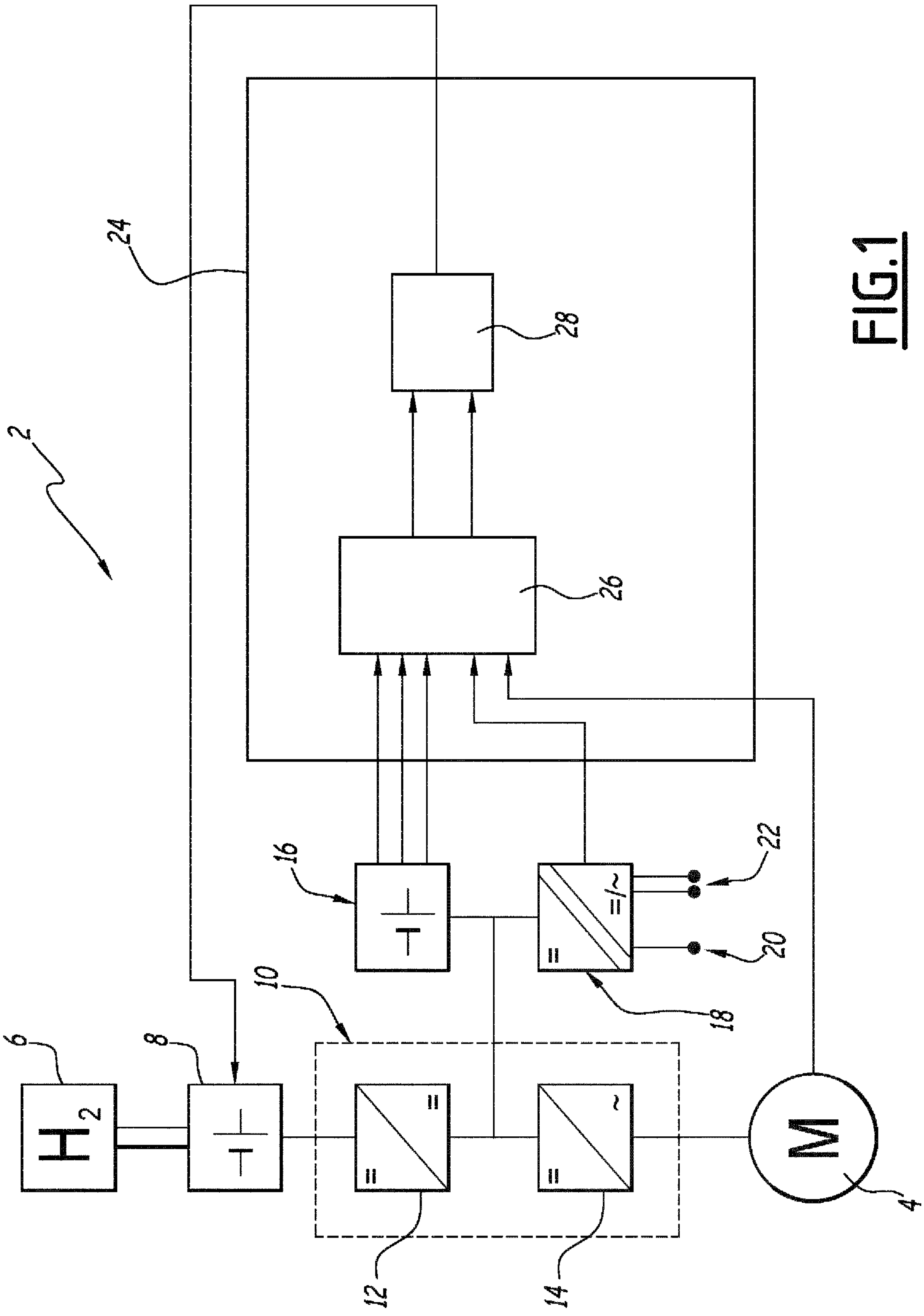

FIG.1

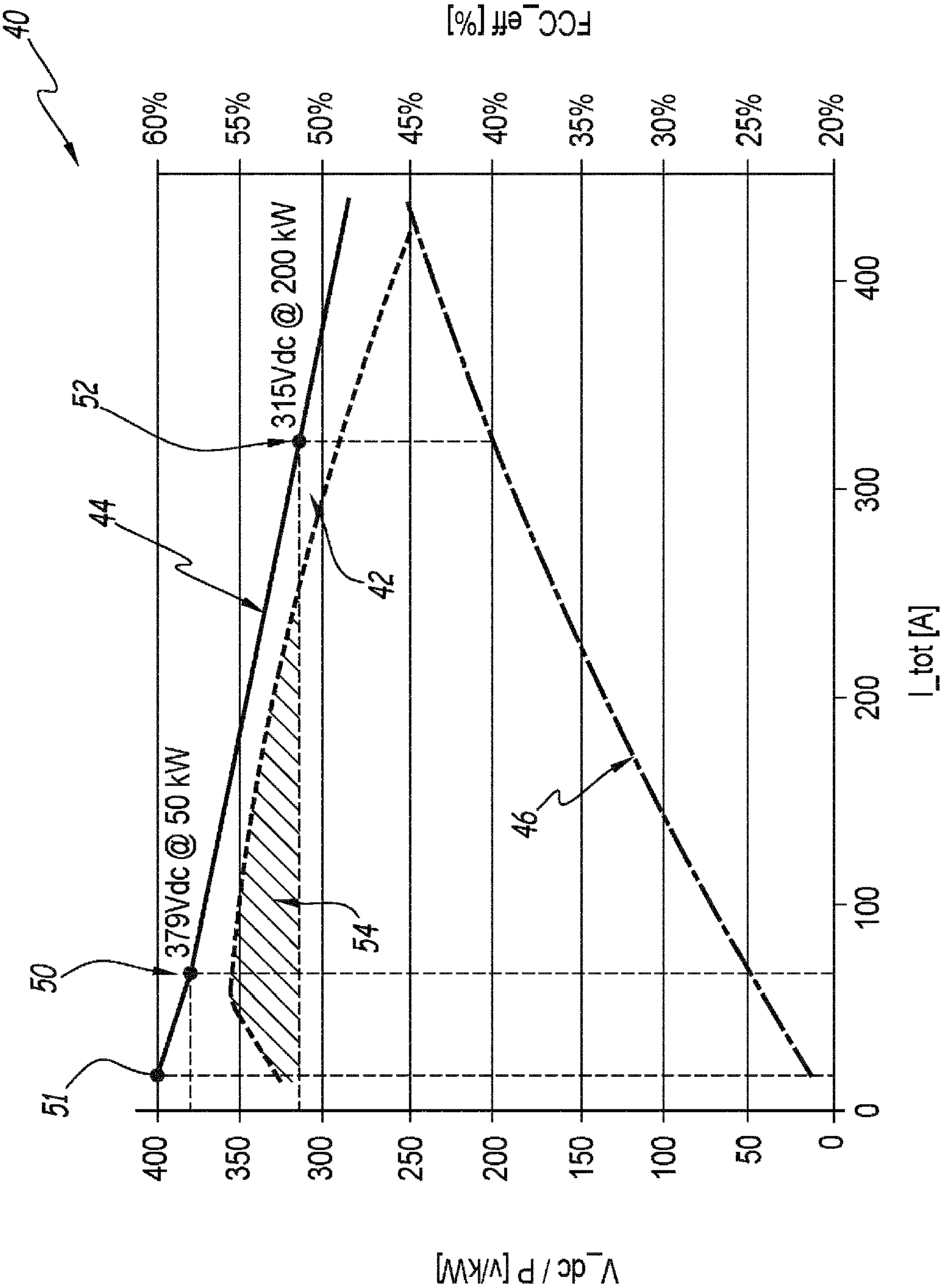
40
FCC_eff [%]
60%
55%
50%
45%
40%
35%
30%
25%
20%
379Vdc @ 50 kW
315Vdc @ 200 kW
51
50
52
44
42
54
46
400
350
300
250
200
150
100
50
0
V_dc / P [v/kW]
I_tot [A]

FIG.2

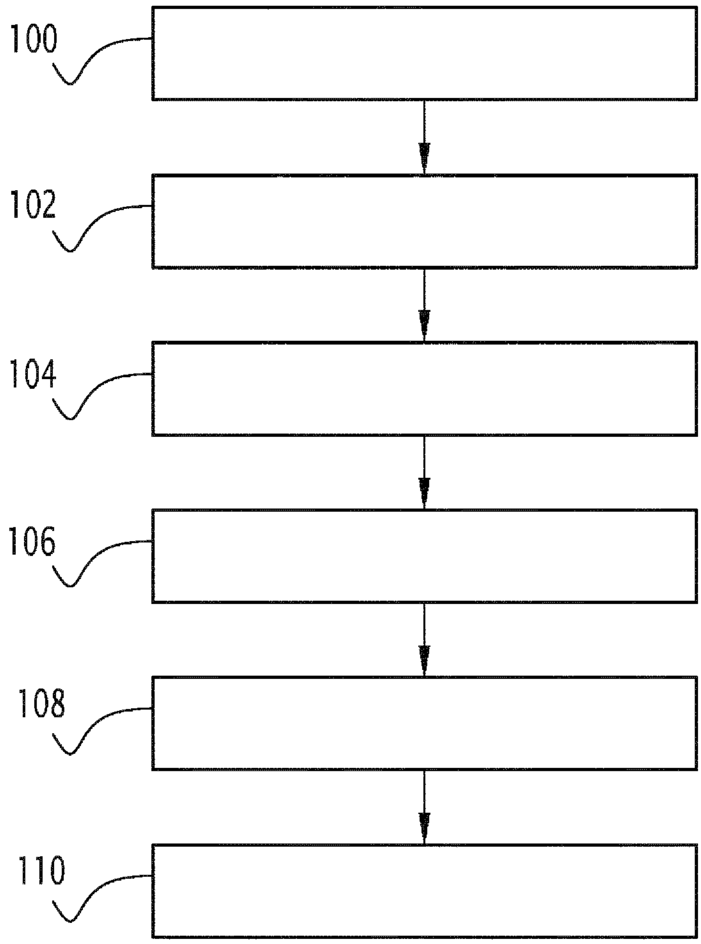

FIG.3