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TAMURA et al.

(54) **POWER SOURCE APPARATUS FOR VEHICLE**

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(52) **U.S. Cl.** **307/9.1**

(57) **ABSTRACT**

A power source apparatus mounted to a vehicle is equipped with a lead-acid battery and a lithium battery. An open circuit voltage and an internal resistance of each of the batteries are determined to satisfy the following conditions (a1), (a2), and (a3): (a1) In the use range of SOC of the lead-acid battery and the use range of SOC of the lithium battery, there is an equal voltage point Vds at which the open circuit voltage V**0** (Pb) of the lead-acid battery becomes equal to the open circuit voltage V**0** (Li) of the lithium battery; (a2) The relationship of V**0** (Li)>V**0** (Pb) is satisfied in the upper limit side of the use range of SOC of the battery; and (a3) A terminal voltage Vc (Li) of the lithium battery is not more than a set voltage Vreg of a regulator when a maximum current flows in the lithium battery.

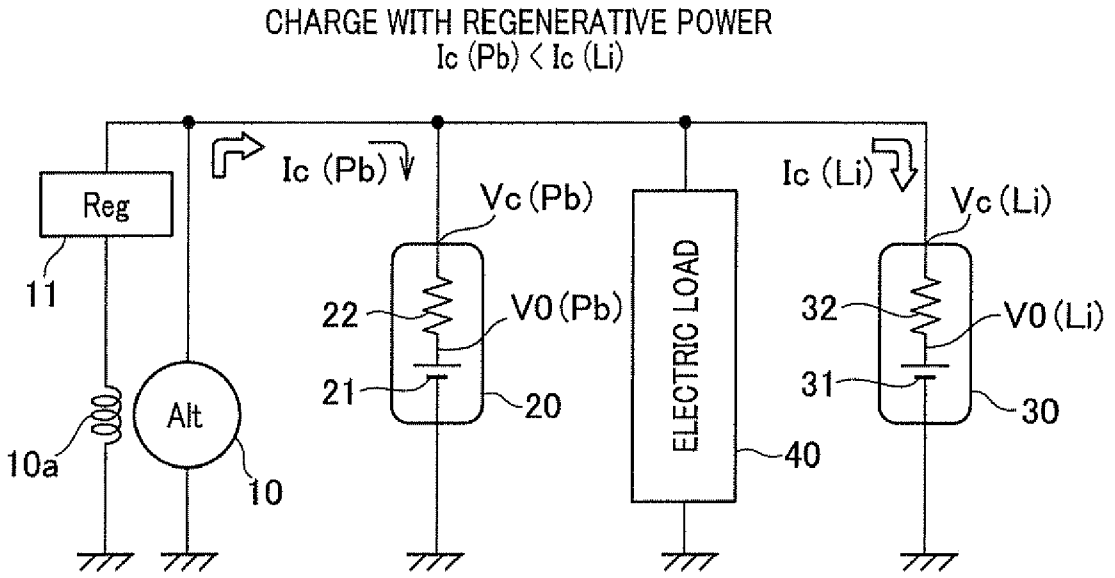


FIG.1A

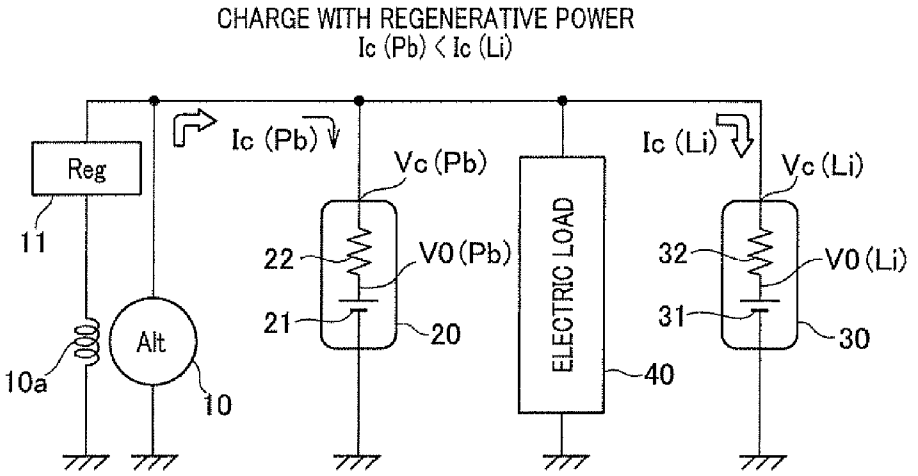

CHARGE WITH REGENERATIVE POWER
Ic (Pb) < Ic (Li)
Reg
11
Alt
10a
10
Ic (Pb)
Vc (Pb)
22
V0 (Pb)
21
20
ELECTRIC LOAD
40
Ic (Li)
Vc (Li)
32
V0 (Li)
31
30

FIG.1B

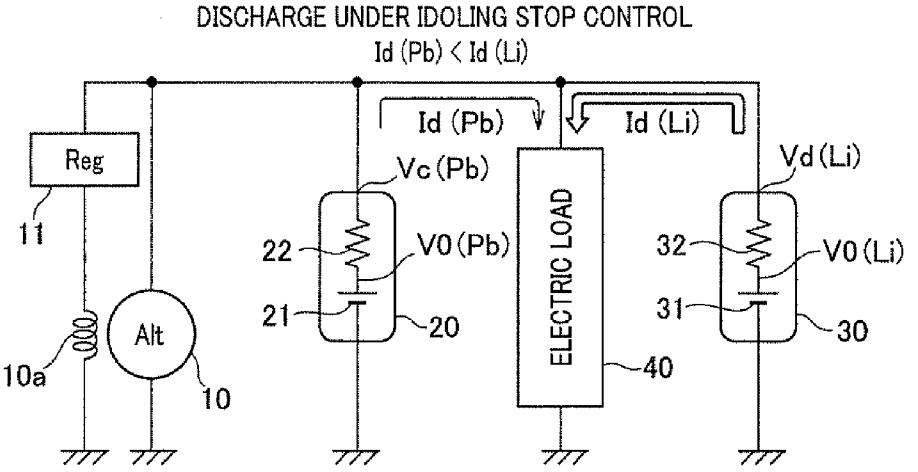

DISCHARGE UNDER IDOLING STOP CONTROL
Id (Pb) < Id (Li)
Reg
11
Alt
10a
10
Id (Pb)
Id (Li)
Vc (Pb)
22
V0 (Pb)
21
20
ELECTRIC LOAD
40
Vd (Li)
32
V0 (Li)
31
30

FIG.2A

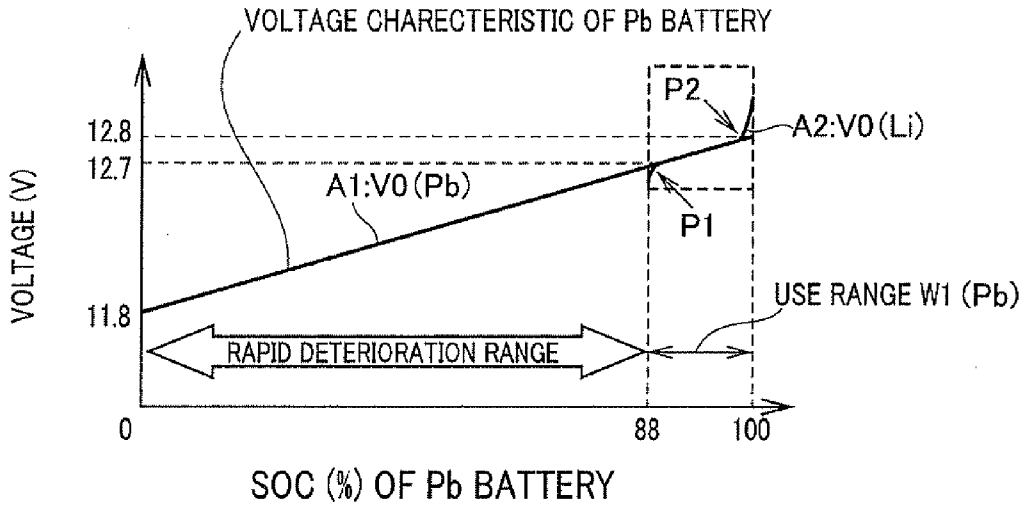

VOLTAGE CHARECTERISTIC OF Pb BATTERY
P2
A2:V0 (Li)
12.8
12.7
A1:V0 (Pb)
P1
VOLTAGE (V)
USE RANGE W1 (Pb)
11.8
RAPID DETERIORATION RANGE
0
88
100
SOC (%) OF Pb BATTERY

FIG.2B

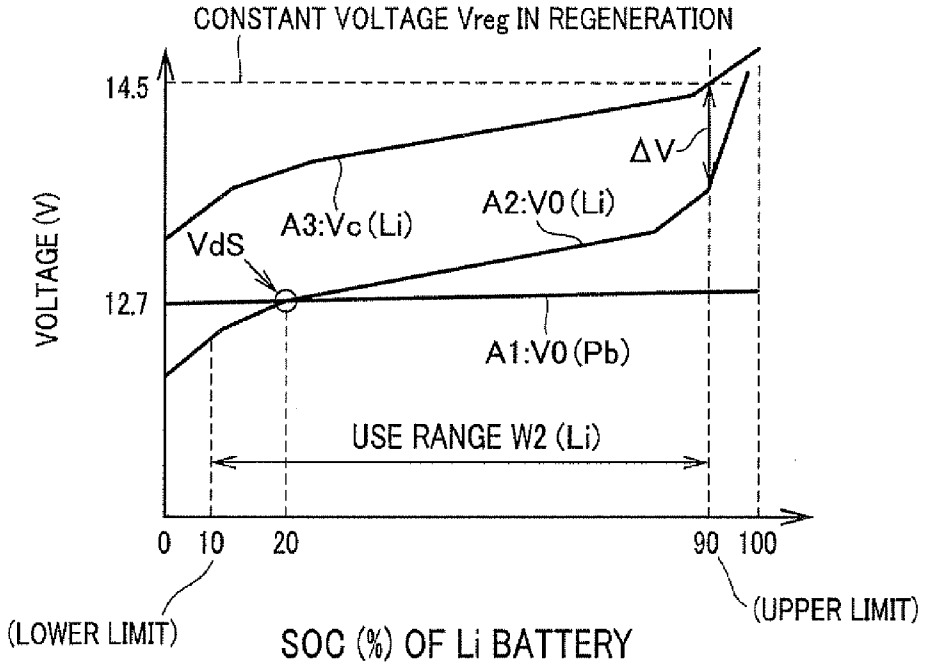

CONSTANT VOLTAGE Vreg IN REGENERATION
14.5
ΔV
A3:Vc (Li)
A2:V0 (Li)
VdS
VOLTAGE (V)
12.7
A1:V0 (Pb)
USE RANGE W2 (Li)
0
10
20
90
100
(LOWER LIMIT)
(UPPER LIMIT)
SOC (%) OF Li BATTERY

FIG.3

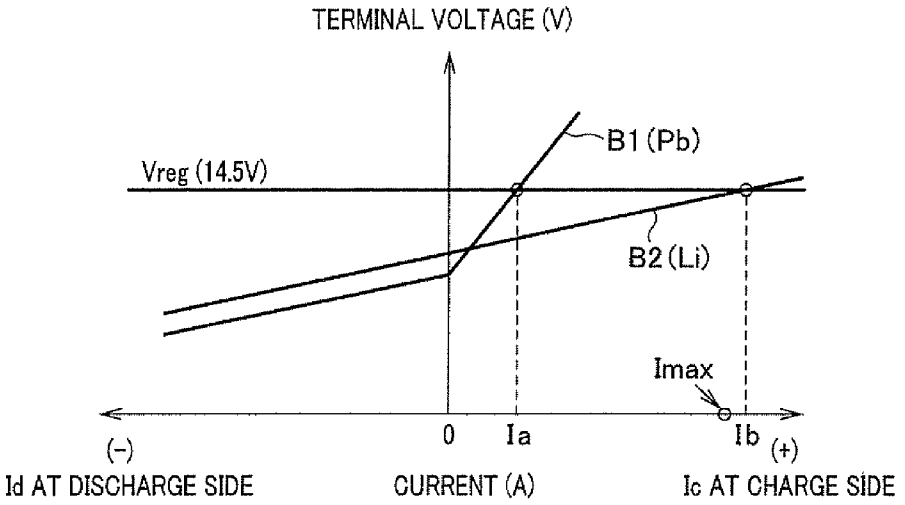


FIG.4A

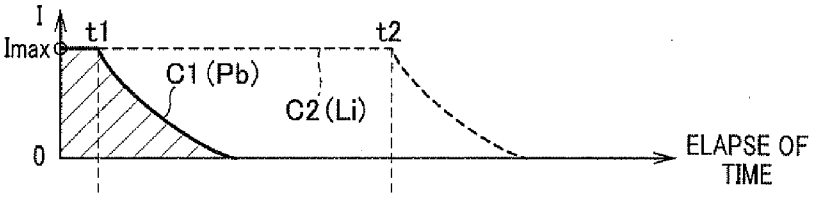


FIG.4B

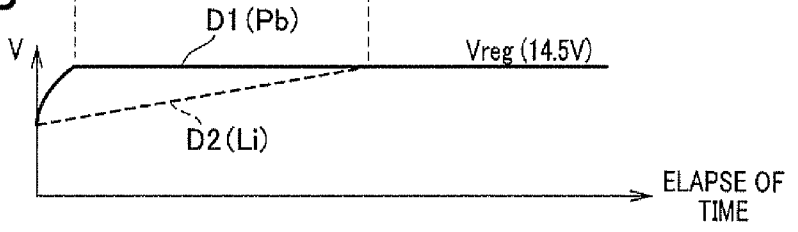


FIG.5

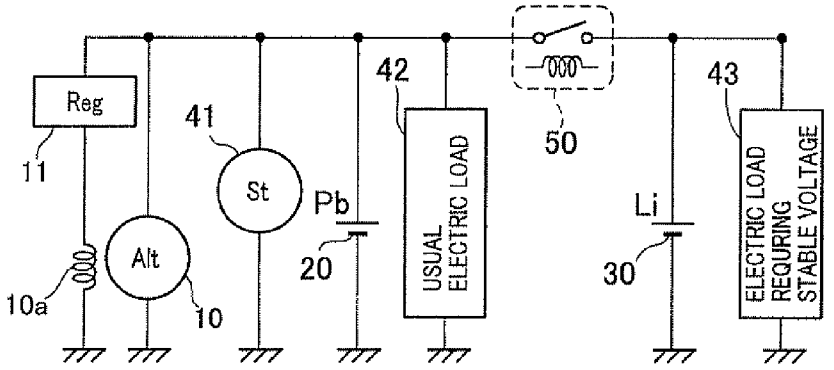


FIG.6

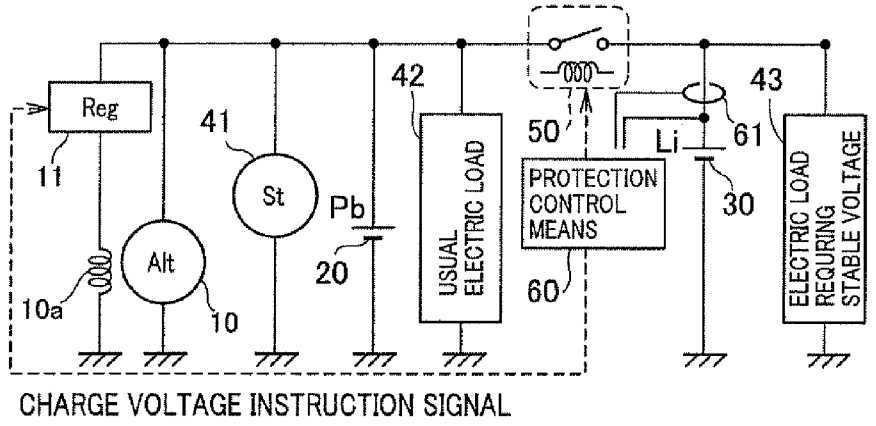


FIG.7

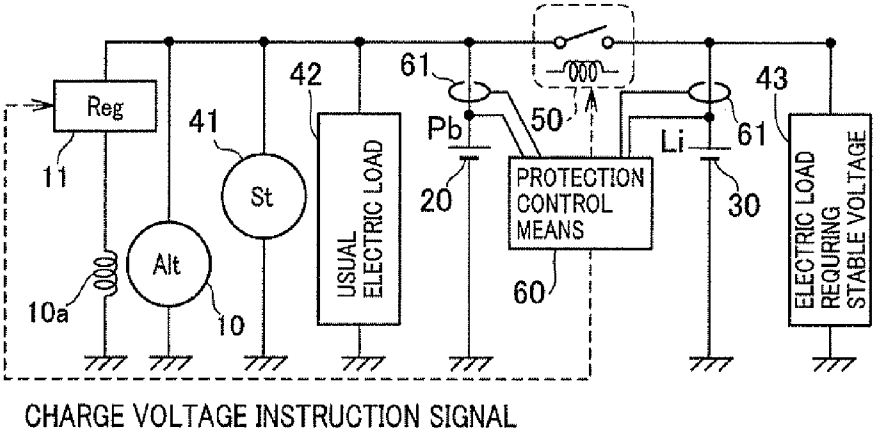


FIG.8

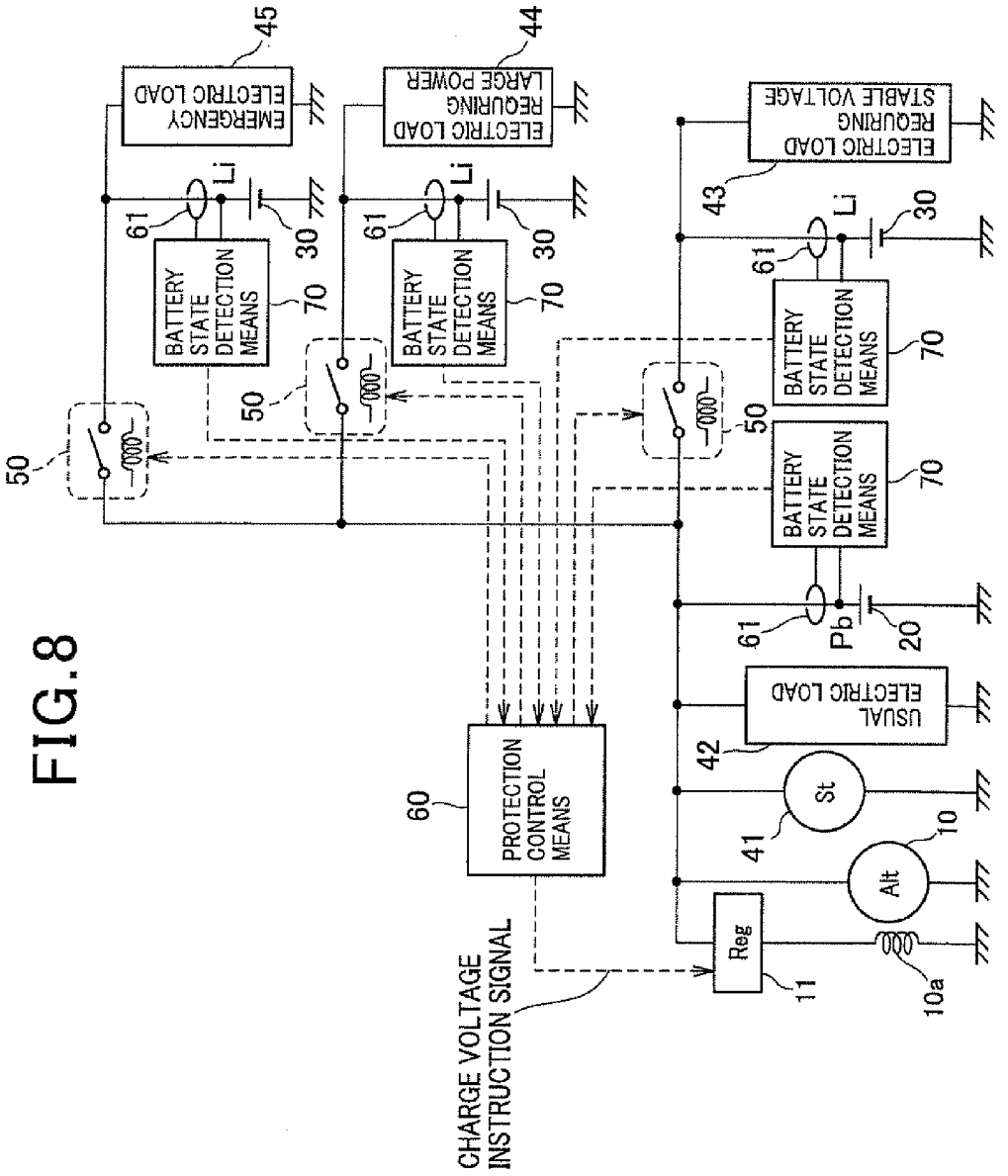

45
EMERGENCY ELECTRIC LOAD
44
ELECTRIC LOAD REQUIRING LARGE POWER
ELECTRIC LOAD REQUIRING STABLE VOLTAGE
43
Li
30
61
BATTERY STATE DETECTION MEANS
70
50
Pb
20
USUAL ELECTRIC LOAD
42
St
41
Alt
10
Reg
11
10a
60
PROTECTION CONTROL MEANS
CHARGE VOLTAGE INSTRUCTION SIGNAL

FIG.9

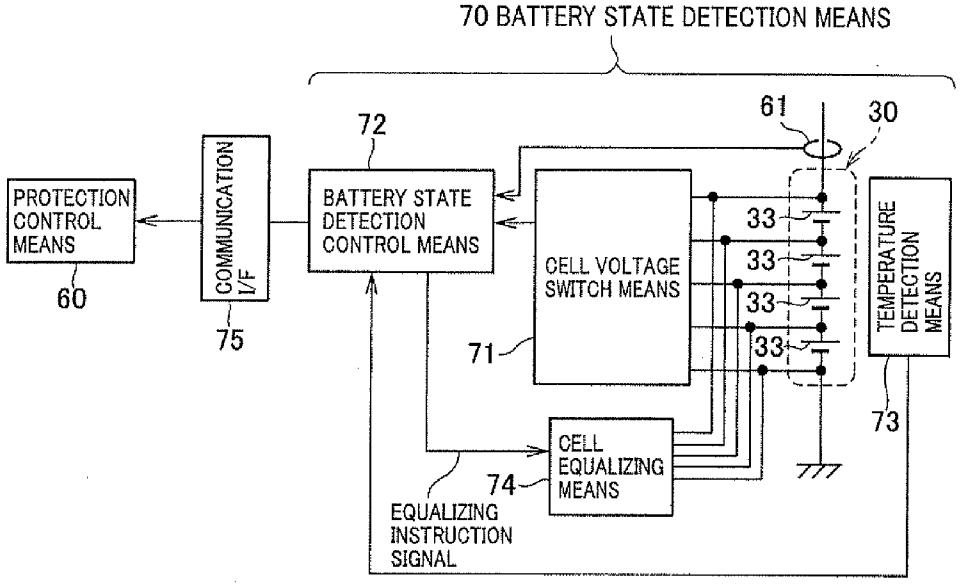

70 BATTERY STATE DETECTION MEANS
61
30
72
PROTECTION CONTROL MEANS
60
COMMUNICATION I/F
75
BATTERY STATE DETECTION CONTROL MEANS
CELL VOLTAGE SWITCH MEANS
71
33
33
33
33
TEMPERATURE DETECTION MEANS
73
CELL EQUALIZING MEANS
74
EQUALIZING INSTRUCTION SIGNAL

FIG.10

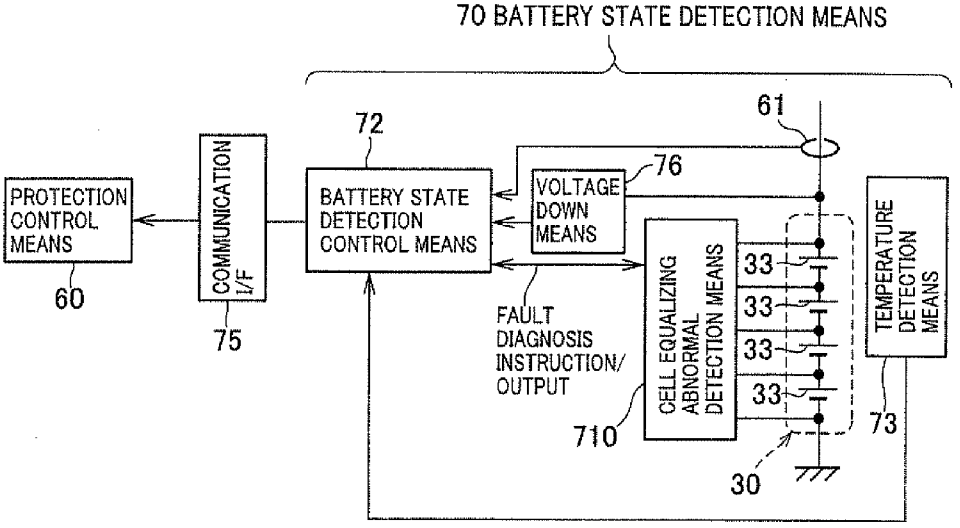

70 BATTERY STATE DETECTION MEANS
61
72
76
PROTECTION CONTROL MEANS
60
COMMUNICATION I/F
75
BATTERY STATE DETECTION CONTROL MEANS
VOLTAGE DOWN MEANS
FAULT DIAGNOSIS INSTRUCTION/ OUTPUT
CELL EQUALIZING ABNORMAL DETECTION MEANS
710
33
33
33
33
TEMPERATURE DETECTION MEANS
73
30

FIG.11A

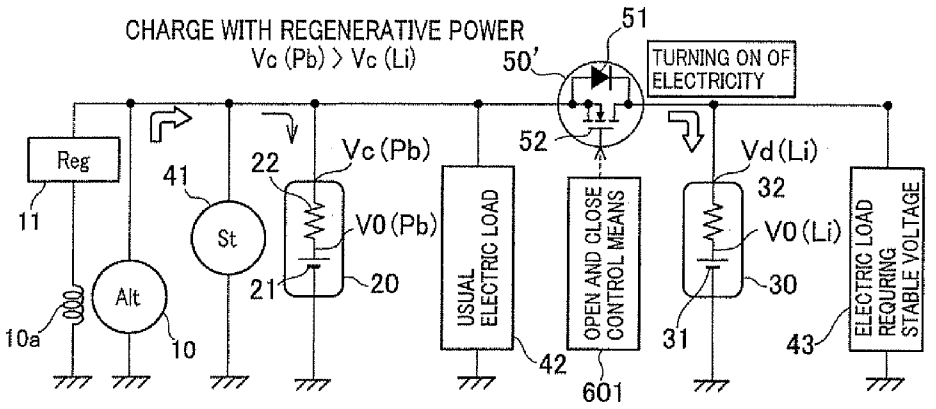


FIG.11B

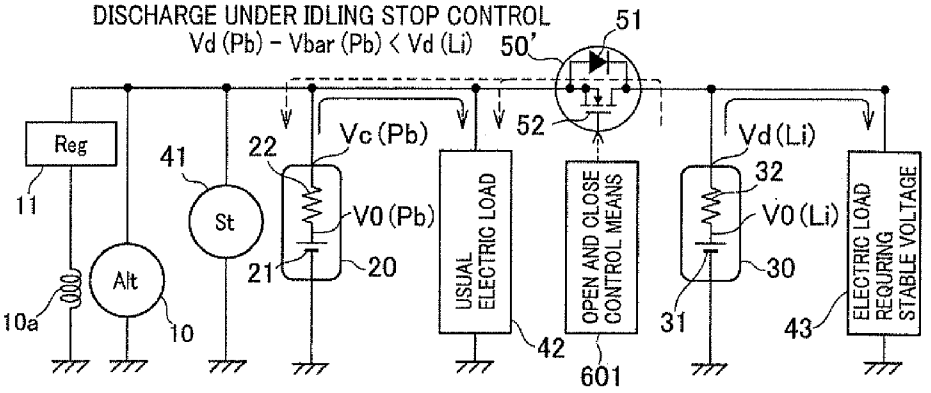


FIG.11C

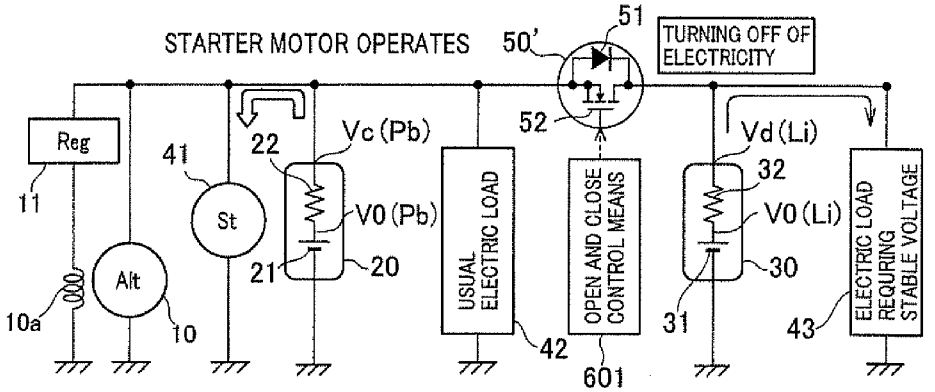


FIG.12A

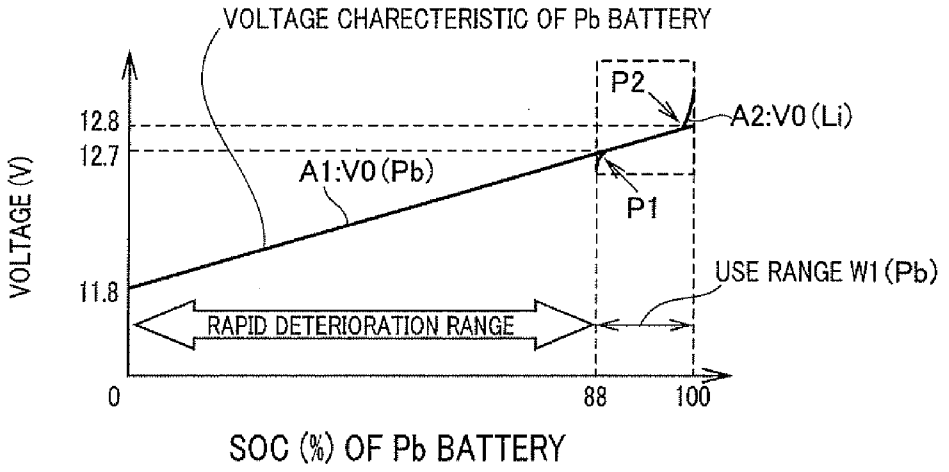


FIG.12B

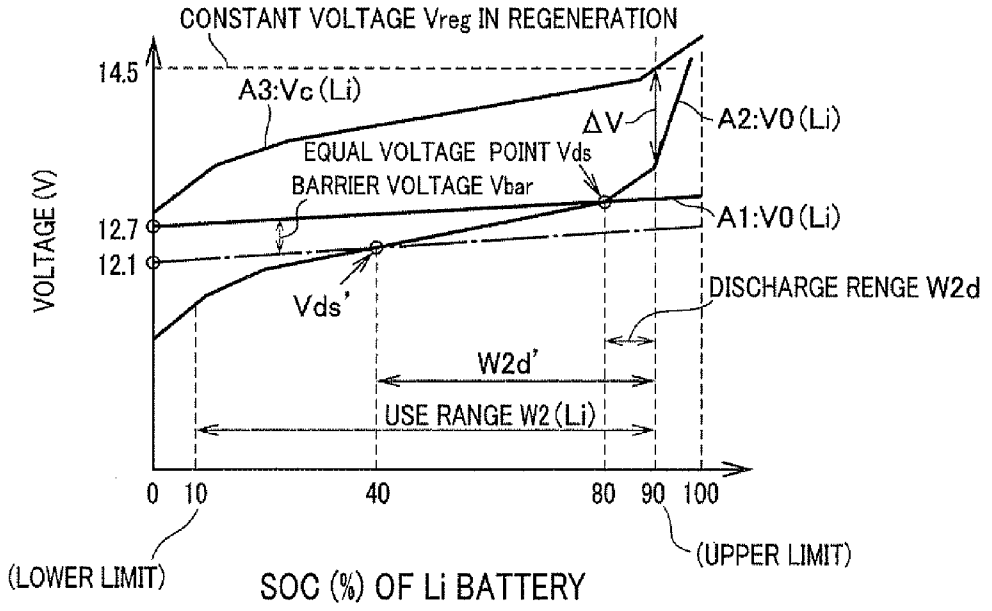


FIG.13

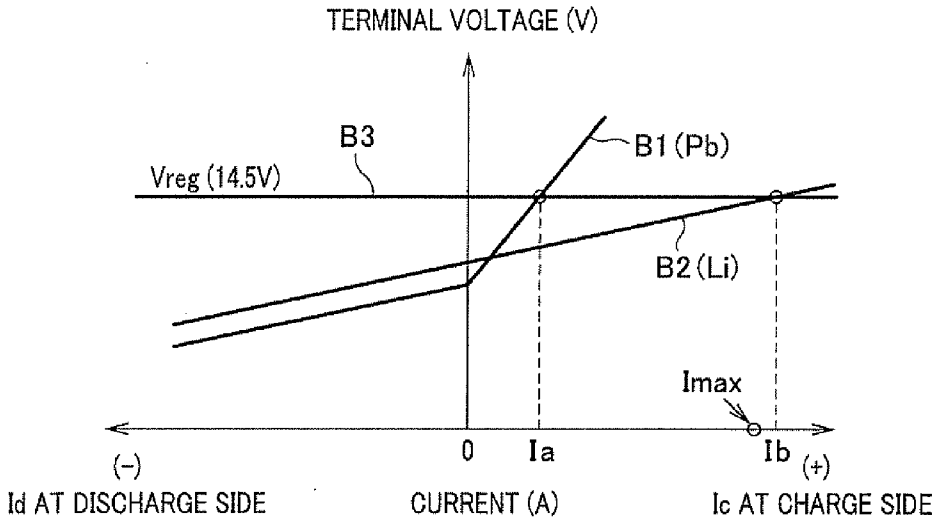


FIG.14A

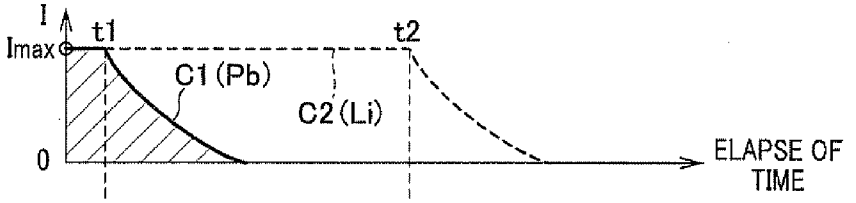


FIG.14B

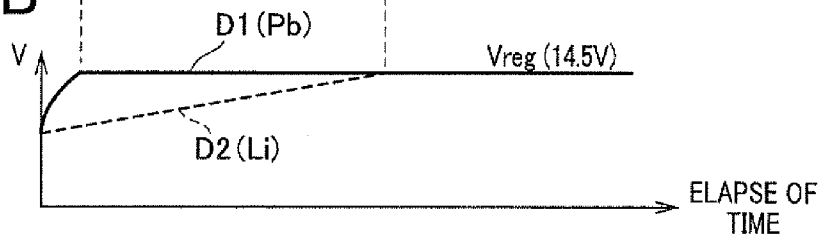


FIG.15

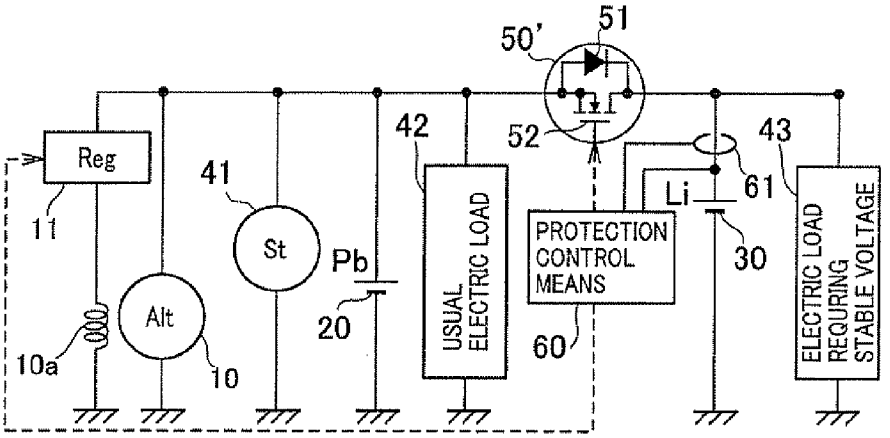

50'
51
52
42
43
Reg
11
41
St
Pb
20
Alt
10a
10
USUAL ELECTRIC LOAD
PROTECTION CONTROL MEANS
60
Li
61
30
ELECTRIC LOAD REQURING STABLE VOLTAGE

FIG.16

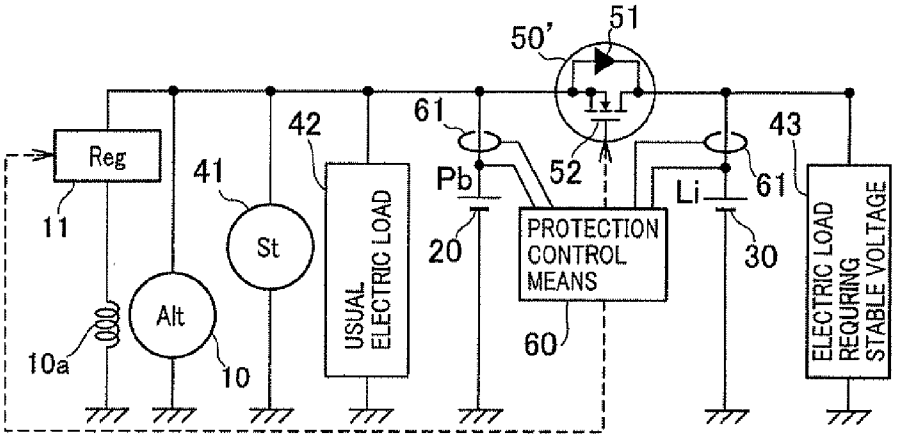

50'
51
52
61
42
43
Reg
11
41
St
Pb
20
Alt
10a
10
USUAL ELECTRIC LOAD
PROTECTION CONTROL MEANS
60
Li
61
30
ELECTRIC LOAD REQURING STABLE VOLTAGE

FIG. 17

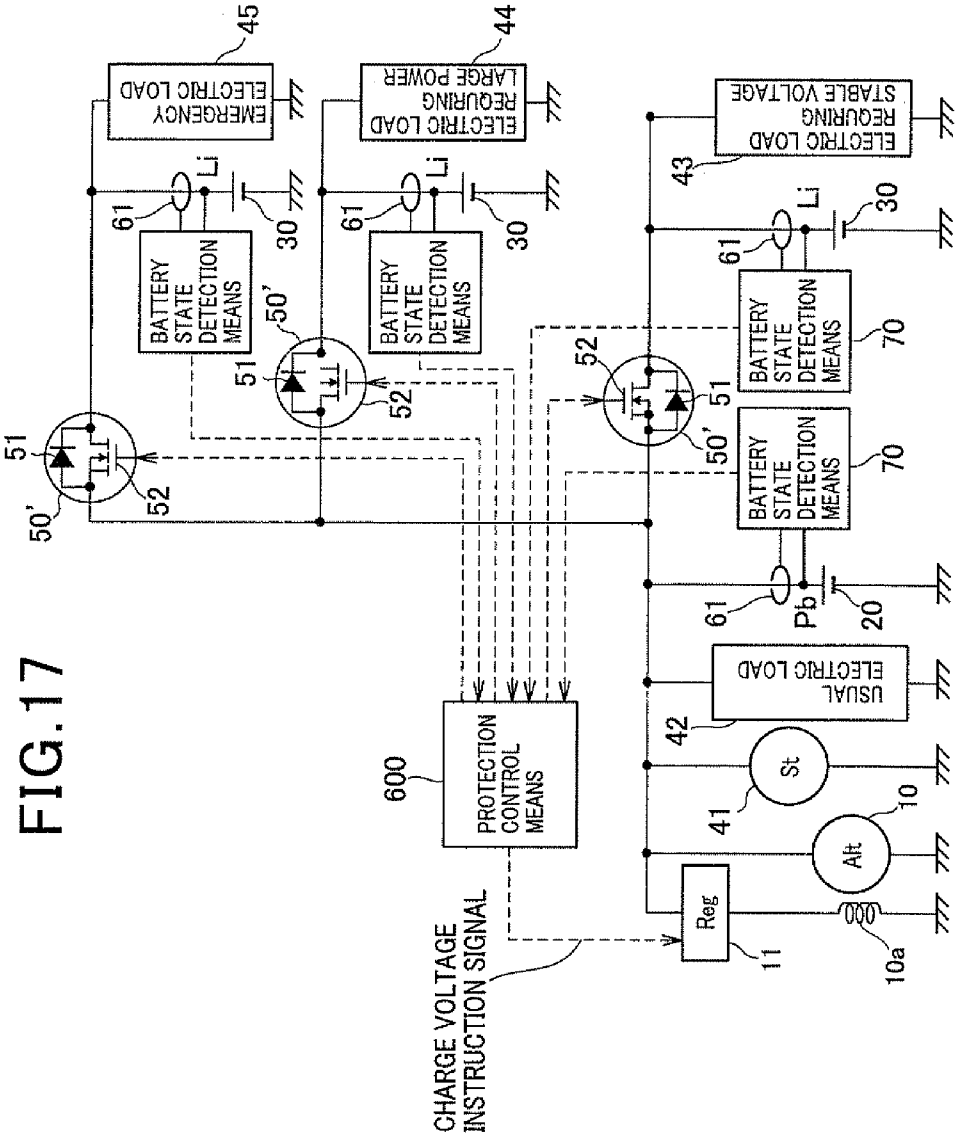

45
EMERGENCY ELECTRIC LOAD
44
ELECTRIC LOAD REQUIRING LARGE POWER
43
ELECTRIC LOAD REQUIRING STABLE VOLTAGE
Li
61
30
BATTERY STATE DETECTION MEANS
70
50'
51
52
Pb
20
USUAL ELECTRIC LOAD
42
St
41
Alt
10
Reg
11
10a
600
PROTECTION CONTROL MEANS
CHARGE VOLTAGE INSTRUCTION SIGNAL

FIG.18

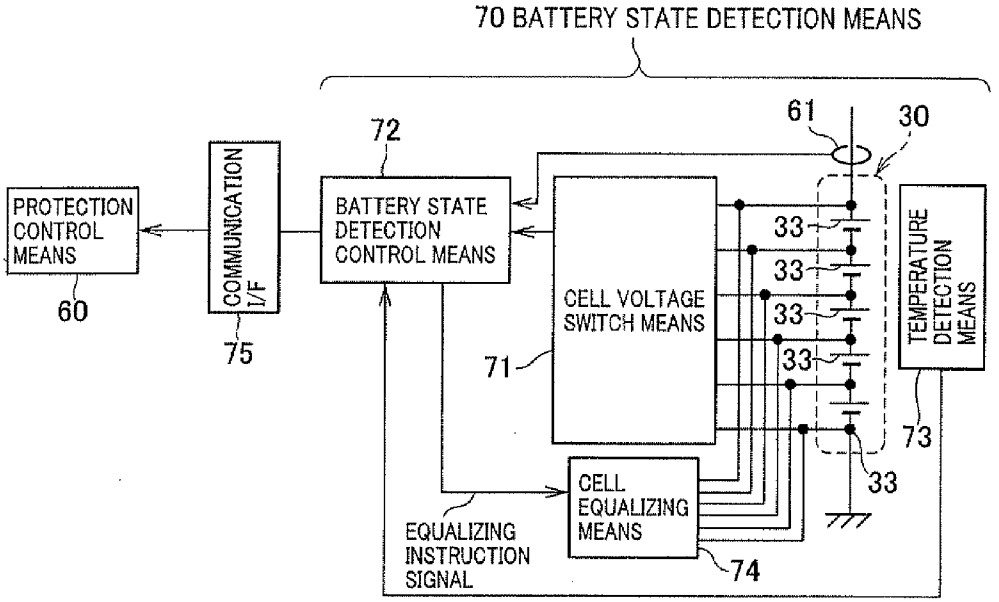
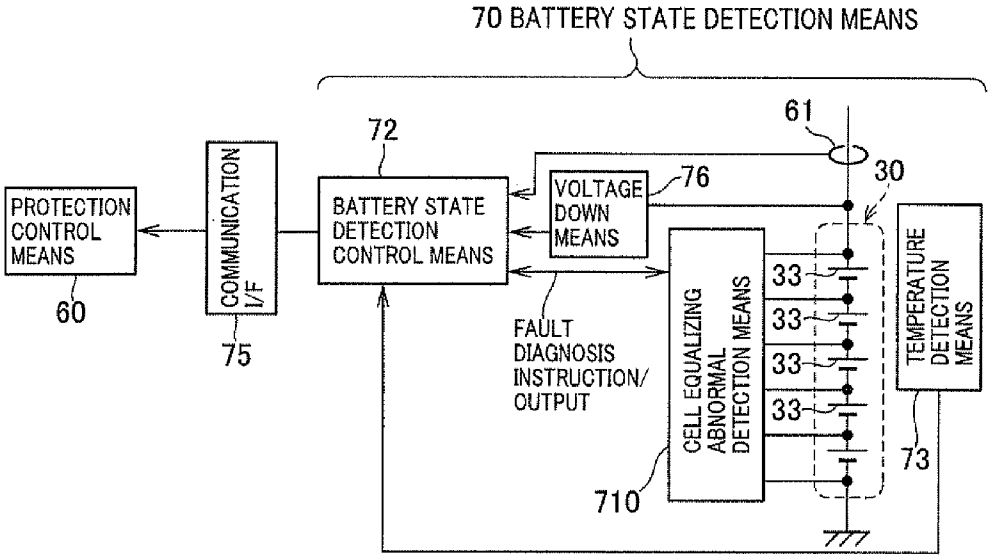

70 BATTERY STATE DETECTION MEANS
61
30
72
PROTECTION CONTROL MEANS
60
COMMUNICATION I/F
75
BATTERY STATE DETECTION CONTROL MEANS
CELL VOLTAGE SWITCH MEANS
71
33
33
33
33
33
TEMPERATURE DETECTION MEANS
73
CELL EQUALIZING MEANS
74
EQUALIZING INSTRUCTION SIGNAL

FIG.19


70 BATTERY STATE DETECTION MEANS
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72
PROTECTION CONTROL MEANS
60
COMMUNICATION I/F
75
BATTERY STATE DETECTION CONTROL MEANS
VOLTAGE DOWN MEANS
76
FAULT DIAGNOSIS INSTRUCTION/ OUTPUT
CELL EQUALIZING ABNORMAL DETECTION MEANS
710
33
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33
33
TEMPERATURE DETECTION MEANS
73

FIG.20

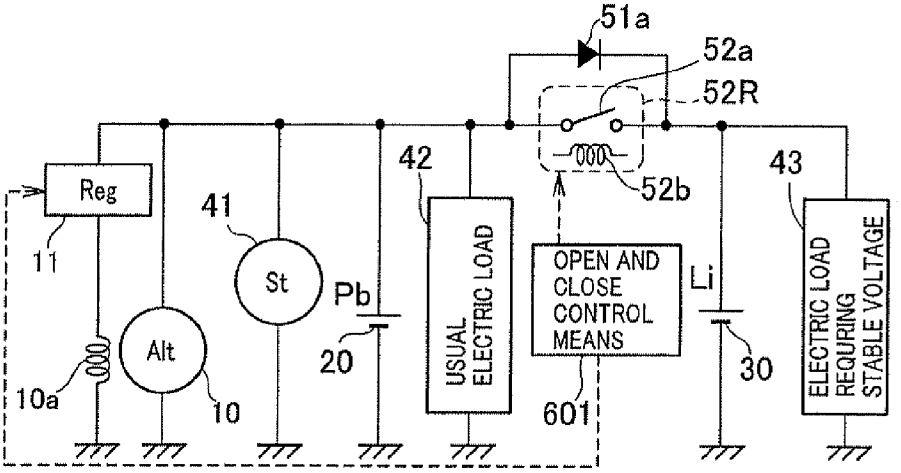
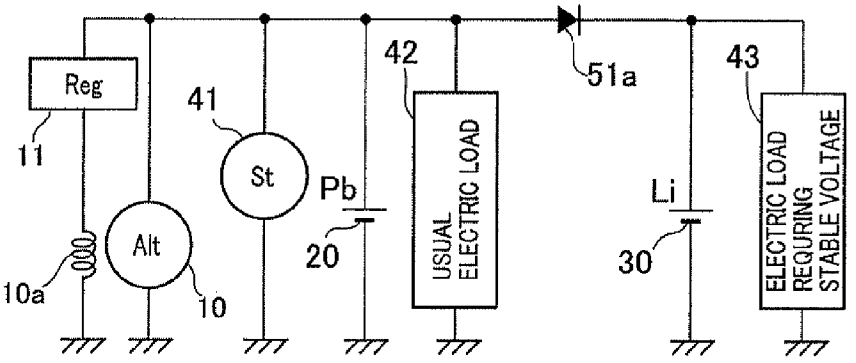

51a
52a
52R
52b
Reg
11
41
St
Pb
20
42
USUAL ELECTRIC LOAD
OPEN AND CLOSE CONTROL MEANS
601
Li
30
43
ELECTRIC LOAD REQUIRING STABLE VOLTAGE
Alt
10a
10

FIG.21


Reg
11
41
St
Pb
20
42
USUAL ELECTRIC LOAD
51a
Li
30
43
ELECTRIC LOAD REQUIRING STABLE VOLTAGE
Alt
10a
10

POWER SOURCE APPARATUS FOR VEHICLE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application is related to and claims priority from Japanese Patent Applications No. 2009-156947 filed on Jul. 1, 2009 and No. 2009-223947 filed on Sep. 29, 2009, the contents of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to a power source apparatus to be applied to vehicles.

[0004] 2. Description of the Related Art

[0005] A vehicle with an internal combustion engine generally has a lead-acid battery in order to supply electric power to various types of electrical loads such as a starter motor mounted on the vehicle. The lead-acid battery is cheap in cost when compared with high density energy batteries (high performance batteries) such as nickel batteries and lithium batteries, but has a low durability resistance to frequent charge and discharge. For example, because a lead-acid battery mounted on a vehicle with idle reduction function (which is a function to automatically stop idling to save and reduce fuel consumption) discharges electric power frequently, this causes a rapid deterioration of the lead-acid battery. In particular, a lead-acid battery mounted on a vehicle with an alternator capable of regenerating electric power when the vehicle decelerates is charged with such regenerative electric power frequently, this frequent charge would cause a rapid deterioration. Using a high performance battery to avoid the above drawback of the lead-acid battery would cause a large manufacturing cost.

[0006] Conventional techniques disclosed by the following technical documents D1 to D5 have proposed an improved structure where high performance batteries (as secondary battery) with high price and lead-acid battery with low price are mounted in parallel to a vehicle.

D1: Japanese patent laid open publication No. JP 2007-46508;

D2: Japanese patent laid open publication No. JP 2007-131134;

D3: Japanese patent laid open publication No. JP 2008-29058;

D4: Japanese patent laid open publication No. JP 2008-155814; and

D5: Japanese patent laid open publication No. JP 2009-126395.

[0007] That is, during idle reduction mode (which is capable to stop the engine during idling in order to reduce fuel consumption), electric power such as regenerative electric power is preferentially supplied to the high performance battery, and electric power of the high performance battery is preferentially supplied to the electrical loads. On the other hand, from the above viewpoint to reduce the electric power consumption while a vehicle stops in a car park for a long period of time, it is controlled so that the lead-acid battery supplies electric power to electrical loads. As described above, a combination of two types of batteries makes it possible to downsize the high performance battery, and to suppress the increase of the manufacturing cost.

[0008] By the way, overcharge or over discharge of a battery would cause a rapid deterioration. It is therefore preferable to use the battery within an optimum SOC (state of charge, hereinafter, will be referred to as the "the use range of SOC") which is not overcharged or discharged, where the SOC indicates the charge state of the battery, because an open circuit voltage of the battery corresponds to SOC. In other words, the change of SOC of the battery has a different open circuit voltage of the battery. In general, the open circuit voltage (for example, 12.7 V to 12.8 V) of a lead-acid battery is not equal, within the use range of SOC, to an open circuit voltage of a high performance battery.

[0009] Because the lead-acid battery and the high performance battery are connected in parallel in a power source apparatus, a current flows from the battery with a high terminal voltage Vd to the battery with a low terminal voltage when discharging, and this would cause the batteries to be in an over discharged condition which is out from the use range of SOC. In general, the terminal voltage Vd of a battery can be expressed by the following formula (1):

$$Vd = V0 - Id \times R \quad (1),$$

where Id is a discharging current of the battery, R is an internal resistance of the battery, and V**0** is an open circuit voltage of the battery.

[0010] The conventional techniques disclosed by the technical documents D1 to D5 previously described have proposed a structure to use a DC/DC converter which is placed between those batteries such as a high performance battery and a lead-acid battery. This structure can adjust the terminal voltage of the high performance battery, which is higher in terminal voltage than that of the lead-acid battery, by the DC/DC converter, and prevent a current which flows from the high performance battery having a high terminal voltage to the lead-acid battery of a low terminal voltage in order to prevent the lead-acid battery from overcharge.

[0011] However, because such a DC/DC converter is a high price device, it is difficult to decrease the total manufacturing cost of a power source apparatus for vehicle which requires a DC/DC converter in order to prevent a lead-acid battery from overcharge.

SUMMARY OF THE INVENTION

[0012] It is an object of the present invention to provide a power source apparatus which is mounted to vehicles equipped with a high performance battery (or a high energy density battery which serves as a secondary battery) and a lead-acid battery, which is capable of suppressing deterioration of the lead-acid battery and reducing its manufacturing cost without incorporating any DC/DC converter.

[0013] In accordance with a first aspect of the present invention, there is provided a power source apparatus which is applied to various types of vehicles with an alternator and a constant voltage control means. The constant voltage control means is capable of adjusting a voltage of the electric power supplied from the alternator to a set voltage. The power source apparatus is comprised of a lead-acid battery and a secondary battery. The lead-acid battery is electrically connected to an alternator. The secondary battery is electrically connected in parallel to the lead-acid battery. The secondary battery is higher in output power density and energy density than the lead-acid battery.

[0014] In the power source apparatus according to the first aspect of the present invention, an open circuit voltage and an

internal resistance of the lead-acid battery and an open circuit voltage and an internal resistance of the secondary battery are determined in order to satisfy the following conditions (a), (b), and (c):

[0015] (a) an equal voltage point at which the open circuit voltage of the lead-acid battery becomes equal to the open circuit voltage of the secondary battery is present in a use range of state of charge (SOC) of the lead-acid battery and a use range of SOC of the secondary battery;

[0016] (b) the open circuit voltage of the secondary battery is higher than the open circuit voltage of the lead-acid battery at an upper limit side from the equal voltage point in the use range of SOC of the secondary battery; and

[0017] (c) a terminal voltage of the secondary battery when a maximum charging current flows in the secondary battery is less than the set voltage which is set by the constant voltage control means.

[0018] In the power source apparatus according to the present invention, the open circuit voltages and the internal resistance of the lead-acid battery and the secondary battery (such as a lithium battery) are determined in order to satisfy the above condition (a). This allows that the terminal voltage Vd (Pd) within the use range of SOC of the lead-acid battery is approximately equal to the terminal voltage Vd (Li) within the use range of SOC of the lithium battery, and this makes it possible to have a small difference between or a same voltage potential between the lead-acid battery and the secondary battery. Accordingly, this allows the secondary battery to flow a very small current to the lead-acid battery without using any DC/DC converter in the power source apparatus, and it is thereby possible to prevent the lead-acid battery from overcharge. It is therefore possible to produce the power source apparatus with low manufacturing cost because of not using any DC/DC converter.

[0019] In the power source apparatus according to the present invention, the open circuit voltages and the internal resistance of the lead-acid battery and the secondary battery are determined in order to satisfy the above condition (b). This allows the lead-acid battery to discharge because the secondary battery is higher in open circuit voltage than the lead-acid battery when the secondary battery is charged with an electric capacity which is higher than that at the equal voltage point within the use range of SOC of the secondary battery. This allows the secondary battery to preferentially discharge rather than the lead-acid battery. Because the lead-acid battery has a low durability to the frequent discharge operation and the frequency of discharge from the lead-acid battery is decreased, the structure of the power source apparatus according to the present invention can prevent the lead-acid battery from deterioration in charging capacity and performance.

[0020] In the power source apparatus according to the first aspect of the present invention, the open circuit voltages and the internal resistance of the lead-acid battery and the secondary battery are determined in order to satisfy the above condition (c). This can increase the frequency of preferentially charging the secondary battery rather than the lead-acid battery by the following reasons.

[0021] That is, because the terminal voltage Vc (Pb) (expressed by the following formula (F2)) of an available lead-acid battery when the maximum charging current flows becomes larger than the set voltage which is set by the constant voltage control means, it would become difficult to charge the lead-acid battery when the maximum charging current flows.

[0022] Even when the lead-acid battery has a less residual capacity and the terminal voltage Vc (Pb) of the lead-acid battery is lower than the set voltage, the terminal voltage Vc (Pb) of the lead-acid battery is rapidly increased and it would becomes difficult to charge the lead-acid battery because the lead-acid battery has a large internal resistance value R (Pb) when the lead-acid battery is charged. This would be difficult to charge the lead-acid battery. The terminal voltage Vc of a battery during charge is expressed by F2: $Vc=V\mathbf{0}+Ic\times R$ . . . (F2), where Ic is a charge current, R is an internal resistance of the battery, and V**0** is an open circuit voltage of the battery.

[0023] On the other hand, in the power source apparatus according to the first aspect of the present invention, the terminal voltage Vc (Li) of the secondary battery when the maximum charging current flows in the secondary battery is set to a voltage which is lower than the set voltage. In other words, because the terminal voltage of the secondary battery is always below the set voltage even when the terminal voltage Vc (Li) has the maximum voltage as the upper limit in the use range of SOC of the secondary battery, it is possible to always charge the secondary battery. Accordingly, this makes it possible to increase the frequency of preferentially charging the secondary battery rather than the lead-acid battery. Because the frequency of discharge from the lead-acid battery can be decreased and the lead-acid battery has a low durability to the frequent discharge operation, it is possible to suppress the deterioration of the lead-acid battery.

[0024] In accordance with a second aspect of the present invention, there is provided a power source apparatus for vehicle, which is applied to various types of vehicles with an alternator and a constant voltage control means. The constant voltage control means is capable of adjusting a voltage of electric power generated by the alternator to a set voltage. The power source apparatus has a lead-acid battery and a secondary battery, and a rectifying means. The lead-acid battery is electrically connected to the alternator. The secondary battery is electrically connected in parallel to the lead-acid battery. The secondary battery is higher in output density or energy density than the lead-acid battery. The rectifying means is placed between the lead-acid battery and the secondary battery so that a forward current direction of the rectifying means has a direction from the lead-acid battery to the secondary battery. The rectifying means has a barrier voltage therein to the current which flows in the forward direction through the rectifying means. In the power source apparatus, an open circuit voltage and an internal resistance of the lead-acid battery and an open circuit voltage and an internal resistance of the secondary battery are determined in order to satisfy following conditions (a'), (b'), and (c'):

[0025] (a') an equal voltage point is present in a use range of state of charge (SOC) of the lead-acid battery and a use range of SOC of the secondary battery, where at the equal voltage point, the open circuit voltage of the secondary battery becomes equal to a subtracted voltage which is obtained by subtracting the barrier voltage of the rectifying means from the open circuit voltage of the lead-acid battery;

[0026] (b') the open circuit voltage of the secondary battery is higher than the subtracted voltage of the lead-acid

battery at an upper limit side from the equal voltage point in the use range of SOC of the secondary battery; and

[0027] (c') a terminal voltage of the secondary battery when a maximum charging current flows in the secondary battery is not more than the set voltage, where the set voltage is set by the constant voltage control means.

[0028] A description will now be given of the above effects (a'), (b'), and (c'), and the technical feature for the power source apparatus according to the second aspect of the present invention equipped with the rectifying means.

[0029] In the power source apparatus according to second aspect of the present invention, the open circuit voltages and the internal resistance of the lead-acid battery and the secondary battery are determined in order to satisfy the above condition (a').

[0030] This allows that the terminal voltage Vd (Pd) (in more detail, the subtract voltage obtained by subtracting the barrier voltage from the terminal voltage Vd (Pb) when discharging to the electric load placed in position at the secondary battery side observed from the rectifying means) within the use range of SOC of the lead-acid battery becomes approximately equal to the terminal voltage Vd (Li) within the use range of SOC of the lithium battery. That is, this makes it possible to have a small difference in voltage between the lead-acid battery and the secondary battery, or a same voltage potential between the lead-acid battery and the secondary battery. Accordingly, this allows the battery having a high voltage to flow a very small current to another battery having a low voltage without using any DC/DC converter in the power source apparatus, and it is thereby possible to prevent each of those batteries from overcharge and over discharge. It is therefore possible to decrease the manufacturing cost of the power source apparatus because of not using any DC/DC converter.

[0031] In the power source apparatus according to the second aspect of the present invention, the open circuit voltages and the internal resistance of the lead-acid battery and the secondary battery are determined in order to satisfy the above condition (b'). This allows for the secondary battery having a high open circuit voltage to discharge because the open circuit voltage V**0** (Li) of the secondary battery is higher than the subtracted voltage which is obtained by subtracting the barrier voltage from the open circuit voltage V**0** (Pb) of the lead-acid battery when the secondary battery is more charged rather than the charged capacity at the equal voltage point within the use range of SOC of the secondary battery. This makes it possible to increase the frequency of preferentially discharge from the secondary battery rather than the lead-acid battery. Because the frequency of discharging from the lead-acid battery can be decreased, and the lead-acid battery has a low durability to the frequent discharge operation, the feature of the present invention can prevent the lead-acid battery from deterioration.

[0032] In the power source apparatus according to the second aspect of the present invention, the open circuit voltages and the internal resistance of the lead-acid battery and the secondary battery are determined in order to satisfy the above condition (c'). This can increase the frequency of preferentially charging the secondary battery rather than the lead-acid battery by the following reasons.

[0033] That is, because the terminal voltage Vc (Pb) (expressed by the following formula (F2)) of an available lead-acid battery is larger than the set voltage which is set by the constant voltage control means when the maximum charging current flows, it would become impossible to charge the lead-acid battery when the maximum charging current flows.

[0034] Even when the lead-acid battery has a less residual capacity and the terminal voltage Vc (Pb) of the lead-acid battery is lower than the set voltage, because the lead-acid battery has a large internal resistance value R (Pb) when the lead-acid battery is charged, the terminal voltage Vc (Pb) of the lead-acid battery is rapidly increased rather than the set voltage. This would be difficult to charge the lead-acid battery.

[0035] The terminal voltage Vc of a battery during charging is expressed by the following formula (F2): Vc=V**0**+Ic×R . . . (F2), where Ic is a charge current, R is an internal resistance of the battery, and V**0** is an open circuit voltage of the battery.

[0036] On the other hand, in the power source apparatus according to the second aspect of the present invention, like the first aspect of the present invention, previously described, the terminal voltage Vc (Li) of the secondary battery, when the maximum charging current flows in the secondary battery, is set to a voltage which is lower than the set voltage. In other words, because the terminal voltage of the secondary battery is always below the set voltage even when the terminal voltage Vc (Li) has the maximum voltage in the use range of SOC of the secondary battery, it is possible to always charge the secondary battery. Accordingly, this makes it possible to increase the frequency of preferentially charging the secondary battery rather than the lead-acid battery. Because the frequency of discharging from the lead-acid battery is decreased and the lead-acid battery has a low durability to the frequent discharge operation, the present invention can prevent the lead-acid battery from deterioration.

[0037] The horizontal line in FIG. **12**B designates the SOC of the lithium battery **30** (secondary battery), the solid line A**2** in FIG. **12**B denotes a voltage characteristic line which shows a relationship between the SOC and the open circuit voltage V**0** (Li) of the lithium battery **30**. The solid line A**1** in FIG. **12**B denotes a voltage characteristic line which shows a relationship between the SOC and the open circuit voltage V**0** (Pb) of the lead-acid battery **20**. In FIG. **13**B, the position at 0% in the horizontal line showing the SOC of the lithium battery corresponds to the point at 88% of SOC of the lead-acid battery.

[0038] The reference character Vds shown in FIG. **12**B indicates the equal voltage point at which the open circuit voltages of the lithium battery (secondary battery) and the lead-acid battery are equal together when the power source apparatus without any rectifying means, which is different from the structure of the power source apparatus of the present invention with the rectifying means. Because the terminal voltage Vd (Pb) of the lead-acid battery is higher than the open circuit voltage Vd (Li) of the secondary battery at the lower limit side from the equal voltage point in the use range W**2** (Li) of SOC of the lithium battery (secondary battery), the lead-acid battery discharges its electric power, and the secondary battery does not discharge. Accordingly, it is sufficient to shift the equal voltage point Vds toward the lower limit side in the use range W**2** (Li) of SOC of the lithium battery (secondary battery) in order to increase the frequency of preferentially discharging from the secondary battery rather than from the lead-acid battery.

[0039] In the above viewpoint, the power source apparatus according to the second aspect of the present invention is equipped with the rectifying means (which is composed of a

diode, for example) in order to shift the equal voltage point toward the lower limit side (Vds--->Vds') by the barrier voltage Vbar, where at the equal voltage point, the open circuit voltage of the secondary battery becomes equal to the open circuit voltage of the lead-acid battery.

[0040] In other words, the voltage characteristic line **A1** of the lead-acid battery is apparently shifted toward the lower limit side as expressed by the long and dash line shown in FIG. **12**B. This can expand the upper area by the area W**2***d* toward the upper limit side from the equal voltage point Vds in the use range W**2** (Li) of SOC of the lithium battery (secondary battery). This can increase the opportunity for the lithium battery to preferentially discharge rather than from the lead-acid battery.

[0041] The starter motor requires a larger electric power than other electric loads mounted to vehicles when the starter motor starts to operate. Supplying such a large electric power from the secondary battery to the starter motor prevents the secondary battery from being downsized because the secondary battery is in general a higher price device than the lead-acid battery. Accordingly, it is preferable for the lead-acid battery instead of the lithium battery (secondary battery) to supply such a large electric power to the starter motor of a large power consumption.

[0042] In the above viewpoint, the power source apparatus according to the second aspect of the present invention has the rectifying means (such as a diode, for example) which is placed so that the forward current direction in the rectifying direction becomes the direction from the lead-acid battery to the secondary battery. Accordingly, when the power source apparatus has the structure in which the electric load (such as a starter motor) is electrically connected with a node in the lead-acid battery side which is opposite from the secondary battery side observed from the rectifying means, it is possible for the rectifying means to prevent the current supplied from the secondary battery to the electric load such as a starter motor which requires a large electric power.

BRIEF DESCRIPTION OF THE DRAWINGS

[0043] A preferred, non-limiting embodiment of the present invention will be described by way of example with reference to the accompanying drawings, in which:

[0044] FIG. **1**A and FIG. **1**B are block diagrams showing a schematic electric circuit of a power source apparatus for vehicles according to a first embodiment of the present invention;

[0045] FIG. **2**A is a view showing a use range of SOC of a lead-acid battery mounted to a vehicle with the power source apparatus according to the first embodiment of the present invention;

[0046] FIG. **2**B is a view showing a use range of SOC of a lithium battery (secondary battery) mounted to the vehicle with the power source apparatus according to the first embodiment of the present invention;

[0047] FIG. **3** is a view showing a difference in I-V characteristics between the lead-acid battery and the lithium battery in the power source apparatus according to the first embodiment of the present invention;

[0048] FIG. **4**A shows a current change of the lead-acid battery and the lithium battery in the elapse of time;

[0049] FIG. **4**B shows a terminal voltage change of the lead-acid battery and the lithium battery in the elapse of time;

[0050] FIG. **5** is a block diagram showing a schematic electric circuit of a power source apparatus for vehicle according to a second embodiment of the present invention;

[0051] FIG. **6** is a block diagram showing a schematic electric circuit of a power source apparatus for vehicle according to a third embodiment of the present invention;

[0052] FIG. **7** is a block diagram showing a schematic electric circuit of a power source apparatus for vehicles according to a fourth embodiment of the present invention;

[0053] FIG. **8** is a block diagram showing a schematic electric circuit of a power source apparatus for vehicle according to a fifth embodiment of the present invention;

[0054] FIG. **9** is a block diagram mainly showing a detailed structure of the battery state detection means in the power source apparatus according to a sixth embodiment of the present invention;

[0055] FIG. **10** is a block diagram mainly showing a detailed structure of the battery state detection means in the power source apparatus according to a seventh embodiment of the present invention;

[0056] FIG. **11**A, FIG. **11**B, and FIG. **11**C are block diagrams showing a schematic electric circuit of a power source apparatus for vehicles according to an eighth embodiment of the present invention;

[0057] FIG. **12**A is a view showing a use range of SOC of a lead-acid battery mounted to a vehicle with the power source apparatus according to the eighth embodiment of the present invention;

[0058] FIG. **12**B is a view showing a use range of SOC of a lithium battery mounted to the vehicle with the power source apparatus according to the eighth embodiment of the present invention;

[0059] FIG. **13** is a view showing a difference in I-V characteristics between the lead-acid battery and the lithium battery in the power source apparatus according to the first embodiment of the present invention;

[0060] FIG. **14**A and FIG. **14**B show a change of a current and a terminal voltage of the lead-acid battery and the lithium battery;

[0061] FIG. **15** is a block diagram showing a schematic electric circuit of a power source apparatus for vehicle according to a ninth embodiment of the present invention;

[0062] FIG. **16** is a block diagram showing a schematic electric circuit of a power source apparatus for vehicle according to a tenth embodiment of the present invention;

[0063] FIG. **17** is a block diagram showing a schematic electric circuit of a power source apparatus for vehicle according to an eleventh embodiment of the present invention;

[0064] FIG. **18** is a block diagram showing a schematic electric circuit of a power source apparatus for vehicle according to a twelfth embodiment of the present invention;

[0065] FIG. **19** is a block diagram showing a schematic electric circuit of a power source apparatus for vehicle according to a thirteenth embodiment of the present invention;

[0066] FIG. **20** is a block diagram showing a schematic electric circuit of a power source apparatus for vehicle according to a fourteenth embodiment of the present invention; and

[0067] FIG. **21** is a block diagram showing a schematic electric circuit of a power source apparatus for vehicle according to a fifteenth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0068] Hereinafter, various embodiments of the present invention will be described with reference to the accompanying drawings. In the following description of the various embodiments, like reference characters or numerals designate like or equivalent component parts throughout the several diagrams.

First Embodiment

[0069] A description will now be given of the power source apparatus for vehicle according to the first embodiment of the present invention with reference to FIG. **1**A, FIG. **1**B, FIG. **2**A, FIG. **2**B, FIG. **3**, FIG. **4**A, and FIG. **4**B.

[0070] The power source apparatus according to the first embodiment can be applied to vehicles with an internal combustion engine. For example, the power source apparatus according to the first embodiment can be applied to various types of vehicles equipped with an idle reduction apparatus. The idle reduction apparatus automatically stops the operation of the internal combustion engine when a predetermined engine stop condition is satisfied, and then automatically restarts the internal combustion engine when a predetermined engine restart condition is satisfied. The idling reduction apparatus will be referred to as the "idle stop apparatus or idle stop function" through the following explanation.

[0071] The vehicle equipped with the power source apparatus according to the first embodiment has a starter motor to rotate a crank shaft of the internal combustion engine when the internal combustion engine starts to operate. However, the vehicle in the first embodiment does not mount any driving motor capable of assisting the vehicle to drive

[0072] FIG. **1**A and FIG. **1**B are block diagrams showing a schematic electric circuit of the power source apparatus according to the first embodiment. As shown in FIGS. **1**A and **1**B, an alternator **10** (electric generator), a regulator **11** (constant voltage control means), a lead-acid battery **20**, a lithium battery **30** (secondary battery), and electrical loads **40** such as a starter motor. The lead-acid battery **20**, the lithium battery **30**, and the electrical loads **40** are electrically connected in parallel to the alternator **10**.

[0073] The alternator **10** generates electric power when receiving a rotary energy transmitted through the crank shaft of the internal combustion engine. Specifically, the rotor of the alternator **10** engages with the crank shaft. Rotation of the rotor of the alternator **10** when receiving the rotary energy of the crank shaft generates an exciting current in a rotor coil **10***a* of the alternator **10**. The exciting current then flows in the rotor coil **10***a*. An alternating current is induced in a stator coil of the alternator **10** according to the magnitude of the exciting current. A rectifier (not shown) rectifies the induced alternating current to a direct current. The regulator **11** adjusts the magnitude of the rectified current which is flowing through the rotor coil **10***a* so as to control a voltage of the alternator **10** generated by the induced current to be constant (a constant voltage Vreg). This makes it possible to suppress fluctuation of the output voltage of the alternator **10**. In the first embodiment, the constant voltage Vreg is 14.5 V.

[0074] The electric power generated in the alternator **10** is supplied to the electrical loads **40**, and also supplied to the lead-acid battery **20** and the lithium battery **30**. During the operation not to generate any electric power by the alternator **10** when the internal combustion engine stops, the lead-acid battery **20** and the lithium battery **30** supply the electric power to the electrical loads **40**. The power source apparatus according to the first embodiment is equipped with a protection control means (not shown). This protection control means controls a discharge capacity and a charge capacity so as to keep the electric energy of the battery within the use range of SOC (state of charge) of each battery such as the lead-acid battery **20** and the lithium battery **30**. The SOC is a residual capacity or energy in the battery. By the way, the SOC is a ratio of a charged energy to a full charged energy of the battery, the above discharged capacity is the electric energy supplied from the lead-acid battery **20** and the lithium battery **30** to the electrical loads **40**, and the above charged capacity is the electric energy supplied from the alternator **10** to the lead-acid battery **20** and the lithium battery **30**.

[0075] In the first embodiment, the alternator **10** generates the electric power by the regenerative energy of the vehicle which is generated when the vehicle speed is decreased. The regenerative electric power is charged to the lead-acid battery **20** and the lithium battery **30** (mainly charged to the lithium battery **30**). Such regenerative electric power is obtained only when the vehicle speed is increased, for example, when the vehicle runs downhill, and a fuel injection to the internal combustion engine is stopped.

[0076] The lead-acid battery **20** is a known usual battery. Specifically, the lead-acid battery **20** is composed of a plurality of cells connected in series and an electrolytic solution. Each of the cells in the lead-acid battery **20** has a positive electrode, and a negative electrode. Lead dioxide (PbO_2) is used as the positive electrode active material, lead (Pb) is used as the negative electrode active material, and sulfuric acid (H_2SO_4) is used as the electrolytic solution. In general, the lead-acid battery **20** is larger in charge capacity than the lithium battery **30**.

[0077] On the other hand, the lithium battery **30** uses oxide which contains lithium (for example, lithium metal composite oxide) as the positive electrode active material and/or adsorbent material (for example, activated carbon) as the positive electrode. Specifically, $LiCoO_2$, $LiMn_2O_4$, $LiNiO_2$, $LiFePO_4$, etc. are used as the positive electrode active material. In addition, the lithium battery **30** uses carbon, graphite, lithium-doped carbon or graphite, lithium titanium oxide (Li_2TiO_2) or alloy which contains Si or Sn as the negative electrode active material. The lithium battery **30** contains an organic electrolyte as electrolytic solution. Like the structure of the lead-acid battery **20**, the lithium battery **30** is composed of a plurality of cells having the above electrodes connected in series.

[0078] In FIG. **1**A, and FIG. **1**B, reference numbers **21** and **31** designate a battery cell assembly of the lead-acid battery **20** and a battery cell assembly of the lithium battery **30**, respectively, and reference numbers **22** and **32** denote an internal resistance of the lead-acid battery **20** and the lithium battery **30**, respectively.

[0079] In the following explanation, an open circuit voltage V**0** of the battery is a voltage generated by the battery cell assemblies **21** and **31**. The terminal voltages Vd and Vc of the battery are voltages expressed by the following equation:

$$Vd=V0-Id\times R \quad \text{(F1); and}$$

$$Vc=V0+Ic\times R \quad \text{(F2),}$$

where Id is a discharge current, Ic is a charge current, R is an internal resistance of the battery, and V**0** is an open circuit voltage of the battery.

[0080] An exciting current of the alternator **10** is flowing to the battery having a low terminal voltage Vc when each of the lead-acid battery **20** and the lithium battery **30** is charged by the current generated by the alternator **10** because the lead-acid battery **20** and the lithium battery **30** are connected in series. On the other hand, the battery having a high terminal voltage Vd charges a current to the electrical loads **40** when the electric power is supplied to the electrical loads **40**.

[0081] During the regenerative mode of the vehicle, it is controlled for the terminal voltage Vd (Li) of the lithium battery **30** to become many times lower than the terminal voltage Vd (Pb) of the lead-acid battery **20** in order to preferentially charge the lithium battery **30** rather than the lead-acid battery **20**. In addition, during the discharging mode, it is also controlled for the terminal voltage Vd (Li) of the lithium battery **30** to become many times higher than the terminal of the lead-acid battery **20** in order to preferentially discharge the electric energy from the lithium battery **30** rather than the lead-acid battery **20**.

[0082] The above control can be achieved by adjusting the open circuit voltage V**0** and the internal resistance R of each of the lead-acid battery **20** and the lithium battery **30**. That is, the open circuit voltage V**0** of the battery can be adjusted by selecting an optimum positive electrode active material, an optimum negative electrode active material, and an optimum electrolytic solution of the lithium battery **30**.

[0083] A description will now be given of the method of setting the condition to satisfy the relationship of Vc (Li: Lithium battery)<Vc (Pb: lead-acid battery) during a regenerative generation and the condition to satisfy the relationship of Vd (Li)>Vd (Pb) during discharge, in the power source apparatus according to the first embodiment with reference to FIG. **2**A, FIG. **2**B, and FIG. **3**.

[0084] FIG. **2**A is a view showing the use range of SOC of the lead-acid battery **20** mounted to the vehicle with the power source apparatus according to the first embodiment. FIG. **2**B is a view showing the use range of SOC of the lithium battery **30** in the power source apparatus according to the first embodiment.

[0085] In FIG. **2**A, the horizontal line designates the SOC of the lead-acid battery **20**, the solid line A**1** denotes a voltage characteristic line which shows a relationship between the SOC and the open circuit voltage V**0** (Pb) of the lead-acid battery **20**. As shown in FIG. **2**A, the more the SOC increases by increasing the charged energy, the more the open circuit voltage V**0** (Pb) increases.

[0086] In FIG. **2**B, the horizontal line designates the SOC of the lithium battery **30**, the solid line A**2** denotes a voltage characteristic line which shows a relationship between the SOC and the open circuit voltage V**0** (Li) of the lithium battery **30**. The more the SOC increases by increasing the charged energy, the more the open circuit voltage V**0** (Li) increases. In particular, although the SOC increases according to the increase of the charged energy, the slope which shows the voltage characteristic line of the lead-acid battery **20** becomes low during a range between inflection points P**1** and P**2** shown in FIG. **2**A.

[0087] The overcharge state and the over discharge state of each of the lead-acid battery **20** and the lithium battery **30** would cause a rapid deterioration. Accordingly, it is necessary for the protection control means, previously described, to control the charging capacity to the lithium battery **30** and the lead-acid battery **20**, and the discharging capacity from the lead-acid battery **20** and the lithium battery **30**. That is, it is necessary to use each of the lead-acid battery **20** and the lithium battery **30** within the use range of SOC.

[0088] The use range W**1** (Pb) of SOC of the lead-acid battery **20** is within the range of 88% to 100% of SOC. On the other hand, the use range W**2** (Li) of SOC of the lithium battery **30** is within the range of 10% to 90% of SOC. The upper limit of the use range W**2** (Li) of SOC of the lithium battery **30** is smaller than 100%, and the lower limit of the use range W**2** (Li) of SOC of the lithium battery **30** is larger than zero %.

[0089] Accordingly, the range of 0% to 88% of SOC of the lead-acid battery **20** causes the rapid deterioration. FIG. **2**B also shows an expansion of the area indicated by the dotted line shown in FIG. **2**A which indicates the use range W**1** (Pb) of SOC of the lead-acid battery **20**. The position of 0% of SOC of the lithium battery **30** indicated by the horizontal line in FIG. **2**B corresponds to the position of 88% of the use range W**1** (Pb) of SOC of the lead-acid battery **20**.

[0090] The lithium battery **30** is set in order to obtain the voltage characteristic A**2** of the lithium battery **30** which satisfies the following conditions (a), (b), (c), (d), and (e). Specifically, it is possible to obtain the voltage characteristic A**2** which satisfies the conditions (a), (b), (c), (d), and (e) by selecting an optimum combination of the positive electrode active material, the negative electrode active material, and the solid electrolyte of the lithium battery **30**.

<Condition (a)>

[0091] There is an equal voltage point Vds at which the open circuit voltage V**0** (Pb) of the lead-acid battery **20** is equal to the open circuit voltage V**0** (Li) of the lithium battery **30** in the use range W**1** (Pb) of SOC of the lead-acid battery **20** and the use range W**2** (Li) of SOC of the lithium battery **30**. This equal voltage point Vds is present in the range of the inflection points P**1** and P**2**, where a slope of voltage characteristic line A**2** of the lithium battery **30** in this range is small.

<Condition (b)>

[0092] The open circuit voltage V**0** (Li) of the lithium battery **30** is higher than the open circuit voltage V**0** (Pb) of the lead-acid battery **20** at the upper limit side of the equal voltage point Vds in the use range W**2** (Li) of SOC of the lithium battery **30**. In more detail, the equal voltage point Vds is present at the lower limit side rather than the upper limit side (90%) of the use range W**2** (Li) of SOC of the lithium battery **30** in order to set the equal voltage point Vds within the range of P**1** and P**2**. The slope of the voltage characteristic line A**2** of the lithium battery **30** is larger than the slope of the voltage characteristic line A**1** of the lead-acid battery **20** at the upper limit side of the equal voltage point Vds in the use range W**2** (Li) of SOC of the lithium battery **30**.

<Condition (c)>

[0093] The terminal voltage Vc (Li) of the lithium battery **30** when the maximum charging current flows in the lithium battery **30** is smaller than the constant voltage Vreg which is controlled by the regulator **11**. In other words, the terminal voltage Vc (Li) of the lithium battery **30** is smaller than the constant voltage Vreg, which is the terminal voltage Vc (Li) (see the solid line A**3** shown in FIG. **2**B) when the lithium battery **30** is charged at the upper limit value (90%) of the use range W**2** (Li) of SOC of the lithium battery **30**.

[0094] Reference character ΔV shown in FIG. **2**B indicates a voltage drop part by the internal resistance **32** at the upper

limit value (90%), which corresponds to the term (Ic×R) in the equation (F2), previously described.

<Condition (d)>

[0095] The open circuit voltage V**0** (Li) of the lithium battery **30** is lower than the open circuit voltage V**0** (Pb) of the lead-acid battery **20** in the lower limit side from the equal voltage point Vds in the use range W**2** (Li) of SOC of the lithium battery **30**. In more detail, the equal voltage point Vds is set to a value at the upper limit side from the lower limit side (10%) of the use range W**2** (Li) of SOC of the lithium battery **30** in order to set the equal voltage point Vds in the range of P**1** to P**2**.

[0096] In the range in the lower limit side observed from the equal voltage point Vds in the use range W**2** (Li) of SOC of the lithium battery **30**, the slope of the voltage characteristic line A**2** of the lithium battery **30** is larger than the slope of the voltage characteristic line A**1** of the lead-acid battery **20**.

<Condition (e)>

[0097] The range in the upper limit side observed from the equal voltage point Vds is wider than the range in the lower limit side observed from the equal voltage point Vds in the use range W**2** (Li) of SOC of the lithium battery **30**. In more detail, the equal voltage point Vds is set to a value in the lower limit side observed from the intermediate point between the range of P**1** and p**2** in order to set the equal voltage point Vds in the range of P**1** to P**2**. This satisfies the relationship of Vd (Li)>Vd (Pb) in a large part in the use range W**2** (Li) of SOC of the lithium battery **30**.

[0098] FIG. **3** is a view showing a difference in I-V characteristics between the lead-acid battery **20** and the lithium battery **30** in the power source apparatus according to the first embodiment. In FIG. **3**, the solid line B**1** indicates the I-V characteristic of the lead-acid battery **20**, the solid line B**2** designates the I-V characteristic of the lithium battery **30**, the solid line B**3** denotes the constant voltage Vreg, the horizontal line indicates the current value Ic and the current value Id, the vertical line indicates the terminal voltage Vc and the terminal voltage Vd. In FIG. **3**, the current Ic during charging is expressed by a positive value, and the current Id during discharging is expressed by a negative value.

[0099] In the I-V characteristic B**1** and the I-V characteristic B**2**, the more the charging current Ic increase, the more the terminal voltage Vc increases (Ic×R is increased). The more the charging current Ic decreases, the more the terminal voltage Vc decreases (Ic×R is decreased). That is, the change of the charging current Ic is in proportion to the change of the charging current Ic. The slope of each of the I-V characteristic B**1** and the I-V characteristic B**2** indicates the internal resistance R. In particular, the lithium battery **30** has the same internal resistance value R (Pb) during both charging and discharging. On the other hand, an internal resistance value R (Pb) in charging of the lead-acid battery **20** is larger than that in discharging of the lead-acid battery **20**.

[0100] In the first embodiment, it is set to satisfy the relationship of R (Li)<R (Pb) in charging, and to satisfy the relationship of R (Li)≦R (Pb) in discharging. It is also set to satisfy the relationship of Vd (Li)>Vd (Pb) in discharging, to satisfy the relationship of Vc (Li)≧Vc (Pb) in a range close to Ic=zero, and to satisfy the relationship of Vc (Li)<Vc (Pb) in other part. The above setting control can be achieved by the condition where the internal resistance value R (Li) of the lithium battery **30** is smaller than the internal resistance value R (Pb) of the lead-acid battery **20** in charging.

[0101] The power source apparatus having the above structure according to the first embodiment of the present invention has the following features (A**1**) to (A**6**).

(A**1**) Making the voltage characteristic A**2** to satisfy the condition (a) (the equal voltage point Vds is present in the range between the inflection points P**1** and P**2**) generates the state without any large voltage difference between the lithium battery **30** and the lead-acid battery **20** because the terminal voltage Vd (Li) in the use range of SOC of the lithium battery **30** is approximately equal to the terminal voltage Vd (Pb) in the use range W**1** of SOC of the lead-acid battery **20** during discharge, as shown in FIG. **2**A.

[0102] Therefore even if does not use any DC/DC converter (which is used in the conventional power source apparatus), it is possible to prevent a current which flows from the lithium battery **30** to the lead-acid battery **20**, in other words, it is possible to flow a current of an extremely small quantity from the lithium battery **30** to the lead-acid battery **20**. The structure of the power source apparatus according to the first embodiment can thereby suppress the lead-acid battery **20** from being in overcharge state without any DC/DC converter. This makes it possible to adequately reduce the manufacturing cost of the power source apparatus because of not using any DC/DC converter.

(A**2**) Making the voltage characteristic A**2** to satisfy the condition (b) (the relationship of Vd (Li)>Vd (Pb) at the upper limit side observed from the equal voltage point Vds) to the voltage characteristic A**1** allows the lithium battery **30** to discharge a current, for example, to the electric load **43** which requires a constant voltage, because the open circuit voltage of the lithium battery **30** is higher than that of the lead-acid battery **20**, in the state where the lithium battery **30** is higher charged than the equal voltage point Vds in the use range W**2** (Li) of SOC of the lithium battery **30**.

[0103] Because this condition increases the frequency of discharging a current from the lithium battery **30** when compared with from the lead-acid battery **20** and decreases the frequency of discharging a current from the lead-acid battery **20** with a low durability to frequent discharging, this makes it possible to suppress the deterioration of the lead-acid battery **20**.

(A**3**) Making the voltage characteristic A**2** to satisfy the condition (c) (Vc (Li)<Vreg when the maximum charging current flows) to the voltage characteristic A**1** can increase the frequency of charging the lithium battery **30** rather than the lead-acid battery **20** by the following reasons.

[0104] In the case of charging the lead-acid battery **20** with the regenerative energy without using the lithium battery **30**, because the internal resistance **22** of the lead-acid battery **20** is larger than that of the lithium battery **30**, as shown in FIG. **3**, the terminal voltage Vc (Pb) of the lead-acid battery **20** reaches the constant voltage Vreg at the point when the charging current reaches the current value Ia. On the other hand, the structure of the power source apparatus equipped with the lithium battery **30** satisfies the relationship of Vc (Li)<Vreg even when the charging current has the maximum value, it is possible to further charge the lithium battery **30**.

[0105] In the example shown in FIG. **3**, the terminal voltage Vc (Li) of the lithium battery **30** reaches the constant voltage Vreg when the charging current reaches the current value Ib which is larger than the maximum charging current Imax.

[0106] This will be explained in detail with reference to FIG. **4**A and FIG. **4**B. FIG. **4**A shows a current change of the lead-acid battery **20** and the lithium battery **30** in the elapse of

time. FIG. **4**B shows a terminal voltage change of the lead-acid battery **20** and the lithium battery **30** in the elapse of time. In FIG. **4**A and FIG. **4**B, the solid lines C**1** and D**1** indicate the change of the charging current and the terminal voltage Vc (Pb) when the lead-acid battery **20** is charged with the regenerative electric power at the maximum charging current Imax without using the lithium battery **30**. The solid lines C**2** and D**2** in FIG. **4**A and FIG. **4**B show the change of the charging current and the change of the terminal voltage Vc (Li), respectively, when the lithium battery **30** is charged with the regenerative electric power at the maximum charging current Imax in the power source apparatus according to the first embodiment.

[0107] As previously explained with reference to FIG. **3**, because the relationship of Imax>Ia is satisfied when the lead-acid battery **20** is charged with the regenerative electric power, the charging current rapidly drops at the timing t**1** and converges toward zero, as shown in FIG. **4**A. This state would be difficult to charge the lead-acid battery **20**. In this case, the area designated by slanting lines in FIG. **4**A corresponds to the charged capacity of the lead-acid battery **20**.

[0108] On the other hand, because the relationship of Imax≦Ib is satisfied when the lithium battery **30** is charged with the regenerative electric power, the charging current maintains the value Imax until the timing t**2** where the SOC of the lithium battery **30** reaches the upper limit value (90%). This allows the lithium battery **30** to be usually charged and to increase its changeable capacity.

[0109] As described above, according to the first embodiment of the present invention, it is possible to increase the frequency to charge the lithium battery **30** rather than the frequency to charge the lead-acid battery **20**. This can decrease the accumulated charged capacity of the lead-acid battery **20** which has a low durability, and suppress the deterioration of the lead-acid battery **20**.

(A**4**) Making the voltage characteristic A**2** to satisfy the condition (d) (Vd (Li)<Vd (Pb) at the lower limit side observed from the equal voltage point Vds) to the voltage characteristic A**1** allows the lead-acid battery **20**, instead of the lithium battery **30**, to discharge the electric power to the electrical loads **40** when the lithium battery **30** preferentially discharge the electric power to the electric load **40** and the SOC of the lithium battery **30** is lower than the equal voltage point Vds.

[0110] Further, the current flows from the lead-acid battery **20** to the lithium battery **30**, this increases the SOC of the lithium battery **30** toward the equal voltage point Vds. As a result, it is possible to suppress the lithium battery **30** from over discharge.

(A**5**) Making the voltage characteristic A**2** to satisfy the condition (e) to the voltage characteristic A**1** allows the range to satisfy the relationship of Vd (Li)>Vd (Pb) based on the condition (b), where the condition (e) satisfies that the range in the upper limit side observed from the equal voltage point Vds is wider in area than the range in the lower limit side observed from the equal voltage point Vds. This makes it possible to increase the frequency of preferentially discharging from the lithium battery **30** rather than from the lead-acid battery **20**. This makes it possible to increase the deterioration resistance of the lead-acid battery **20**.

(A**6**) Adding the lithium battery **30** which satisfies the conditions (a) to (e) into a power source apparatus which is comprised of the alternator **10**, the regulator **11**, and the lead-acid battery **20** makes it possible to obtain the features of the present invention, previously described without using any DC/DC converter. It is possible to realize the power source apparatus according to the first embodiment of the present invention in a conventional power source apparatus with a less change in hardware design.

Second Embodiment

[0111] A description will be given of the power source apparatus according to the second embodiment of the present invention with reference to FIG. **5**. FIG. **5** is a block diagram showing a schematic electric circuit of the power source apparatus according to the second embodiment.

[0112] In the structure of the power source apparatus according to the second embodiment shown in FIG. **5**, the lithium battery **30** supplies the electric power to electrical loads **43** which require an approximate constant voltage or a voltage which is changed within at least a predetermined voltage range. For example, there are a navigation system and an audio system as the electrical loads **43** mounted to vehicles. When the power source apparatus supplies electric power, a voltage of which is fluctuated, not constant, or changed out from a predetermined allowable range, and when the voltage of the electric power temporarily drops below a minimum operation voltage, the navigation system and/or audio system as the electric load **43** are reset in operation. This would cause various problems. In order to avoid this, it is necessary for the power source apparatus to supply the voltage of the electric power which is an approximate constant voltage which is larger than the minimum operation voltage.

[0113] On the other hand, the lead-acid battery **20** supplies the electric power to the starter motor **41** and usual electrical loads **42** such as a defroster heater for a rear window, and a ventilation fan for an air conditioner system. The starter motor **41** requires a large electric power when compared with the electrical loads **42** and **43**. When the lead-acid battery **20** supplies such a large electric power to the starter motor **41**, the terminal voltage Vd (Pb) of the lead-acid battery **20** rapidly drops.

[0114] However, the structure of the power source apparatus according to the second embodiment has the electromagnetic relay **50** to open and close the electric connection between the lithium battery **30** and the starter motor **41** in order to avoid the rapid drop of the terminal voltage Vd (Li) of the lithium battery **30**. Specifically, while the lead-acid battery **20** supplies the electric power to the starter motor **41**, the electromagnetic relay **50** is opened in order to avoid the voltage drop of the lithium battery **30**. This makes it possible for the lithium battery **30** to supply a stable electric power, a voltage of which is slightly changed within a predetermined voltage range, to the electrical loads **43**.

[0115] When the lead-acid battery **20** does not store an adequate capacity to start the starter motor **41**, it is possible to turn on the electromagnetic relay **50** to supply the electric power to the starter motor **41**. That is, when the lead-acid battery **20** has a low SOC, it is controlled so that the lithium battery **30** rather than the lead-acid battery **20** preferentially supplies the electric power to the starter motor **41**.

[0116] As described above, the power source apparatus according to the second embodiment of the present invention has the following effect (7) in addition to the effects (1) to (6), previously described in the first embodiment. (7) The lithium battery **30** supplies the electric power to the electrical loads **43** which require an approximate constant voltage or a stable voltage which is changed within the predetermined voltage

range, and the lead-acid battery **20** supplies the electric power to the starter motor **41**. While the lead-acid battery **20** supplied the electric power to the starter motor **41**, the electromagnetic relay **50** operates to open. This makes it possible to supply to the electrical loads **43** the electric power whose voltage has a small fluctuation in voltage.

Third Embodiment

[0117] A description will be given of the power source apparatus according to the third embodiment of the present invention with reference to FIG. **6**. FIG. **6** is a block diagram showing a schematic electric circuit of the power source apparatus according to the third embodiment of the present invention.

[0118] The power source apparatus according to the third embodiment has a protection control means **60** which controls the charging capacity to and discharging capacity from the lithium battery **30** in order to avoid the overcharging to the lithium battery **30** and the over discharging from the lithium battery **30**.

[0119] The protection control means **60** always receives detection signals regarding the terminal voltages Vc and Vd or the open circuit voltage V**0** (Li) of the lithium battery **30**, and a detection signal transferred from a current detection means **61** which detects a current flowing in the lithium battery **30**.

[0120] The protection control means **60** instructs the electromagnetic relay **50** to open (voltage drop suppression operation) when the terminal voltage Vd of the lithium battery **30** during discharging becomes below the lower limit voltage. This control protects the lithium battery **30** from over discharge. It is possible to set the lower limit voltage based on a voltage which corresponds to the lower limit SOC value (10%) shown in FIG. **2**B.

[0121] When the terminal voltage Vc of the lithium battery **30** during charge exceeds the upper limit voltage, the protection control means **60** instructs the electromagnetic relay **50** to open (voltage rise suppression operation). This control protects the lithium battery **30** from over charging. It is possible to set the upper limit voltage based on a voltage which corresponds to the upper limit SOC value (90%) shown in FIG. **2**B.

[0122] The protection control means **60** further outputs an instruction signal to the regulator **11** to change the constant voltage Vreg of the regulator **11** according to the voltage of the lithium battery **30**. This makes it possible to prevent or protect the lithium battery **30** from overcharge and over discharge.

[0123] That is, the protection control means **60** instructs the regulator **11** to increase the constant voltage Vreg when the voltage of the lithium battery **30** becomes lower than the lower limit value. This increases the charging capacity to the lithium battery **30** and protects the lithium battery **30** from over discharge.

[0124] On the other hand, the protection control means **60** instructs the regulator **11** to decrease the constant voltage Vreg when the voltage of the lithium battery **30** exceeds the upper limit value. This suppresses the charging capacity to the lithium battery **30**, and protects the lithium battery **30** from overcharge.

[0125] As describe above, the power source apparatus according to the third embodiment of the present invention reliably avoids the lithium battery **30** from over discharge because the protection control means **60** instructs the electromagnetic relay **50** to open when the terminal voltage of the lithium battery **30** becomes lower than the use range W**2** (Li) of the lithium battery **30** in addition during the supply of the electric power to the starter motor **41**.

[0126] Further, the power source apparatus according to the third embodiment of the present invention can reliably avoid the lithium battery **30** from overcharge because the protection control means **60** instructs the electromagnetic relay **50** to open.

[0127] Because the power source apparatus according to the third embodiment of the present invention performs the over discharge and overcharge protection operation by changing the constant voltage Vreg by the protection control means **60**. This can precisely control the voltage of the lithium battery **30**, and this makes thereby it possible to perform the over discharge protection and the overcharge protection for the lithium battery **30** with high accuracy.

Fourth Embodiment

[0128] A description will be given of the power source apparatus according to the fourth embodiment of the present invention with reference to FIG. **7**. FIG. **7** is a block diagram showing a schematic electric circuit of a power source apparatus according to the fourth embodiment.

[0129] In the third embodiment previously described, the power source apparatus has the protection control means **60** to protect the lithium battery **30** from overcharge and over discharge.

[0130] On the other hand, the protection control means **60** in the power source apparatus of the fourth embodiment further performs the overcharge operation and the over discharge operation for the lead-acid battery **20** in addition to the function of the third embodiment.

[0131] That is, the protection control means **60** instructs the regulator **11** to increase the constant voltage Vreg when the voltage of the lead-acid battery **20** becomes under the lower limit voltage. This performs the over discharge operation of the lead-acid battery **20**. On the other hand, the protection control means **60** instructs the regulator **11** to decrease the constant voltage Vreg when the voltage of the lead-acid battery **20** exceeds the upper limit voltage. This performs the overcharge operation of the lead-acid battery **20**.

[0132] As describe above, the power source apparatus according to the fourth embodiment of the present invention correctly changes the constant Vreg according to the voltage of the lead-acid battery **20**, in addition to changing the constant voltage Vreg according to the voltage of the lithium battery **30**. This can precisely control the voltage of the lead-acid battery **20** in addition to the voltage of the lithium battery **30**, and makes thereby it possible to perform the over discharge protection and the overcharge protection for the lead-acid battery **20** as well as the lithium battery **30** with high accuracy.

Fifth Embodiment

[0133] A description will be given of the power source apparatus according to the fifth embodiment of the present invention with reference to FIG. **8**. FIG. **8** is a block diagram showing a schematic electric circuit of the power source apparatus according to the fifth embodiment.

[0134] The power source apparatus according to the fifth embodiment has a plurality of the lithium batteries **30**. In the structure of the power source apparatus according to the fifth

embodiment, the electric power is supplied from the different lithium batteries **30** to various types of the electric loads **43**, **44**, and **45**, where the electrical loads **43** requires an approximate constant voltage or a stable voltage which is changed within the predetermined voltage range, the electric loads **44** requires a large electric power, and the electric load **45** requires a voltage in order to reliably operate when an emergency occurs.

[0135] Specifically, there is an electric motor mounted to a power steering apparatus as one example of the electric load **44** which requires a large electric power. The electric load **44** can operate by some fluctuating voltage, which is different from the electrical loads **43** which require an approximate constant voltage, previously described.

[0136] There is a communication apparatus as one example of the electric load **45** which requires a certain operation when an emergency occurs. This communication apparatus transmits abnormality information to a repair operator in a car dealership to diagnose and repair the vehicle, for example, when the internal combustion engine mounted to the vehicle has a failure and does not start. Therefore it is not necessary for such a type of the electric load **44** to use a large electric power and a constant voltage.

[0137] The power source apparatus according to the fifth embodiment shown in FIG. **8** has a plurality of the electromagnetic relays **50**, battery state detection means **70**, and the current detection means **61**, like the power source apparatus shown in FIG. **6**. That is, the electromagnetic relay **50**, the battery state detection means **70**, and the current detection means **61** are placed every lithium battery **30**.

[0138] The battery state detection means **70** always detects the terminal voltages Vc, Vd or the open circuit voltage V**0** (Li) of the lithium battery **30**, and a current flowing through the lithium battery **30**. The battery state detection means **70** then transfers the detection signals to the protection control means **60**. The protection control means **60** receives the detection signals transferred from the battery state detection means **70**, and performs the overcharge control and the over discharge control by using the electromagnetic relay **50**, and also performs the overcharge and over discharge protection control by adjusting the constant voltage Vreg, like the protection control means **60** shown in FIG. **6**.

[0139] As describe above, the power source apparatus according to the fifth embodiment of the present invention has a plurality of the lithium batteries **30**. The lithium batteries **30** correspond to the electrical loads, respectively. This structure makes it possible to suppress the deterioration of each of the lithium batteries **30**. In particular, because the electric load **45** for emergency has the dedicated lithium battery **30**, it is possible to suppress the deterioration of the lithium battery **30** and to avoid the risk of not supplying the electric power to the electric load **45**.

Sixth Embodiment

[0140] A description will be given of the power source apparatus according to the sixth embodiment of the present invention with reference to FIG. **9**. FIG. **9** is a block diagram mainly showing a detailed structure of the battery state detection means **70** in the power source apparatus shown in FIG. **8**.

[0141] The battery state detection means **70** is comprised of a cell voltage switch means **71**, a battery state detection control means **72**, a temperature detection means **73**, and a cell equalizing means **74**. The cell voltage switch means **71**, the battery state detection control means **72**, the temperature detection means **73**, and the cell equalizing means **74** serve as equalizing means.

[0142] The cell voltage switch means **71** detects the voltage of each of a plurality of the battery cells **33** which form the lithium battery **30**. The cell voltage switch means **71** has a function to select one of the battery cells **33** in order to detect its voltage. The cell voltage switch means **71** detects the voltage of the selected battery cell and then transfers the detected voltage value to the battery state detection control means **72**. The battery state detection control means **72** also receives a detected current value of the current which flows in the lithium battery **30**. The battery state detection control means **72** further receives a temperature value of the lithium battery **30** detected by the temperature detection means **73**.

[0143] The battery state detection control means **72** calculates the terminal voltages Vc, Vd or the open circuit voltage V**0** (Li) of the lithium battery **30** based on the voltage of each of the battery cells **33**. The battery state detection control means **72** transfers the calculated voltage, the current value of the lithium battery **30**, and the temperature value of the lithium battery **30** to the protection control means **60** through the communication interface **75**. The protection control means **60** receives the information such as the above voltage value, the current value, and the temperature value transferred from the battery state detection control means **72**, and performs the protection control based on the received information.

[0144] The battery state detection control means **72** calculates a discharge capacity from the battery cell **33** having a high SOC, and a charge capacity to the battery cell **33** having a low SOC based on the received voltage value of the battery cell **33**. The battery state detection control means **72** outputs an equalizing instruction signal corresponding to the calculation result to the cell equalizing means **74**. When receiving the equalizing instruction signal, the cell equalizing means **74** instructs each of the battery cells **33** to discharge or charge based on the received equalizing instruction signal in order to equalize the SOC (state of charge as a residual capacity) in each of the battery cells **33**.

[0145] As describe above, the power source apparatus according to the sixth embodiment of the present invention can equalize the SOC in each of the battery cells **33**. This makes it possible to avoid the presence of the overcharged battery cells **33** and the battery cells having an adequate SOC during charging. Like this, it is also possible to avoid the presence of the over discharged battery cells **33** and the battery cells having an adequate SOC during discharging. The power source apparatus according to the sixth embodiment can suppress the advance of deterioration of the lithium battery **30**.

Seventh Embodiment

[0146] A description will be given of the power source apparatus according to the seventh embodiment of the present invention with reference to FIG. **10**.

[0147] In the power source apparatus according to the sixth embodiment previously described shown in FIG. **9**, the cell voltage switch means **71** and the battery state detection control means **72** are formed with different circuit parts. The power source apparatus according to the seventh embodiment has a single IC **710** (integrated circuit as cell equalizing abnormal detection means) which is composed of the cell voltage switch means **71** and the cell equalizing means **74**.

[0148] FIG. **10** is a block diagram mainly showing a detailed structure of the battery state detection means **70** comprised of the single IC chip **710** in the power source apparatus according to the seventh embodiment.

[0149] The cell equalizing abnormal detection means **710** detects the voltage of each of the battery cells **33**, and calculates the charging capacity to or discharging capacity from each of the battery cells **33** based on the detected voltage. The cell equalizing abnormal detection means **710** equalizes the residual capacity of each of the battery cells **33** by charging and discharging each of the battery cells **33** based on the calculation result.

[0150] The cell equalizing abnormal detection means **710** further detects whether or not the detected voltage of each of the battery cells **33** is within a predetermined normal range in order to detect the abnormality of each of the cell batteries **33**. When receiving an abnormal diagnosis instruction signal transferred from the battery state detection control means **72**, the cell equalizing abnormal detection means **710** starts to perform the abnormal detection operation previously described, and transfers the detection result to the battery state detection control means **72**.

[0151] A voltage down means **76** decreases the voltage of the lithium battery **30** to a voltage of not more than 5 V, with which a microcomputer can operate. Such a voltage signal decreased by the voltage down means **76** is transferred to the battery state detection control means **72**, and then further transferred to the protection control means **60** through the communication interface **75**.

[0152] As described above, the power source apparatus according to the seventh embodiment of the present invention has the effect to perform the abnormal detection operation for each of the battery cells **33** in addition to have the same effects of the power source apparatus according to the sixth embodiment.

(Other Modifications)

[0153] The present invention is not limited by the first to seventh embodiments previously described. It is possible to have the following structures or to selectively combine the structures of the first to seventh embodiments.

[0154] For example, it is possible to use a semiconductor switch such as MOSFET and IGBT or a manual switch instead of the electromagnetic relay **50**. Such a semiconductor switch has a superior response function and superior durability when compared with the electromagnetic relay **50**, but is generally a high price.

[0155] It is also possible to use a combination of a diode and a resistance instead of using the electromagnetic relay **50** which has a switching mechanism to connect the lithium battery **30** with the starter motor **41**, and to disconnect the electrical connection between the lithium battery **30** and the starter motor **41**. The combination of the diode and the resistance can suppress the current which flows to the starter motor **41** from the lithium battery **30** in order to suppress the voltage drop of the lithium battery **30**.

[0156] Although each of the first to seventh embodiments uses the lithium battery **30** having the voltage characteristic A**2** composed of non-aqueous electrolyte, it is possible to use a nickel battery composed of nickel compound, instead of using the lithium battery **30**, unless it satisfies at least the conditions (a) to (c), previously described.

[0157] In each of the first to seventh embodiments, the equal voltage point Vds is present at the upper limit side observed from the lower limit value (10%) in the use range W**2** (Li) of SOC of the lithium battery **30**. However, the concept of the present invention is not limited by this. For example, it is possible to set the equal voltage point Vds to the lower limit value.

[0158] In each of the first to seventh embodiments, the vehicles with the power source apparatus have the regenerative function. However, the concept of the present invention is not limited by this. For example, it is possible to apply the power source apparatus to vehicles without the regenerative function. By the way, because the vehicle having the regenerative function has a high frequency to charge the regenerative energy to the battery, it is possible to show the feature of the present invention to suppress the deterioration of the lead-acid battery **20** by reducing the accumulated charged capacity in the lead-acid battery **20** with a low durability.

Eighth Embodiment

[0159] A description will now be given of the power source apparatus according to the eighth embodiment of the present invention with reference to FIG. **11**A, FIG. **11**B, FIG. **11**C, FIG. **12**A, FIG. **12**B, FIG. **13**; and FIG. **14**A, and FIG. **14**B.

[0160] The power source apparatus according to the eighth embodiment can be applied to various types of vehicles with an internal combustion engine. For example, the power source apparatus according to the eighth embodiment can be applied to a vehicle equipped with an idle reduction apparatus. The idle reduction apparatus automatically stops the operation of the internal combustion engine when a predetermined engine stop condition is satisfied, and also automatically restarts the internal combustion engine when a predetermined engine restart condition is satisfied, as previously described. The idling reduction apparatus will be referred to as the "idle stop apparatus or idle stop function" through the following explanation.

[0161] In the eighth embodiment, the vehicle equipped with the power source apparatus has a starter motor to rotate a crank shaft of the internal combustion engine when the internal combustion engine starts to operate. However, the vehicle does not mount any driving motor capable of assisting the vehicle to drive.

[0162] FIG. **11**A, FIG. **11**B, and FIG. **1**C are block diagrams showing a schematic electric circuit of the power source apparatus for vehicle according to the eighth embodiment. As shown in FIG. **11**A, FIG. **11**B, and FIG. **11**C, the alternator **10** (electric generator), the regulator **11** (constant voltage control means), the lead-acid battery **20**, the lithium battery **30** (secondary battery), and various types of electrical loads **41**, **42**, and **43**, and a MOS FET **50'** (open and close means, rectifying means). The lead-acid battery **20**, the lithium battery **30**, and the electrical loads **41**, **42**, and **43** are electrically connected in parallel to the alternator **10**.

[0163] The MOS FET **50'** is placed between the lithium battery **30** and a connection node which connects the alternator **10** with the lead-acid battery **20**. The MOS FET **50'** serves as the open and close means to close (ON) and open (OFF) the electric connection between the lithium battery **30** and the connection node which connects the alternator **10** with the lead-acid battery **20**.

[0164] The MOS FET **50'** also serves as the rectifier means in views of its structure. That is, the internal circuit of the MOS FET **50'** is equivalent to a circuit in which a semiconductor switch part **52** (open and close control means) and a parasitic diode **51** connected in parallel. The open and close

control means **601** generates and transfers an control signal to the gate of the semiconductor switch part **52**. That is, the open and close control means **601** controls to switch ON operation (close) and OFF operation (open) of the MOS FET **50'**.

[0165] The electric load **43** in the electric loads **41** to **43** requires a constant voltage or a stable voltage which is changed within a predetermined voltage range. The electric load **43** is connected to the lithium battery **30** side observed from the MOS FET **50'**. This structure allows the lithium battery **30** to supply electric power to the electric load **43** (see the solid arrow mark at right side in FIG. **11**B and FIG. **11**C).

[0166] For example, there are a navigation system and an audio system as the electrical load **43**, for example, mounted to vehicles. When the power source apparatus supplies electric power, a voltage of which is fluctuated, not constant, or changed out from a predetermined voltage range, and when the voltage of the electric power temporarily drops below a minimum operation voltage, the navigation system and/or audio system as the electric load **43** are reset in operation. This would cause various problems. In order to avoid these problems, it is necessary for the power source apparatus to supply the electric power, a voltage of which must be an approximate constant voltage which is larger than the minimum operation voltage.

[0167] On the other hand, the electric load **41** is a starter motor to start the operation of the internal combustion engine. The electric load **42** is a usual electrical load such as a defroster heater for a rear window and a ventilation fan for an air conditioner system. The starter motor **41** and the electric load **42** are connected to the lead-acid battery **20** side observed from the MOS FET **50'**. That is, the lead-acid battery **20** supplies electric power to the starter motor **41** and the usual electric load **42** (see the solid arrow line at left side in FIG. **11**B and the outline arrow mark at left side in FIG. **11**C).

[0168] The starter motor **41** requires a large electric power when compared with other electrical loads **42** and **43**. When the lead-acid battery **20** supplies such a large electric power to the starter motor **41**, the terminal voltage Vd (Pb) of the lead-acid battery **20** rapidly drops.

[0169] However, the structure of the power source apparatus according to the eighth embodiment has the MOS FET **50'** to open and close the electric connection between the lithium battery **30** and the starter motor **41** in order to avoid the rapid drop of the terminal voltage Vd (Li) of the lithium battery **30**. Specifically, while the lead-acid battery **20** supplies the electric power to the starter motor **41**, the MOS FET **50'** is switched in order to prevent the voltage drop of the lithium battery **30**. This makes it possible for the lithium battery **30** to supply electric power, a voltage of which is slightly changed within a predetermined voltage range, to the electrical loads **43**.

[0170] When the lead-acid battery **20** does not store an adequate capacity to start the starter motor **41**, it is possible to turn on the MOS FET **50'** to supply the electric power to the starter motor **41**. That is, when the lead-acid battery **20** has a low SOC, it is controlled so that the lithium battery **30** rather than the lead-acid battery **20** preferentially supplies the electric power to the starter motor **41**. In the example shown in FIG. **11**A, FIG. **11**B, and FIG. **11**C, the usual electric load **42** is electrically connected to the lead-acid battery **20** side observed in position from the MOS FET **50'**. However, it is also possible to electrically connect the usual electric load **42** with the lithium battery **30** in order for the lithium battery **30** to supply a part of the electric power which is required by the electric load **42**.

[0171] The open and close control means **601** instructs the MOS FET **50'** to open (to be turned off) during the ordinary mode, but, instructs it to close (to be turned on) in order to charge the lithium battery **30** with a large current, and to discharge the electric capacity of the lithium battery **30** to the lead-acid battery **20** (see FIG. **11**A). For example, the open and close control means **601** instructs the MOS FET **50'** to be turned on in order to efficiently charge the lithium battery **30** with a large current of regenerative electric power generated when the vehicle speed is decreased, or in order to charge the lead-acid battery **20** from the lithium battery **30** when the lead-acid battery **20** is in the overcharged state based on information such as the SOC of the lead-acid battery **20** and the vehicle speed.

[0172] During the turned-off state of the MOS FET **50'**, the parasitic diode **51** rectifies the charging current which flows to the lithium battery **30** or discharging current which flows from the lithium battery **30**. That is, during the off state of the MOS FET **50'**, the current can flow from the alternator **10** or the lead-acid battery **20** to the lithium battery **30**, but cannot flow from the lithium battery **30** to the alternator **10** or the lead-acid battery **20** (see FIG. **11**C).

[0173] Because the parasitic diode **51** has a barrier voltage Vbar (which is a voltage required to cause an electric conduction at a connection part between two different materials such as p-n junction), a voltage drop is generated in the electric power flowing through the parasitic diode **51** by the barrier voltage Vbar. Therefore, a current flows to the lithium battery **30** through the parasitic diode **51**. The lithium battery **30** is thereby charged when the terminal voltage Vd (Li) when the lithium battery **30** is not more than a difference voltage obtained by subtracting the barrier voltage Vbar from the voltage of the electric power generated by the alternator **10** or the terminal voltage Vd (Pb) of the lead-acid battery **20** when the MOS FET **50'** is turned off.

[0174] Under the turned off state of the MOS FET **50'** when the lithium battery **30** is charged with the regenerative electric power which is regenerated by the alternator during the deceleration of the vehicle, a large current flows to the lithium battery **30** (secondary battery) through the parasitic diode **51**. This causes a large energy loss when the generated current flows through the parasitic diode **51**.

[0175] In order to avoid such the large energy loss in the parasitic diode **51**, the power source apparatus according to the eighth embodiment instructs the MOS FET **50'** to be turned on when the lithium battery **30** is charged with the regenerative energy generated by the alternator when the vehicle speed is decreased (see FIG. **11**C). This control operation of the power source apparatus allows the current of the regenerative electric power to flow into the lithium battery **30** by bypassing it through the parasitic diode **51**. This eliminates the energy loss generated in the parasitic diode **51**. That is, it is possible to avoid the energy loss generated by the alternator **10**.

[0176] The power source apparatus according to the eighth embodiment instructs the MOS FET **50'** to be turned on in order to charge the lead-acid battery **20** with the electric power (electric capacity) from the lithium battery **30**, for example, when the lead-acid battery **20** has not an adequate

capacity to supply the electric power to the usual electric load **42** and the starter motor **41** (see dotted arrow lines shown in FIG. **11**B).

[0177] The control to turn on the MOS FET **50'** when the terminal voltage Vd (Pb) of the lead-acid battery **20** is lower than the terminal voltage Vd (Li) of the lithium battery **30** makes it possible to supply the electric power from the lithium battery **30** to the lead-acid battery **20**, and to the usual electric load **42** and the starter motor **41**.

[0178] The alternator **10** generates electric power when receiving a rotary energy transmitted through the crank shaft of the internal combustion engine. Specifically, the rotor of the alternator **10** engages with the crank shaft. Rotation of the rotor of the alternator **10** when receiving the rotary energy of the crank shaft generates an exciting current in a rotor coil **10***a* of the alternator **10**. The exciting current then flows in the rotor coil **10***a*. An alternating current is thereby induced in a stator coil of the alternator **10** according to the magnitude of the exciting current. A rectifier (not shown) rectifies the induced alternating current to a direct current. The regulator **11** adjusts the magnitude of the rectified current which is flowing through the rotor coil **10***a* so as to control a voltage of the alternator **10** generated by the induced current to be constant (a constant voltage Vreg). This makes it possible to suppress fluctuation of the output voltage of the alternator **10**. In the eighth embodiment, the constant voltage Vreg is 14.5 V.

[0179] The electric power generated in the alternator **10** is supplied to the electrical loads **41**, **42**, and **43**, and also supplied to the lead-acid battery **20** and the lithium battery **30**. During the operation not to generate any electric power in the alternator **10** when the internal combustion engine stops, the lead-acid battery **20** and the lithium battery **30** supply the electric power to the electrical loads **41**, **42**, and **43**. The power source apparatus according to the eighth embodiment is equipped with a protection control means (not shown). This protection control means controls a discharged capacity and a charged capacity so as to keep the electric energy of the battery within the use range of SOC (state of charge) of the battery such as the lead-acid battery **20** and the lithium battery **30**, where the SOC is a ratio of a charged energy to a full charged energy of the battery, the above discharged capacity is the electric capacity supplied from the lead-acid battery **20** and the lithium battery **30** to the electrical loads **41**, **42**, and **43**, and the above charged capacity is the electric energy supplied from the alternator **10** to the lead-acid battery **20** and the lithium battery **30**.

[0180] In the eighth embodiment, the alternator **10** generates the electric power by the regenerative energy of the vehicle which is generated when the vehicle speed is reduced. The regenerative electric power is charged to the lead-acid battery **20** and the lithium battery **30** (mainly to the lithium battery **30**). Such a regenerative electric power is obtained only when the vehicle speed is reduced in the deceleration state and a fuel injection to the internal combustion engine is stopped.

[0181] The lead-acid battery **20** is a known usual battery. Specifically, the lead-acid battery **20** is composed of a plurality of cells connected in series and an electrolytic solution. Each of the cells in the lead-acid battery **20** has a positive electrode, and a negative electrode. Lead dioxide (PbO_2) is used as the positive electrode active material, lead (Pb) is used as the negative electrode active material, and sulfuric acid (H_2SO_4) is used as the electrolytic solution. In general, the lead-acid battery **20** is larger in charging capacity than the lithium battery **30**.

[0182] On the other hand, the lithium battery **30** uses oxide containing lithium (for example, lithium metal composite oxide) as the positive electrode active material and/or adsorption material (for example, activated carbon) as the positive electrode. Specifically, $LiCoO_2$, $LiMn_2O_4$, $LiNiO_2$, $LiFePO_4$, etc. are used as the positive electrode active material. Further, the lithium battery **30** uses carbon, graphite, lithium-doped carbon or graphite, lithium titanium oxide (for example, Li_2TiO_2), or alloy which contains Si or Sri as the negative electrode active material. The lithium battery **30** contains an organic electrolyte as electrolytic solution. Like the structure of the lead-acid battery **20**, the lithium battery **30** is composed of a plurality of cells having the above electrodes connected in series. In particular, the eighth embodiment uses lithium titanium oxide as the negative electrode active material in the lithium battery **30**.

[0183] In FIG. **11**A, FIG. **11**B, and FIG. **11**C, reference numbers **21** and **31** designate a battery cell assembly of the lead-acid battery **20** and a battery cell assembly of the lithium battery **30**, respectively, and reference numbers **22** and **32** indicate an internal resistance of the lead-acid battery **20** and the lithium battery **30**, respectively.

[0184] In the following explanation, an open circuit voltage V**0** of the battery is a voltage generated by the battery cell assemblies **21** and **31**. The terminal voltages Vd and Vc of the battery are voltages expressed by the following equation:

$$Vd=V0-Id\times R \quad \text{(F1); and}$$

$$Vc=V0+Ic\times R \quad \text{(F2),}$$

where Id is a discharging current, Ic is a charging current, R is an internal resistance of the battery, and V**0** is an open circuit voltage of the battery.

[0185] As shown in the equations (F1) and (F2), the more the internal resistance R increases, the more the terminal voltage Vd of the battery decreases when the battery discharges its capacity. Further, the more the internal resistance R increases, the more the terminal voltage Vc of the battery increases when the battery is charged.

[0186] Because the lead-acid battery **20** and the lithium battery **30** are connected in parallel, as shown in FIG. **11**A, the induced current generated in the alternator **10** flows into the battery with a low terminal voltage during charging. On the other hand, the electric energy of the battery with a high terminal voltage is supplied to the electric load **40** during discharge.

[0187] During the regenerative mode of the vehicle, it is controlled for the terminal voltage Vd (Li) of the lithium battery **30** to be many times lower than the terminal voltage Vd (Pb) of the lead-acid battery **20** in order to preferentially charge the lithium battery **30** rather than the lead-acid battery **20**. In addition, during the discharging mode, it is controlled for the terminal voltage Vd (Li) of the lithium battery **30** to be many times higher than the terminal voltage of the lead-acid battery **20** in order to preferentially discharge the electric energy from the lithium battery **30** rather than the lead-acid battery **20**, where the terminal voltage Vd (Pb) of the lead-acid battery **20** is the voltage obtained by subtracting the barrier voltage Vbar of the parasitic diode from the terminal voltage Vd (Pb).

[0188] The above control can be achieved by adjusting the open circuit voltage V**0** and the internal resistance R of each

of the lead-acid battery **20** and the lithium battery **30**. That is, the open circuit voltage V**0** of the battery can be adjusted by selecting an optimum positive electrode active material, an optimum negative electrode active material, and an optimum electrolytic solution of the lithium battery **30**.

[0189] A description will now be given of the method of setting the condition to satisfy the relationship of Vc (Li: Lithium battery)<Vc (Pb: lead-acid battery) during a regenerative energy charging and the condition to satisfy the relationship of Vd (Li)>Vd (Pb) during discharge, in the power source apparatus according to the eighth embodiment with reference to FIG. **12**A, FIG. **12**B, and FIG. **13**.

[0190] FIG. **12**A is a view showing a use range of SOC of the lead-acid battery **20** in the power source apparatus according to the eighth embodiment. FIG. **12**B is a view showing a use range of SOC of the lithium battery **30** in the power source apparatus according to the eighth embodiment.

[0191] In FIG. **12**A, the horizontal line designates the SOC of the lead-acid battery **20**, the solid line A**1** denotes a voltage characteristic line which shows a relationship between the SOC and the open circuit voltage V**0** (Pb) of the lead-acid battery **20**. As shown in FIG. **12**A, the more the SOC increases by increasing the charged energy, the more the open circuit voltage V**0** (Pb) increases.

[0192] In FIG. **12**B, the horizontal line designates the SOC of the lithium battery **30**, the solid line A**2** denotes a voltage characteristic line which shows a relationship between the SOC and the open circuit voltage V**0** (Li) of the lithium battery **30**. The more the SOC increases by increasing the charged energy, the more the open circuit voltage V**0** (Li) increases. In particular, although the SOC increases according to the increase of the charged energy, the slope which shows the voltage characteristic line of the lead-acid battery **20** becomes low during a range between inflection points P**1** and P**2** shown in FIG. **12**A.

[0193] The overcharged state and the over discharged state of each of the lead-acid battery **20** and the lithium battery **30** would cause a rapid deterioration thereof. Accordingly, it is necessary for the protection control means, previously described, to control the charging capacity to the lithium battery **30** and the lead-acid battery **20**, and the discharging capacity from the lead-acid battery **20** and the lithium battery **30**, that is, to use each of the lead-acid battery **20** and the lithium battery **30** within the use range of SOC.

[0194] The use range W**1** (Pb) of SOC of the lead-acid battery **20** is within a range of 88% to 100%. On the other hand, the use range W**2** (Li) of SOC of the lithium battery **30** is within a range of 10% to 90%. The upper limit of the use range W**2** (Li) of SOC of the lithium battery **30** is smaller than 100%, and the lower limit of the use range W**2** (Li) of SOC of the lithium battery **30** is larger than zero %.

[0195] Accordingly, the range of 0% to 88% of SOC of the lead-acid battery **20** causes the rapid deterioration. FIG. **12**B also shows an expansion of the area indicated by the dotted line shown in FIG. **12**A which indicates the use range W**1** (Pb) of SOC of the lead-acid battery **20**. The position at 0% of SOC of the lithium battery **30** indicated by the horizontal line in FIG. **12**B corresponds to the position of 88% of the use range W**1** (Pb) of SOC of the lead-acid battery **20**.

[0196] The lithium battery **30** is set in order to obtain the voltage characteristic A**2** of the lithium battery **30** which satisfies the following conditions (a'), (b'), (c'), (d'), and (e'). Specifically, it is possible to obtain the voltage characteristic A**2** which satisfies the conditions (a'), (b'), (c'), (d'), and (e') by selecting an optimum combination of the positive electrode active material, the negative electrode active material, and the solid electrolyte of the lithium battery **30**.

<Condition (a')>

[0197] There is the equal voltage point Vds at which the open circuit voltage V**0** (Pb) of the lead-acid battery **20** is equal to the open circuit voltage V**0** (Li) of the lithium battery **30** in the use range W**1** (Pb) of SOC of the lead-acid battery **20** and the use range W**2** (Li) of SOC of the lithium battery **30**. The equal voltage point Vds is present in the range between the inflection points P**1** and P**2**, where a slope of voltage characteristic line A**2** of the lithium battery **30** in this range is small. In particular, the equal voltage point at which the lithium battery **30** is equal in open circuit voltage to the lead-acid battery **20** is shifted toward the lower limit side of SOC of the lithium battery **30** by the barrier voltage Vbar (see Vds' shown in FIG. **12**B). In other words, the voltage characteristic line A**1** of the lead-acid battery **20** is shifted toward the low voltage side as indicated by the alternate long and dash line shown in FIG. **12**B.

<Condition (b')>

[0198] The open circuit voltage V**0** (Li) of the lithium battery **30** is higher than the voltage, which is obtained by subtracting the barrier voltage Vbar of the parasitic diode **51** from the open circuit voltage V**0** (Pb), at the upper limit side of the equal voltage point Vds' in the use range W**2** (Li) of SOC of the lithium battery **30**. In more detail, the equal voltage point Vds' is present at the lower limit side rather than the upper limit side (90%) of the use range W**2** (Li) of SOC of the lithium battery **30** in order to set the equal voltage point Vds' within the range of P**1** and P**2**. The slope of the voltage characteristic line A**2** of the lithium battery **30** is larger than the slope of the voltage characteristic line A**1** of the lead-acid battery **20** at the upper limit side of the equal voltage point Vds' in the use range W**2** (Li) of SOC of the lithium battery **30**.

<Condition (c')>

[0199] The terminal voltage Vc (Li) of the lithium battery **30** when the maximum charging current flows in the lithium battery **30** is smaller than the constant voltage Vreg which is controlled by the regulator **11**. In other words, the terminal voltage Vc (Li) of the lithium battery **30**, as the terminal voltage Vc (Li) (see the solid line A**3** shown in FIG. **12**B) when the lithium battery **30** is charged, at the upper limit value (90%) of the use range W**2** (Li) of SOC of the lithium battery **30**, is smaller than the constant voltage Vreg. Reference character ΔV shown in FIG. **12**B indicates a voltage drop part by the internal resistance **32** at the upper limit value (90%), which corresponds to the term (Ic×R) in the equation (F2), previously described.

<Condition (d')>

[0200] The open circuit voltage V**0** (Li) of the lithium battery **30** is lower than the open circuit voltage V**0** (Pb) of the lead-acid battery **20** in the lower limit side from the equal voltage point Vds' in the use range W**2** (Li) of SOC of the lithium battery **30**. In more detail, the equal voltage point Vds' is set to a value at the upper limit side from the lower limit side (10%) of the use range W**2** (Li) of SOC of the lithium battery **30** in order to set the equal voltage point Vds' in the range of P**1** to P**2**.

[0201] In the range in the lower limit side observed from the equal voltage point Vds' in the use range W**2** (Li) of SOC of the lithium battery **30**, the slope of the voltage characteristic

line A2 of the lithium battery **30** is larger than the slope of the voltage characteristic line A1 of the lead-acid battery **20**.

<Condition (e')>

[0202] The range in the upper limit side observed from the equal voltage point Vds' is wider than the range in the lower limit side observed from the equal voltage point Vds' in the use range W2 (Li) of SOC of the lithium battery **30**. In more detail, the equal voltage point Vds' is set to a value at the lower limit side from the intermediate point between the range of P1 and p2 in order to set the equal voltage point Vds' in the range of P1 to P2. This satisfies the relationship of Vd (Li)>Vd (Pb)−Vbar in a large part in the use range W2 (Li) of SOC of the lithium battery **30**.

[0203] FIG. **13** is a view showing a difference in I-V characteristics between the lead-acid battery **20** and the lithium battery **30** in the power source apparatus according to the first embodiment. In FIG. **13**, the solid line B1 indicates the I-V characteristic of the lead-acid battery **20**, the solid line B2 designates the I-V characteristic of the lithium battery **30**, the solid line B3 denotes the constant voltage Vreg, the horizontal line indicates the current value Ic and the current value Id, the vertical line indicates the terminal voltage Vc and the terminal voltage Vd. In FIG. **13**, the current Ic during charge is expressed by a positive value, and the current Id during discharging is expressed by a negative value.

[0204] In the I-V characteristics B1 and B2, the more the charging current Ic increases, the more the terminal voltage Vc increases (Ic×R is increased). The more the charging current Id decreases, the more the terminal voltage Vd decreases (Ic×R is decreased). That is, the change of the charging current Ic is in proportion to the change of the charging current Ic. The slope of each of the I-V characteristics B1 and B2 indicates the internal resistance R. In particular, the lithium battery **30** has the same internal resistance value R (Pb) during both charge and discharge. On the other hand, an internal resistance value R (Pb) in charging of the lead-acid battery **20** is larger than that in discharging of the lead-acid battery **20**.

[0205] In the eighth embodiment, it is set to satisfy the relationship of R (Li)<R (Pb) in charging, and to satisfy the relationship of R (Li)≦R (Pb) in discharging. It is also set to satisfy the relationship of Vd (Li)>Vd (Pb)−Vbar in discharging when the MOS FET **50'** is turned off (on the other hand, to satisfy the relationship of Vd (Li)>Vd (Pb) when the MOS FET **50'** is turned on), further to satisfy the relationship of Vc (Li)≧Vc (Pb) in a range which is close to Ic=zero during charging when the MOS FET **50'** is turned on, and to satisfy the relationship of Vc (Li)<Vc (Pb) in other part (Vc (Li)+Vbar<Vc (Pb)) when the MOS FET **50'** is turned off). The above setting control can be achieved by the condition where the internal resistance value R (Li) of the lithium battery **30** is smaller than the internal resistance value R (Pb) of the lead-acid battery **20** in charging.

[0206] The power source apparatus having the above structure according to the eighth embodiment of the present invention has the following features (B1) to (B12).

(B1) Making the voltage characteristic A2 to satisfy the condition (a') (the equal voltage point Vds is present in the range between the inflection points P1 and P2, and the equal voltage point Vds' is present when the MOS FET **50'** is turned on) generates the state without any large voltage difference between the lithium battery **30** and the lead-acid battery **20** because the terminal voltage Vd (Li) in the use range of SOC of the lithium battery **30** is approximately equal to the terminal voltage Vd (Pb) in the use range W1 of SOC of the lead-acid battery **20** during discharging, as shown in FIG. **12**A.

[0207] Therefore even if does not use any DC/DC converter (which is used in the conventional power source apparatus) and the MOS FET **50'** is turned on, it is possible to suppress a current from the lithium battery **30** to the lead-acid battery **20**, in other words, it is possible to flow a current corresponding to an extremely small capacity from the battery having a high voltage to the battery having a low voltage in the lithium battery **30** and the lead-acid battery **20**. The structure of the power source apparatus according to the eighth embodiment can thereby suppress the lithium battery **30** and the lead-acid battery **20** from being in overcharge and over discharge without using any DC/DC converter. This makes it possible to adequately reduce the manufacturing cost of the power source apparatus because of using no DC/DC converter.

(B2) Making the voltage characteristic A2 to satisfy the condition (b') (the relationship of Vd (Li)>Vd (Pb)−Vbar at the upper limit side from the equal voltage point Vds') to the voltage characteristic A1 allows the lithium battery **30** to discharge a current to the electric load **43** which requires a constant voltage, because the open circuit voltage of the lithium battery **30** is higher than that of the lead-acid battery **20**, in the state where the lithium battery **30** is charged higher rather than the capacity at the equal voltage point Vds' in the use range W2 (Li) of SOC of the lithium battery **30**.

[0208] Because this condition increases the frequency of discharging a current from the lithium battery **30** when compared with from the lead-acid battery **20** and decreases the frequency of discharging a current from the lead-acid battery **20** with a low durability to a frequent discharging, this makes it possible to suppress deterioration of the lead-acid battery **20**.

[0209] In the structure where the electric load **42** is placed in position at the lithium battery **30** side observed from the MOS FET **50'**, and the lithium battery **30** supplies the electric energy (capacity) to the electric load **42**, it is possible to preferentially discharge the electric energy from the lithium battery **30** rather than the lead-acid battery **20** when the voltage characteristic A2 is made in order to satisfy the above condition (b').

(B3) Making the voltage characteristic A2 to satisfy the condition (c') (Vc (Li)<Vreg when the maximum charging current flows) to the voltage characteristic A1 can increase the frequency of charging the lithium battery **30** rather than the lead-acid battery **20** by the following reasons.

[0210] In the case of charging the lead-acid battery **20** with the regenerative energy without using the lithium battery **30**, because the internal resistance **22** of the lead-acid battery **20** is larger than that of the lithium battery **30**, as shown in FIG. **13**, the terminal voltage Vc (Pb) of the lead-acid battery **20** reaches the constant voltage Vreg at the point when the charging current reaches the current value Ia.

[0211] On the other hand, the structure of the power source apparatus equipped with the lithium battery **30** satisfies the relationship of Vc (Li)<Vreg even when the charging current becomes the maximum value, it is possible to further charge the lithium battery **30**.

[0212] In the example shown in FIG. **13**, the terminal voltage Vc (Li) of the lithium battery **30** reaches the constant voltage Vreg when the charging current reaches the current value Ib which is larger than the maximum charging current Imax.

[0213] This will be explained in detail with reference to FIG. **14**A and FIG. **14**B. FIG. **14**A shows a current change of the lead-acid battery **20** and the lithium battery **30** in the elapse of time. FIG. **14**B shows a terminal voltage change of the lead-acid battery **20** and the lithium battery **30** in the elapse of time. In FIG. **14**A and FIG. **14**B, the solid lines C**1** and D**1** indicate the change of the charging current and the terminal voltage Vc (Pb) when the lead-acid battery **20** is charged with the regenerative electric power at the maximum charging current Imax without using the lithium battery **30**. The solid lines C**2** and D**2** in FIG. **14**A and FIG. **14**B show the change of the charging current and the change of the terminal voltage Vc (Li), respectively, when the lithium battery **30** is charged with the regenerative electric power at the maximum charging current Imax in the power source apparatus according to the eighth embodiment.

[0214] As previously explained with reference to FIG. **13**, because the relationship of Imax>Ia is satisfied when the lead-acid battery **20** is charged with the regenerative electric power, the charging current rapidly drops at the timing t**1** and converges to zero, as shown in FIG. **14**A. This state would be difficult to charge the lead-acid battery **20**. In this case, the area designated by slanting lines in FIG. **14**A corresponds to the charged capacity of the lead-acid battery **20**.

[0215] On the other hand, because the relationship of Imax≦Ib is satisfied when the lithium battery **30** is charged with the regenerative electric power, the charging current maintains the value Imax until the timing t**2** where SOC of the lithium battery **30** reaches the upper limit value (90%). This allows the lithium battery **30** to be always charged and to increase the quantity of chargeable capacity.

[0216] As described above, according to the eighth embodiment of the present invention, it is possible to increase the frequency to charge the lithium battery **30** rather than the frequency to charge the lead-acid battery **20**. This can decrease the accumulated charged capacity of the lead-acid battery **20** which has a low durability, and suppress the deterioration of the lead-acid battery **20**.

(B**4**) Making the voltage characteristic A**2** to satisfy the condition (d') (Vd (Li)<Vd (Pb) at the lower limit side from the equal voltage point Vds') to the voltage characteristic A**1** allows the lead-acid battery **20**, instead of the lithium battery **30**, to discharge the electric power to the electrical loads **40** when the lithium battery **30** preferentially discharges the electric power (capacity) to the electric load **40** and the SOC of the lithium battery **30** is lower than the equal voltage point Vds'.

[0217] Further, the current flows from the lead-acid battery **20** to the lithium battery **30**, this increases the SOC of the lithium battery **30** toward the equal voltage point Vds'. As a result, it is possible to suppress the lithium battery **30** from over discharge.

(B**5**) Making the voltage characteristic A**2** to satisfy the condition (e') to the voltage characteristic A**1** allows the range to satisfy the relationship of Vd (Li)>Vd (Pb)−Vbar based on the condition (b'), where the condition (e') satisfies that the range at the upper limit side from the equal voltage point Vds' is wider in area than the range at the lower limit side from the equal voltage point Vds'. This makes it possible to increase the frequency to preferentially discharge from the lithium battery **30** rather than from the lead-acid battery **20**. This makes it possible to increase the effect of the deterioration resistance of the lead-acid battery **20**.

(B**6**) The power source apparatus according to the eighth embodiment has is the MOS FET **50'**, previously explained. The presence of the MOS FET **50'** shifts the equal voltage point (Vds--->Vds') toward the lower limit side by the barrier voltage Vbar of the parasitic diode **51**, where the open circuit voltage of the lithium battery **30** is equal to the open circuit voltage of the lead-acid battery **20** at the equal voltage point. In other words, the voltage characteristic line A**1** of the lead-acid battery **20** is apparently shifted toward the lower limit voltage as designated by the long and dash line shown in FIG. **12**B. This makes it possible to expand the area (discharging area W**2***d*), as designated by W**2***d*', in the upper limit side observed from the equal voltage point Vds' in the use range W**2** (Li) of SOC of the lithium battery **30**, and further to increase the frequency of discharging the energy from the lithium battery **30**, rather than from the lead-acid battery **20**, to the electric load **43** which requires a constant voltage.

(B**7**) In general, the starter motor **41** requires a large electric power when it starts to operate, when compared with other electric loads **42** and **43**. Supplying a large electric power from the lithium battery **30** to the electric load such as the starter motor **41** prevents the size reduction of the lithium battery **30** which is a high price rather than that of the lead-acid battery **20**.

[0218] In the eighth embodiment, the lead-acid battery **20** supplies a large electric power to the starter motor **41** which consumes a large energy when it starts to operate in order to reduce the size and capacity of the lithium battery **30**. Still further, because the forward direction of the parasitic diode **51** in the MOS FET **50'** is set to the current direction from the lead-acid battery **20** to the lithium battery **30**, this structure can prevent the current from flowing to the starter motor **41** from the lithium battery **30**. Moreover, because the MOS FET **50'** is turned off during the operation of the starter motor **41**, it is possible to reliably prevent the current from flowing to the starter motor **41** from the lithium battery **30**.

(B**8**) When the lithium battery **30** is charged with the electric power generated by the alternator **10**, it is necessary to turn on the MOS FET **50'**. The charging current, that is, a generated current in the alternator **10** flows into the lithium battery **30** by bypassing the parasitic diode **51**. Bypassing the parasitic diode **51** can avoid the energy loss to be caused by the parasitic voltage Vbar of the parasitic diode **51**, it is possible to decrease the energy loss generated by the alternator **10**. In particular, because the MOS FET **50'** is turned on when the lithium battery **30** is charged with the regenerative energy generated in the alternator **10**, it is possible to decrease the energy loss which is caused when a large regenerative current flows through the parasitic diode **51**. This is one of superior features of the present invention.

(B**9**) When the conditions (a'), (b'), and (c'), previously described, are satisfied under the use of lithium phosphate (which serves as positive electrode material) and graphite (which serves as negative electrode material) as a combination of the positive electrode material and the negative electrode material of the lithium battery **30**, it is necessary to increase the electrode area of the lithium battery **30** because the lithium phosphate has a large internal resistance rather than other materials.

[0219] In order to avoid this drawback, the power source apparatus according to the present invention uses lithium cobalt oxide, lithium manganese oxide or lithium nickelate compound as the positive electrode material, and lithium titanium oxide as the negative electrode material. This makes

it possible to reduce the size and cost of the lithium battery **30** while satisfying the conditions (a'), (b'), and (c').

[0220] The use of lithium titanium oxide as the negative electrode material, when compared with using graphite, would cause a drawback to shift the equal voltage point Vds toward the upper limit side, where the open circuit voltage of the lithium battery **30** is equal to the open circuit voltage of the lead-acid battery **20** at the equal voltage point Vds. However, the structure of the power source apparatus according to the eighth embodiment can solve it because it has the MOS FET **50'** which is capable of shifting the equal voltage point Vds toward the lower limit side (Vds--->Vds'). Accordingly, the power source apparatus according to the present invention can solve the above drawbacks and also decrease the electrode area of the lithium battery **30**.

(B**10**) The lithium battery **30** supplies the electric capacity (energy) to the electrical loads **43** which require an approximate constant voltage or a stable voltage which is changed within the predetermined voltage range, and the lead-acid battery **20** supplies the electric power to the starter motor **41**. While the lead-acid battery **20** supplied the electric power to the starter motor **41**, the MOS FET **50'** is turned off. This makes it possible to supply to the electrical loads **43** the electric power whose voltage has a small fluctuation in voltage.

(B**11**) Adding the lithium battery **30** which satisfies the conditions (a') to (e') into an power source apparatus which is comprised of the alternator **10**, the regulator **11**, and the lead-acid battery **20** makes it possible to obtain the features of the present invention, previously described, without using any DC/DC converter. It is possible to realize the power source apparatus according to the eighth embodiment of the present invention by using a conventional power source apparatus with a less change in hardware design.

(B**12**) The power source apparatus according to the eighth embodiment uses the MOS FET **50'** which serves the open and close means and the rectifying means. Because the parasitic diode **51** (which is always formed in the MOS FET **50'**) serves as the rectifying means, it is not necessary to add any additional diode as the dedicated rectifying means.

Ninth Embodiment

[0221] A description will be given of the power source apparatus according to the ninth embodiment of the present invention with reference to FIG. **15**. FIG. **15** is a block diagram showing a schematic electric circuit of the power source apparatus according to the ninth embodiment.

[0222] The power source apparatus according to the ninth embodiment has a protection control means **600** which controls the charging capacity to and discharging capacity from the lithium battery **30** in order to avoid overcharge to the lithium battery **30** and over discharge from the lithium battery **30**.

[0223] The protection control means **600** controls the input signal which is transferred to the gate of the semiconductor switch part **52** in order to switch on-state and off-state of the MOS FET **50'**, like the open and close control means **601** disclosed in the eighth embodiment, previously described,

[0224] The protection control means **600** always receives detection signals regarding the terminal voltages Vc and Vd or the open circuit voltage V**0** (Li) of the lithium battery **30**, and a detection signal regarding the current transferred from a current detection means **61** which detects a current which flows in the lithium battery **30**.

[0225] The protection control means **600** instructs the MOS FET **50'** to open when the terminal voltage Vd of the lithium battery **30** during discharging becomes below the lower limit voltage. This control protects the lithium battery **30** from over discharge. It is possible to set the lower limit voltage based on a voltage which corresponds to the lower limit SOC value (10%) shown in FIG. **12**B.

[0226] When the terminal voltage Vc of the lithium battery **30** during charge exceeds the upper limit voltage, the protection control means **600** instructs the MOS FET **50'** to turn off (voltage rise suppression operation). This control protects the lithium battery **30** from overcharge. It is possible to set the upper limit voltage based on a voltage which corresponds to the upper limit SOC value (90%) shown in FIG. **12**B.

[0227] The protection control means **600** further outputs an instruction signal to the regulator **11** to change the constant voltage Vreg of the regulator **11** according to the voltage of the lithium battery **30**. This makes it possible to protect the lithium battery **30** from overcharge and over discharge.

[0228] That is, the protection control means **600** instructs the regulator **11** to increase the constant voltage Vreg when the voltage of the lithium battery **30** becomes lower than the lower limit value. This increases the charge capacity to the lithium battery **30** and protects the lithium battery **30** from over discharge.

[0229] On the other hand, the protection control means **600** instructs the regulator **11** to decrease the constant voltage Vreg when the voltage of the lithium battery **30** exceeds the upper limit value. This suppresses the charge capacity to the lithium battery **30**, and protects the lithium battery **30** from overcharge.

[0230] As describe above, the power source apparatus according to the ninth embodiment of the present invention reliably prevent the lithium battery **30** from over discharge because the protection control means **600** instructs the MOS FET **50'** to turn on when the terminal voltage of the lithium battery **30** becomes lower than the use range W**2** (Li) of the lithium battery **30** in addition during the supply of the electric power to the starter motor **41**.

[0231] Further, the power source apparatus according to the ninth embodiment of the present invention reliably avoids the lithium battery **30** from overcharge because the protection control means **600** instructs the MOS FET **50'** to turn off.

[0232] Because the power source apparatus according to the ninth embodiment of the present invention performs the over discharge and overcharge protection operation by changing the constant voltage Vreg by the protection control means **600**. This can precisely control the voltage of the lithium battery **30**, and this makes thereby it possible to perform the over discharge protection and the overcharge protection for the lithium battery **30** with high accuracy.

Tenth Embodiment

[0233] A description will be given of the power source apparatus according to the tenth embodiment of the present invention with reference to FIG. **16**. FIG. **16** is a block diagram showing a schematic electric circuit of the power source apparatus according to the tenth embodiment.

[0234] In the ninth embodiment, the power source apparatus has the protection control means **600** to protect the lithium battery **30** from overcharge and over discharge, previously described. In the tenth embodiment, the protection control means **600** further performs the overcharge and over dis-

charge operation for the lead-acid battery **20** in addition to the function of the ninth embodiment.

[0235] That is, the protection control means **600** instructs the regulator **11** to increase the constant voltage Vreg when the voltage of the lead-acid battery **20** becomes under the lower limit voltage. This performs the over discharge operation of the lead-acid battery **20**. On the other hand, the protection control means **600** instructs the regulator **11** to decrease the constant voltage Vreg when the voltage of the lead-acid battery **20** exceeds the upper limit voltage. This performs the overcharge operation of the lead-acid battery **20**.

[0236] As describe above, the power source apparatus according to the tenth embodiment of the present invention correctly changes the constant Vreg according to the voltage of the lead-acid battery **20**, in addition to changing the constant voltage Vreg according to the voltage of the lithium battery **30**. This can precisely control the voltage of the lead-acid battery **20** in addition to the voltage of the lithium battery **30**, and makes thereby it possible to perform the over discharge protection and the overcharge protection for the lead-acid battery **20** as well as the lithium battery **30** with high accuracy.

Eleventh Embodiment

[0237] A description will be given of the power source apparatus according to the eleventh embodiment of the present invention with reference to FIG. **17**. FIG. **17** is a block diagram showing a schematic electric circuit of the power source apparatus according to the eleventh embodiment.

[0238] The power source apparatus according to the eleventh embodiment has a plurality of the lithium batteries **30**. In the structure of the power source apparatus according to the eleventh embodiment, the electric power is supplied from the different lithium batteries **30** to various types of the electric loads **43**, **44**, and **45**, where the electrical loads **43** require an approximate constant voltage or a stable voltage which varies within the predetermined voltage range, the electric loads **44** require a large electric power, and the electric load **45** requires a voltage in order to reliably operate when an emergency occurs.

[0239] Specifically, there is an electric motor mounted to a power steering apparatus as one example of the electric load **44** which requires a large quantity of the electric power. The electric load **44** can operate with some fluctuating voltage, which is different from the electrical loads **43** which require an approximate constant voltage, previously described.

[0240] There is a communication apparatus as one example of the electric load **45** which requires a certain operation when an emergency occurs. This communication apparatus transmits abnormal information to a repair operator in a car dealership to repair the vehicle, for example, when the internal combustion engine mounted to the vehicle causes a failure and does not start to operate. Therefore it is not necessary for such a type of the electric load **44** to use a large electric power and a constant voltage.

[0241] The power source apparatus according to the eleventh embodiment shown in FIG. **17** has a plurality of the MOS FETs **50'**, the battery state detection means **70**, and the current detection means **61**, like the power source apparatus shown in FIG. **15**. That is, the MOS FETs **50'**, the battery state detection means **70**, and the current detection means **61** are placed every lithium battery **30**.

[0242] The battery state detection means **70** always detects the terminal voltages Vc, Vd or the open circuit voltage V**0** (Li) of each of the lithium batteries **30**, and a current flowing through each of the lithium batteries **30**. The battery state detection means **70** then transfers the detection signals to the protection control means **600**. The protection control means **600** receives the detection signals transferred from the battery state detection means **70**, and performs the overcharge control and the over discharge control by using the MOS FETs **50'**, and also performs the overcharge and over discharge protection control by adjusting the constant voltage Vreg, like the protection control means **600** shown in FIG. **15**.

[0243] The electric load **43**, the electric load **44**, and the electric load **45** are electrically connected to the MOS FETs **50'** at the lithium batteries **30** side, not at the lead-acid battery **20** side, observed from the MOS FETs **50'** side. This structure makes it possible to supply necessary electric power from the lithium batteries **30** to the corresponding electric loads **43**, **44**, and **45**, respectively.

[0244] As describe above, the power source apparatus according to the eleventh embodiment of the present invention has a plurality of the lithium batteries **30**. The lithium batteries **30** correspond to the electrical loads, respectively. This structure makes it possible to suppress the deterioration of each of the lithium batteries **30**. In particular, because the electric load **45** for emergency has the dedicated lithium battery **30**, it is possible to suppress the deterioration of the lithium battery **30** and to avoid the risk of not supplying the electric power to the electric load **45**.

Twelfth Embodiment

[0245] A description will be given of the power source apparatus according to the twelfth embodiment of the present invention with reference to FIG. **18**.

[0246] FIG. **18** is a block diagram mainly showing a detailed structure of the battery state detection means **70** in the power source apparatus shown in FIG. **17**.

[0247] The battery state detection means **70** is comprised of a cell voltage switch means **71**, a battery state detection control means **72**, a temperature detection means **73**, and a cell equalizing means **74**. The cell voltage switch means **71**, the battery state detection control means **72**, the temperature detection means **73**, and the cell equalizing means **74** serve as equalizing means.

[0248] The cell voltage switch means **71** detects the voltage of each of a plurality of the battery cells **33** (the twelfth embodiment shows the fifth battery cells **33**) which form the lithium battery **30**. The cell voltage switch means **71** has a function to select one of the battery cells **33** in order to detect its voltage. The cell voltage switch means **71** detects the voltage of the selected battery cell and then transfers the detected voltage value to the battery state detection control means **72**. The battery state detection control means **72** also receives a detected current value of the current which flows in the lithium battery **30**. The battery state detection control means **72** further receives a temperature value of the lithium battery **30** detected by the temperature detection means **73**.

[0249] The battery state detection control means **72** calculates the terminal voltages Vc, Vd or the open circuit voltage V**0** (Li) of the lithium battery **30** based on the voltage of each of the battery cells **33**. The battery state detection control means **72** transfers the calculated voltage, the current value of the lithium battery **30**, and the temperature value of the lithium battery **30** to the protection control means **600** through the communication interface **75**. The protection control means **600** receives the information such as the above

voltage value, the current value, and the temperature value transferred from the battery state detection control means **72**, and performs the protection control based on the received information.

[0250] The battery state detection control means **72** calculates a discharge capacity from the battery cell **33** having a high SOC, and a charge capacity for the battery cell **33** having a low SOC based on the received voltage value of the battery cell **33**. The battery state detection control means **72** outputs an equalizing instruction signal corresponding to the calculation result to the cell equalizing means **74**. When receiving the equalizing instruction signal, the cell equalizing means **74** instructs each of the battery cells **33** to discharge or charge based on the received equalizing instruction signal in order to equalize the SOC (state of charge as a residual electric energy) in each of the battery cells **33**.

[0251] As describe above, the power source apparatus according to the twelfth embodiment of the present invention can equalize the SOC in each of the battery cells **33**. This makes it possible to avoid the presence of the overcharged battery cells **33** and the battery cells having an adequate SOC during charging. Like this, it is also possible to avoid the presence of the over discharged battery cells **33** and the battery cells having an adequate SOC during discharging. The power source apparatus according to the eleventh embodiment can suppress the advance of deterioration of the lithium battery **30**.

Thirteenth Embodiment

[0252] A description will be given of the power source apparatus according to the thirteenth embodiment of the present invention with reference to FIG. **19**.

[0253] In the power source apparatus according to the twelfth embodiment shown in FIG. **18**, the cell voltage switch means **71** and the battery state detection control means **72** are formed with different circuit parts. The power source apparatus according to the thirteenth embodiment has a single IC **710** (integrated circuit as cell equalizing abnormal detection means) which is composed of the cell voltage switch means **71** and the cell equalizing means **74**.

[0254] FIG. **19** is a block diagram mainly showing a detailed structure of the battery state detection means **70** comprised of the single IC chip **710** in the power source apparatus according to the thirteenth embodiment.

[0255] The cell equalizing abnormal detection means **710** detects the voltage of each of the battery cells **33**, and calculates the charging capacity to or discharging capacity from each of the battery cells **33** based on the detected voltage. The cell equalizing abnormal detection means **710** equalizes the residual energy (or residual capacity) of each of the battery cells **33** by charging and discharging each of the battery cells **33** based on the calculation result.

[0256] The cell equalizing abnormal detection means **710** further detects whether or not the detected voltage of each of the battery cells **33** is within a predetermined normal range in order to detect the abnormality of each of the cell batteries **33**. When receiving an abnormal diagnosis instruction signal transferred from the battery state detection control means **72**, the cell equalizing abnormal detection means **710** starts to perform the abnormal detection operation previously described, and transfers the detection result to the battery state detection control means **72**.

[0257] A voltage down means **76** decreases the voltage of the lithium battery **30** to a voltage of not more than 5 V, with which a microcomputer is operable. Such a voltage signal decreased by the voltage down means **76** is transferred to the battery state detection control means **72**, and then further transferred to the protection control means **600** through the communication interface **75**.

[0258] As described above, the power source apparatus according to the thirteenth embodiment of the present invention has the effect to perform the abnormal detection operation for each of the battery cells **33** in addition to have the same effects of the power source apparatus according to the twelfth embodiment.

Fourteenth Embodiment

[0259] A description will be given of the power source apparatus according to the fourteenth embodiment of the present invention with reference to FIG. **20**.

[0260] FIG. **20** is a block diagram showing a schematic electric circuit of the power source apparatus according to the fourteenth embodiment.

[0261] As shown in FIG. **20**, the power source apparatus according to the fourteenth embodiment uses an electromagnetic relay **52**R and a diode **51***a* connected in parallel, instead of the MOS FET **50'**. In this structure, the electromagnetic relay **52**R serves as the open and close means, and the diode **51***a* serves as the rectifying means. Like the parasitic diode **51** has a barrier voltage Vbar, the diode **51***a* also has a barrier voltage Vbar.

[0262] The open and close control means **601** allows a current to flow in an electromagnetic coil **52***b* and prevents the current from flowing in the electromagnetic coil **52***b* of the electromagnetic relay **52**R in order to control the operation of the switch part **52***a* of the electromagnetic relay **52**R.

[0263] In the fourteenth embodiment, when the open and close control means **601** allows the current to flow in the electromagnetic coil **52***b*, the switch part **52***a* of the electromagnetic relay **52**R is turned on. This allows the lithium battery **30** to supply electric energy to the alternator **10** and the lead-acid battery **20**.

[0264] On the other hand, when the open and close control means **601** prevents the current from flowing in the electromagnetic coil **52***b*, the switch part **52***a* of the electromagnetic relay **52**R is turned off. This prevents the electric energy from being supplied from the lithium battery **30** to the alternator **10** and the lead-acid battery **20**.

[0265] As described above, the structure of the power source apparatus according to the fourteenth embodiment has the same effects of that of the eighth embodiment.

[0266] There are the following differences between the eighth embodiment using the MOS FET **50'** and the fourteenth embodiment using the electromagnetic relay **52**R and the diode **51***a:*

[0267] That is, because the MOS FET **50'** has the function of the open and close means and the function of the rectifying means, it is possible to decrease the size and the total number of the components which form the power source apparatus when the power source apparatus uses the MOS FET **50'** when compared with the total number of the components in the power source apparatus which uses the electromagnetic relay **52**R and the diode **51***a*, instead of the MOS FET **50'**.

[0268] Further, it is possible for the semiconductor switch **52** to have a superior response to the operation instruction (regarding the gate voltage and the exciting current) from the open and close control means **601** when compared with the

response in the power source apparatus using the electromagnetic relay **52**R and the diode **51***a*.

[0269] Further, because the control terminal (gate terminal) of the MOS FET **50'** is completely and electrically insulated from other control terminals (the source and drain terminals) of the MOS FET **50'** when the power source apparatus uses the MOS FET **50'**, it is necessary to have a high operation voltage, to be supplied to the control terminal (gate terminal), which is obtained by adding the voltage at the other terminals (source and drain terminals) and the control voltage. It requires a circuit to generate such a high operation voltage.

[0270] On the other hand, because the switch part **52***a* in the electromagnetic relay **52**R is completely and electrically insulated from the electromagnetic coil **52***b* when the power source apparatus uses the electromagnetic relay **52**R, instead of the MOS FET **50'**, this does not require any circuit to generate a high operation voltage. Because using the electromagnetic relay **52**R does not require a high operation voltage, it is possible to avoid any high voltage generating circuit to generate the high operation voltage, and it is possible for the open and close control means **601** to perform a simple on-off control.

Fifteenth Embodiment

[0271] A description will be given of the power source apparatus according to the fifteenth embodiment of the present invention with reference to FIG. **21**.

[0272] FIG. **21** is a block diagram showing a schematic electric circuit of an power source apparatus for vehicles according to the fifteenth embodiment.

[0273] The power source apparatus according to the fifteenth embodiment has the diode **51***a* (which serves as the rectifying means), but does not have the electromagnetic relay **52**R (which serves as the open and close means). The diode **51***a* and the electromagnetic relay **52**R are used in the power source apparatus according to the fourteenth embodiment.

[0274] The power source apparatus according to the fifteenth embodiment has the feature to shift the equal voltage point toward the lower limit side (Vds--->Vds') by the barrier voltage Vbar of the diode **51***a*, where the open circuit voltage of the lithium battery **30** is equal to the open circuit voltage of the lead-acid battery **20** at the agree point.

[0275] Further, because the direction of the diode **51***a* is placed in the forward direction, through which a current flows from the lead-acid battery **20** to the lithium battery **30**, this structure makes it possible to prevent the current from flowing to the starter motor **41** from the lithium battery **30**.

[0276] Because the current of the regenerative power flows into the lithium battery **30** through the diode **51***a* when the lithium battery **30** is charged with the regenerative power, the structure of the power source apparatus according to the fifteenth embodiment somewhat causes an energy loss.

(Other Modifications)

[0277] The present invention is not limited by the eighth to fifteenth embodiments previously described. It is possible to have the following structures or to selectively combine the structures of the eighth to fifteenth embodiments.

[0278] Although the eighth to thirteenth embodiments use the MOS FET **50'** which serves as the open and close means to open and close the electric connection from the lithium battery **30** to the starter motor **41**, it is possible to use a semiconductor switch (field effect transistor) such as IGBT, instead of the MOS FET **50'**, for example. Such a semiconductor switch has a superior response function and superior durability when compared with the MOS FETs **50'**. In particular, because the current in the IGBT flows in the direction which is opposite to the forward direction of the parasitic diode, this requires an additional bypass means in order to decrease an energy loss caused by the barrier voltage of the parasitic diode. On the other hand, using the MOS FET **50'** has a feature which does not require any additional bypass means.

[0279] Although each of the eighth to fifteenth embodiments uses the lithium battery **30** having the voltage characteristic A**2** composed of non-aqueous electrolyte, it is possible to use a nickel battery composed of nickel compound, instead of using the lithium battery **30**, unless it satisfies at least the conditions (a') to (c'), previously described.

[0280] In each of the eighth to fifteenth embodiments, the equal voltage point Vds' is present at the upper limit side from the lower limit value (10%) in the use range W**2** (Li) of SOC of the lithium battery **30**. However, the concept of the present invention is not limited by this. For example, it is possible to set the equal voltage point Vds' to the lower limit value.

[0281] In each of the eighth to fifteenth embodiments, the vehicles with the power source apparatus have the regenerative function. However, the concept of the present invention is not limited by this. For example, it is possible to apply the power source apparatus to vehicles without the regenerative function. By the way, because the vehicle having the regenerative function has a high frequency to charge the regenerative energy to the battery, it is possible to show the feature of the present invention to suppress the deterioration of the lead-acid battery **20** by reducing the accumulated charged-capacity in the lead-acid battery **20** with a low durability.

OTHER FEATURE OF THE PRESENT INVENTION

[0282] In the power source apparatus as another aspect of the present invention, the open circuit voltage and the internal resistance of the lead-acid battery and the open circuit voltage and the internal resistance of the secondary battery are determined so that the open circuit voltage of the secondary battery is lower than the open circuit voltage of the lead-acid battery in the lower limit side from the equal voltage point in the use range of SOC of the secondary battery.

[0283] In the state where the secondary battery is charged rather than the charged capacity which is more than the capacity at the equal voltage point within the use range of SOC of the secondary battery, the secondary battery is preferentially charged rather than the lead-acid battery. When the residual capacity of the secondary battery drops after continuous discharge, there is a probability of causing overcharge of the secondary battery. In order to avoid the over discharge of the secondary battery, because the open circuit voltage of the secondary battery is lower than the open circuit voltage of the lead-acid battery in the lower limit side observed from the equal voltage point, the lead-acid battery starts to discharge the electric capacity when the residual capacity of the secondary battery becomes lower than that indicated by the equal voltage point, and the current flows from the lead-acid battery to the secondary battery to charge the secondary battery. This increases the residual capacity of the secondary battery to that designated by the equal voltage point, and it is thereby possible to prevent the secondary battery from overcharge.

[0284] In the power source apparatus as another aspect of the present invention, the open circuit voltage and the internal resistance of the lead-acid battery and the open circuit voltage and the internal resistance of the secondary battery are determined so that an upper limit side observed from the equal voltage point is wider than the lower limit side observed from the equal voltage point in the use range of SOC of the secondary battery.

[0285] The upper range from the equal voltage point is a range where the open circuit voltage of the secondary battery becomes higher than the open circuit voltage of the lead-acid battery (condition (b'). The more the range at the upper limit side is wide, the more the frequency to preferentially discharge the electric capacity from the secondary battery is increased rather than that from the lead-acid battery. This makes it possible to more suppress the deterioration of the lead-acid battery.

[0286] The power source apparatus as another aspect of the present invention further has a voltage drop suppression means which is capable of suppress discharging from the secondary battery to a starter motor mounted to the vehicle in order to suppress a voltage drop of the secondary battery.

[0287] In general, a starter motor requires a large electric power when the internal combustion engine starts to operate. The voltage of the battery rapidly drops when it supplies electric power to the starter motor. When the voltage of the battery becomes lower than the minimum operable voltage of the electric loads such as a navigation apparatus and an audio stereo system (which require a stable constant voltage), this can cause the electric loads such as a navigation system and an audio stereo apparatus to reset their operation.

[0288] In order to avoid this, the power source apparatus according to the present invention has the voltage drop suppression means which suppresses the discharge of the secondary battery to the starter motor and suppress the voltage drop of the secondary battery. This can avoid that the voltage of the electric power to be supplied to the starter motor becomes lower than the minimum operable voltage of the electric loads which require a stable constant voltage.

[0289] The power source apparatus as another aspect of the present invention further has a protection control means which is capable of protecting the secondary battery from overcharge by limiting a charging capacity into the secondary battery. The protection control means further protects the secondary battery from over discharge by limiting a discharging capacity from the secondary battery so that the residual capacity of the secondary battery is within the use range of the secondary battery. In the power source apparatus according to the present invention, the protection control means limits the charging capacity to the secondary battery or the discharging capacity from the secondary battery by using the voltage drop suppression means.

[0290] This makes it possible to prevent overcharge to the secondary battery and over discharge from the secondary battery during the time period other than the time to drive the starter motor by the voltage drop suppression means capable of suppressing the discharge from the secondary battery to the starter motor. For example, it is possible for the voltage drop suppression means to prevent the charging capacity to the secondary battery, and to avoid the overcharge of the secondary battery when the open circuit voltage of the secondary battery exceeds a threshold value.

[0291] In addition, it is possible for the voltage drop suppression means to decrease the discharging capacity from the secondary battery when the open circuit voltage of the secondary battery becomes below the threshold value.

[0292] The power source apparatus according to another aspect of the present invention further has a protection control means which is capable of protecting the secondary battery from overcharge by controlling a charge capacity into the secondary battery and so that the residual capacity of the secondary battery is within the use range of the secondary battery. In the power source apparatus, the protection control means outputs an instruction signal which instructs the constant voltage control means to decrease the set voltage in order to control the charge capacity to the secondary battery.

[0293] This makes it possible for the constant voltage control means to prevent the secondary battery from overcharge and over discharge. For example, it is possible to decrease the charging capacity to the secondary battery by supplying the instruction signal to the constant voltage control means in order to decrease the set voltage when the open circuit voltage of the secondary battery exceeds the threshold value.

[0294] In addition, it is possible to decrease the discharged capacity from the secondary battery by supplying the instruction signal to the constant voltage control means in order to increase the set voltage when the open circuit voltage of the secondary battery becomes below the threshold value.

[0295] In the power source apparatus as another aspect of the present invention, the voltage drop suppression means is a switch means to open and close an electric connection between the secondary battery and the starter motor, and the switch means opens the electric connection between the secondary battery and the starter motor when the lead-acid battery supplies the electric capacity to the starter motor.

[0296] Because this completely prevents the secondary battery from discharging to the starter motor, it is possible to avoid the voltage drop of the secondary battery when the starter motor starts to operation.

[0297] In the power source apparatus as another aspect of the present invention, the switch means is one of a manual switch, an electromagnetic relay, and a semiconductor switch.

[0298] In the power source apparatus as another aspect of the present invention, the secondary battery is a battery of non-aqueous electrolyte. This makes it possible to easily set the open circuit voltage and the internal resistance of the secondary battery with high energy density in order to satisfy the conditions (a), (b), and (c), previously described, when compared with the case of using a nickel battery.

[0299] In the power source apparatus as another aspect of the present invention, the secondary battery is comprised of a positive electrode made of positive electrode active material, a negative electrode made of negative electrode active material, and an electrolyte, and the negative electrode active material is made of one of carbon, graphite, lithium-doped carbon or graphite, lithium titanium oxide, silicon-containing alloy, and tin-containing alloy, and the positive electrode active material is lithium metal composite oxide and/or adsorbent material (for example, activated carbon) as the positive electrode.

[0300] Thus, in order to satisfy the conditions (a), (b), and (c), previously described, it is possible to easily set the open circuit voltage and the internal resistance of the secondary battery with high energy density by optimally selecting the positive electrode active material and the negative electrode active material capable of occluding and discharging lithium ions

[0301] In the power source apparatus as another aspect of the present invention, the positive electrode active material is made of lithium iron phosphate. Thus, in order to satisfy the conditions (a), (b), and (c), previously described, it is possible to easily set the open circuit voltage and the internal resistance of the secondary battery having a high energy density by selecting and using lithium iron phosphate as the positive electrode active material in the secondary battery.

[0302] In the power source apparatus as another aspect of the present invention, the secondary battery is comprised of a plurality of battery cells electrically connected in series, and further comprising cell equalizing means capable of detecting a voltage of each of the battery cells and of equalizing a residual capacity of each of the battery cells based on the detected voltage of each of the battery cells.

[0303] When the secondary battery is charged and each of the battery cells has a different residual capacity, it would cause for the terminal voltage of the secondary battery to rapidly reach the set voltage. When reaching the set voltage, the battery cell having a high residual capacity exceeds the upper limit of the use range, and on the other hand, the battery cell having a less residual capacity does not reach the upper limit of the use range. This state promotes deterioration of the secondary battery.

[0304] Like the charging operation, when the secondary battery discharges and each of the battery cells has a different residual capacity, the battery cell having a less residual capacity becomes over discharge, and the battery cell having a high residual capacity falls to the state of not reaching the lower limit of the use range. Accordingly, this state also promotes deterioration of the secondary battery.

[0305] In the power source apparatus according to the present invention, the cell equalizing means monitors the voltage of each of the battery cells and equalizes the residual capacity of each of the battery cells. Accordingly, this can avoid the state in which the over charged battery cell and the battery cell having an extra ability to charge the capacity are simultaneously present when the secondary battery is charged. Similarly, this can also avoid the state in which the over discharged battery cell and the battery cell having an extra ability to charge the capacity are simultaneously present when the secondary battery is discharged. This makes it possible to more suppress the deterioration of the secondary battery.

[0306] The power source apparatus as another aspect of the present invention, further has an open and close means and an open and close control means. The open and close control means is connected in parallel to the rectifying means, and is capable of electrically connecting the alternator with the secondary battery and disconnecting the alternator from the secondary battery. The open and close control means instructs the open and close means to close the electrical connection between the alternator and the secondary battery when the secondary battery is charged with electric power generated by the alternator. In addition, the open and close control means instructs the open and close means to open the electrical connection between the alternator and the secondary battery when the rectifying means performs the rectifying operation.

[0307] When the power source apparatus does not have the open and close means, a thermal energy of energy loss (which corresponds to the power of "a barrier voltage×a current of generated power") occurs when the current of the generated power flows through the rectifying means when the current of the electric power generated in the alternator flows into the secondary battery to charge the secondary battery. In particular, when the alternator generates the electric power by the regenerative energy, a large current flows into the secondary battery, and the energy loss is thereby extremely increased.

[0308] In order to solve the above problem, because the open and close means starts to operate when the alternator supplies the electric energy to the secondary battery in order to charge the secondary battery, the current of the generated electric power flows into the secondary battery by bypassing the rectifying means. This can eliminate the energy loss caused by the barrier voltage in the rectifying means, it is possible to decrease the energy loss of the electric power generated by the alternator.

[0309] In a case other than the case to charge the secondary battery, because the open and close means is turned off, it is possible for the power source apparatus according to the present invention to have the following effects (x**1**) and (x**2**): (x**1**) the effect to expand the discharge area W2d' by shifting the equal voltage point Vds' toward the lower limit side which is achieved by the rectifying means; and (x**2**) the effect to prevent the current which flows from the secondary battery to the electric load which requires a large electric power such as a starter motor.

[0310] In the power source apparatus as another aspect of the present invention, the open and close means is composed of a semiconductor switch, and the rectifying means is composed of a parasitic diode of the semiconductor switch (see FIG. **11**A, FIG. **11**B, and FIG. **11**C).

[0311] Further, In the power source apparatus as another aspect of the present invention, the open and close means is composed of an electromagnetic relay which is connected in parallel with the rectifying means (see FIG. **20**).

[0312] That is, because the open and close means and the rectifying means are realized by using the single semiconductor electric part (semiconductor switch shown in FIG. **11**A, FIG. **11**B, and FIG. **11**C), it is possible to decrease the total number of components and to reduce the entire size of the power source apparatus when compared with the case where the open and close means and the rectifying means are formed with different components.

[0313] Still further, it is possible to increase the response characteristic to the instruction to be transferred to the open and close means when compared with the case where the open and close means is composed of an electromagnetic relay.

[0314] However, when the open and close means is composed of such a semiconductor switch, because the control terminal of the semiconductor switch (for example, a gate terminal of a MOS FET) is completely and electrically insulated from other control terminals of the semiconductor switch (source and drain terminals of the MOS FET), it is necessary to have a high operation voltage, to be supplied to the control terminal (gate terminal), which is obtained by adding the voltage at the other terminals (source and drain terminals) and the control voltage. It requires a circuit to generate such a high operation voltage.

[0315] On the other hand, because the switch part of an electromagnetic relay is completely and electrically insulated from the electromagnetic coil when the power source apparatus uses the electromagnetic relay, instead of the semiconductor switch (such as a MOS FET), this does not require any circuit to generate a high operation voltage. Because using the electromagnetic relay does not require a high operation voltage, it is possible to avoid any high voltage generating circuit

to generate the high operation voltage, and it is possible for the open and close control means to perform a simple on-off control.

[0316] It is preferable to use a MOS FET as the semiconductor based on the following reasons. That is, a MOS FET essentially has a parasitic diode therein. This parasitic diode serves as a rectifying means (see the parasitic diode **51** shown in FIG. **11**A, FIG. **11**B, and FIG. **11**C, for example.) In other words, the internal circuit of the MOS FET is equivalent to the circuit composed of the open and close means (semiconductor switch part **52**) and the rectifying means which are connected in parallel. Accordingly, incorporating the MOS FET with the power source apparatus makes it possible for the parasitic diode, which is always formed in the MOS FET, to serve as the rectifying means without any additional diode (as the rectifying means).

[0317] In the power source apparatus as another aspect of the present invention, the open circuit voltage and the internal resistance of the lead-acid battery and the open circuit voltage and the internal resistance of the secondary battery are determined so that the open circuit voltage of the secondary battery is lower than the subtracted voltage of the lead-acid battery at the lower limit side from the equal voltage point in the use range of SOC of the secondary battery, where the subtracted voltage of the lead-acid battery is obtained by subtracting the barrier voltage of the rectifying means from the open circuit voltage of the lead-acid battery.

[0318] As previously described, the secondary battery more discharges electric power rather than that from the lead-acid battery when the secondary battery is charged rather than the charged capacity at the equal voltage point in the use range of SOC of the secondary battery. When continuing the discharge, the secondary battery would enter the over discharge state.

[0319] According to the present invention, because the open circuit voltage of the secondary battery becomes lower than the subtracted voltage in the lower limit side from the equal voltage point, the lead-acid battery starts to discharge, and the current flows from the lead-acid battery to the secondary battery when the SOC of the secondary battery becomes lower than the voltage indicated by the equal voltage point, where the subtracted voltage is obtained by subtracting the barrier voltage from the open circuit voltage V**0** (Pb) of the lead-acid battery. This can prevent the secondary battery from over discharge.

[0320] In the power source apparatus as another aspect of the present invention, the open circuit voltage and the internal resistance of the lead-acid battery and the open circuit voltage and the internal resistance of the secondary battery are determined so that a range at the upper limit side from the equal voltage point in the use range of SOC of the secondary battery is wider than a lower part at the lower limit side from the equal voltage point in the use range of SOC of the secondary battery.

[0321] The upper range from the equal voltage point is a range (which satisfies the condition (b), previously described) where the open circuit voltage of the secondary battery is higher than the subtracted voltage which is obtained by subtracting the barrier voltage from the open circuit voltage V**0** (Pb) of the lead-acid battery. Therefore the more the upper range from the equal voltage point is expanded, the more the frequency to preferentially discharge from the secondary battery is increased. This makes it possible to increase the effect to suppress the deterioration of the lead-acid battery.

[0322] The power source apparatus as another aspect of the present invention further has the protection control means which is capable of protecting the secondary battery from overcharge by limiting a charging capacity to the secondary battery, and of protecting the secondary battery from over discharge by limiting a discharging capacity from the secondary battery so that the residual capacity of the secondary battery is within the use range of the secondary battery. In the power source apparatus, the protection control means limits the charging capacity to the secondary battery or the discharging capacity from the secondary battery by using the voltage drop suppression means.

[0323] For example, when the terminal voltage of the secondary battery becomes more than a threshold value during charging with the regenerative energy, turning off the open and close means can decreases the charging capacity to the secondary battery. This can prevent the secondary battery from overcharge. Further, when the open circuit voltage of the secondary battery becomes more than the threshold value by the overcharge when the charging is completed, because the open circuit voltage of the lead-acid battery is lower than the open circuit voltage of the secondary battery, turning on the open and close means can discharge from the secondary battery. Accordingly, it is possible to decrease the charging capacity to the secondary battery which is in the overcharge state, and this can prevent the secondary battery from overcharge.

[0324] When the open circuit voltage of the secondary battery becomes lower than the threshold value, the open circuit voltage is always lower than the subtracted voltage which is obtained by subtracting the barrier voltage from the open circuit voltage of the lead-acid battery. Performing the open and close means in addition to the charging to the secondary battery from the lead-acid battery through the rectifying means can increase the charging capacity from the lead-acid battery to the secondary battery and thereby prevent the secondary battery from over discharge.

[0325] The power source apparatus as another aspect of the present invention further has a protection control means which is capable of protecting the secondary battery from overcharge by controlling a charging capacity to the secondary battery and protecting the secondary battery from over discharge by controlling a discharging capacity from the secondary battery so that the residual capacity of the secondary battery is within the use range of the secondary battery. In the power source apparatus, the protection control means outputs an instruction signal which instructs the constant voltage control means to decrease the set voltage in order to control the charging capacity to the secondary battery.

[0326] It is possible to prevent the secondary battery from overcharge and over discharge by using the constant voltage control means. For example, when the open circuit voltage of the secondary battery becomes more than the threshold value, outputting the instruction signal to the constant voltage control means to decrease the set voltage can decrease the threshold value, and further suppress the secondary battery from overcharge.

[0327] In addition, when the open circuit voltage of the secondary battery becomes less than the threshold value, outputting the instruction signal to the constant voltage control means to increase the set voltage can increase the threshold value, and further suppress the secondary battery from over discharge.

[0328] In the power source apparatus as another aspect of the present invention, the secondary battery is a battery of non-aqueous electrolyte. This makes it possible for the secondary battery to have a high output power density and a high energy density, and to easily set the open circuit voltage and the internal resistance of the secondary battery in order to satisfy the conditions (a'), (b'), and (c'), when compared with the case using a nickel battery as the secondary battery.

[0329] In the power source apparatus as another aspect of the present invention, the secondary battery is comprised of a positive electrode made of positive electrode active material, a negative electrode made of negative electrode active material, and an electrolyte, the negative electrode active material is one of carbon, graphite, lithium-doped carbon or graphite, lithium titanium oxide, silicon-containing alloy, and tin-containing alloy, and the positive electrode active material is lithium metal composite oxide or activated carbon. Thus, selecting an optimum positive electrode active material and an optimum negative electrode active material to absorb and discharge lithium ions in the secondary battery can easily set the open circuit voltage and the internal resistance of the secondary battery in order to satisfy the conditions (a'), (b'), and (c'), previously described.

[0330] In the power source apparatus as another aspect of the present invention, the negative electrode active material is made of lithium titanium oxide. Selecting lithium titanium oxide as the negative electrode active material in the secondary battery can easily set the open circuit voltage and the internal resistance in order to satisfy the conditions (a'), (b'), and (c'), previously described.

[0331] Because the internal resistance of the positive electrode active material the following combination is larger than that of another active material, it must be required to somewhat increase the electrode area of the positive electrode in order to satisfy the conditions (a'), (b'), and (c'), previously described, where the combination is composed of lithium iron phosphate ($LiFePO_4$) as the positive electrode active material and graphite as the negative electrode active material.

[0332] We provide one improved combination of lithium titanium oxide as the negative electrode active material and an usually used positive electrode active material such as (lithium, lithium manganese oxide, and lithium nickelate compound. This combination, that is, using lithium titanium oxide as the negative electrode active material, makes it possible to reduce the electrode area, the size of the secondary battery, and the manufacturing cost while satisfying the conditions (a'), (b'), and (c'), previously described.

[0333] In the above viewpoint, the secondary battery in the power source apparatus according to the present invention uses lithium titanium oxide as the negative electrode active material. As described above, this makes it possible to downsize the secondary battery and to reduce the manufacturing cost of the power source apparatus because the electrode area of the secondary battery can be decreased.

[0334] Although the use of lithium titanium oxide as the negative electrode material in the secondary battery (lithium battery), when compared with using graphite, would cause a drawback to shift the equal voltage point Vds toward the upper limit side, where the open circuit voltage of the secondary battery is equal to the open circuit voltage of the lead-acid battery at the equal voltage point Vds. However, the structure of the power source apparatus according to the second aspect of the present invention can eliminate such a drawback because it has the MOS FET **50** capable of shifting the equal voltage point Vds toward the lower limit side (Vds--->Vds'). Accordingly, the poser source apparatus according to the second aspect of the present invention can solve the above drawback and also decrease the electrode area of the secondary battery (lithium battery).

[0335] In the power source apparatus as another aspect of the present invention, the secondary battery is comprised of a plurality of battery cells. Those battery cells are electrically connected in series. The power source apparatus as another aspect of the present invention further has a cell equalizing means capable of detecting a voltage of each of the battery cells and of equalizing a residual capacity of each of the battery cells based on the detected voltage of each of the battery cells.

[0336] When each of the battery cells has a different charged capacity, the terminal voltage of the secondary battery rapidly reaches the set voltage on a charging step. When the terminal voltage of the secondary battery reaches the set voltage, the battery cell having a high charged capacity before the charging step exceeds the capacity at the upper limit of the use range of SOC of the secondary battery, and on the other hand, a battery cell having a low charged capacity before the charging step does not reach (becomes less than) the upper limit when terminal voltage of the secondary battery reaches the set voltage. This promotes the deterioration of the secondary battery.

[0337] From the above viewpoint, the power source apparatus according to the second aspect of the present invention has the cell equalizing means which is capable of detecting a voltage of each of the battery cells and of equalizing a residual capacity of each of the battery cells based on the detected voltage of each of the battery cells. It is thereby possible to suppress avoid a mixing state of the battery cells of different charged capacities, overcharged and less charged battery cells, when the secondary battery is charged. Similarly, it is thereby possible to suppress a mixing state of the battery cells of different charged capacities when the secondary battery is discharged.

[0338] In the structure of the power source apparatus according to the present invention, the secondary battery supplies the electric power to the electric loads which require a stable constant voltage or a stable voltage which is fluctuated within the predetermined voltage range. The rectifying means or the open and close means prevent the electric connection between the secondary battery with the starter motor which required a large electric power when it starts to operate in order to avoid the rapid voltage drop in the secondary battery.

[0339] In general, the starter motor requires a large electric power rather than other electric loads mounted to vehicles. When the battery supplies such a large electric power to the starter motor when the starter motor starts to operate, the terminal voltage of the battery rapidly drops. When the battery supplies the decreased voltage of the electric power voltage, after supplying a large electric power to the starter motor, to usual electrical loads such as a defroster heater for a rear window, it would reset the operation of the usual electric loads such as the navigation system and/or the audio system. This would cause various problems in operation. In order to avoid this, the power source apparatus according to the present invention can avoid the secondary battery discharging to the starter motor in order to avoid any rapid voltage drop in

the secondary battery and to supply a stable voltage to the usual electric loads such as the navigation system and the audio system.

[0340] While specific embodiments of the present invention have been described in detail, it will be appreciated by those skilled in the art that various modifications and alternatives to those details could be developed in light of the overall teachings of the disclosure. Accordingly, the particular arrangements disclosed are meant to be illustrative only and not limited to the scope of the present invention which is to be given the full breadth of the following claims and all equivalents thereof.

What is claimed is:

1. A power source apparatus which is mounted to a vehicle with an alternator and a constant voltage control means capable of adjusting a voltage of electric power generated by the alternator to a set voltage, the power source apparatus comprising:

a lead-acid battery electrically connected to an alternator; and

a secondary battery, electrically connected in parallel to the lead-acid battery, having an output power density and an energy density which is higher than an output power density and an energy density of the lead-acid battery,

wherein an open circuit voltage and an internal resistance of the lead-acid battery and an open circuit voltage and an internal resistance of the secondary battery are determined in order to satisfy the following conditions (a), (b), and (c):

(a) an equal voltage point, at which the open circuit voltage of the lead-acid battery becomes equal to the open circuit voltage of the secondary battery, is present in a use range of state of charge (SOC) of the lead-acid battery and a use range of SOC of the secondary battery;

(b) the open circuit voltage of the secondary battery is higher than the open circuit voltage of the lead-acid battery at an upper limit side from the equal voltage point in the use range of SOC of the secondary battery; and

(c) a terminal voltage of the secondary battery when a maximum charging current flows in the secondary battery is not more than the set voltage which is set by the constant voltage control means.

2. The power source apparatus according to claim **1**, wherein the open circuit voltage and the internal resistance of the lead-acid battery and the open circuit voltage and the internal resistance of the secondary battery are determined so that the open circuit voltage of the secondary battery is lower than the open circuit voltage of the lead-acid battery at the lower limit side from the equal voltage point in the use range of SOC of the secondary battery.

3. The power source apparatus according to claim **2**, wherein the open circuit voltage and the internal resistance of the lead-acid battery and the open circuit voltage and the internal resistance of the secondary battery are determined so that an upper part at the upper limit side from the equal voltage point is wider than a lower part at the lower limit side from the equal voltage point in the use range of SOC of the secondary battery.

4. The power source apparatus according to claim **1**, further comprising voltage drop suppression means capable of suppressing discharge from the secondary battery to a starter motor mounted to the vehicle in order to suppress a voltage drop of the secondary battery.

5. The power source apparatus according to claim **4**, further comprising protection control means capable of protecting the secondary battery from overcharge by limiting a charging capacity to the secondary battery and of protecting the secondary battery from over discharge by limiting a discharging capacity from the secondary battery so that the residual capacity of the secondary battery is within the use range of the secondary battery,

wherein the protection control means limits the charging capacity to the secondary battery or the discharging capacity from the secondary battery by using the voltage drop suppression means.

6. The power source apparatus according to claim **1**, further comprising protection control means capable of protecting the secondary battery from overcharge by controlling a charging capacity into the secondary battery and protecting the secondary battery from over discharge by controlling a discharging capacity to the secondary battery so that the residual capacity of the secondary battery is within the use range of the secondary battery,

wherein the protection control means outputs an instruction signal which instructs the constant voltage control means to decrease the set voltage in order to control the charging capacity to the secondary battery.

7. The power source apparatus according to claim **4**, wherein the voltage drop suppression means is a switch means to open and close an electric connection between the secondary battery and the starter motor, and the switch means opens the electric connection between the secondary battery and the starter motor when the lead-acid battery supplies the electric capacity to the starter motor.

8. The power source apparatus according to claim **7**, wherein the switch means is one of a manual switch, an electromagnetic relay, and a semiconductor switch.

9. The power source apparatus according to claim **1**, wherein the secondary battery is a battery of non-aqueous electrolyte.

10. The power source apparatus according to claim **9**, wherein the secondary battery is comprised of a positive electrode made of positive electrode active material, a negative electrode made of negative electrode active material, and an electrolyte, the negative electrode active material is one of carbon, graphite, lithium-doped carbon or graphite, lithium titanium oxide, silicon-containing alloy, and tin-containing alloy, and the positive electrode active material is lithium metal composite oxide or activated carbon.

11. The power source apparatus according to claim **10**, wherein the positive electrode active material is made of lithium iron phosphate.

12. The power source apparatus according to claim **1**, wherein

the secondary battery is comprised of a plurality of battery cells electrically connected in series, and further comprising cell equalizing means capable of detecting a voltage of each of the battery cells and of equalizing a residual capacity of each of the battery cells based on the detected voltage of each of the battery cells.

13. The power source apparatus according to claim **1**, wherein the power source apparatus is mounted to a vehicle with an idling stop function capable of automatically stopping and restarting the operation of the internal combustion engine.

14. A power source apparatus which is mounted to a vehicle with an alternator and a constant voltage control

means capable of adjusting a voltage of electric power generated by the alternator to a set voltage, the power source apparatus comprising:

a lead-acid battery electrically connected to an alternator;

a secondary battery, electrically connected in parallel to the lead-acid battery, is higher in output density or energy density than the lead-acid battery; and

rectifying means placed between the lead-acid battery and the secondary battery so that a forward current direction of the rectifying means becomes a direction from the lead-acid battery to the secondary battery, and the rectifying means having a barrier voltage to the current flowing in the forward direction through the rectifying means,

wherein an open circuit voltage and an internal resistance of the lead-acid battery and an open circuit voltage and an internal resistance of the secondary battery are determined in order to satisfy the following conditions (a'), (b'), and (c'):

(a') an equal voltage point, at which the open circuit voltage of the secondary battery is equal to a subtracted voltage obtained by subtracting the barrier voltage of the rectifying means from the open circuit voltage of the lead-acid battery, is present in a use range of state of charge (SOC) of the lead-acid battery and a use range of SOC of the secondary battery;

(b') the open circuit voltage of the secondary battery is higher than the subtracted voltage of the lead-acid battery at an upper limit side from the equal voltage point in the use range of SOC of the secondary battery; and

(c') a terminal voltage of the secondary battery when a maximum charging current flows in the secondary battery is not more than the set voltage which is set by the constant voltage control means.

15. The power source apparatus according to claim **14**, further comprising:

open and close means, connected in parallel to the rectifying means, capable of electrically connecting the alternator with the secondary battery and disconnecting the alternator from the secondary battery; and

open and close control means to instruct the open and close means to close the electrical connection between the alternator and the secondary battery when the secondary battery is charged with electric power generated by the alternator, and to instruct the open and close means to open the electrical connection between the alternator and the secondary battery when the rectifying means performs the rectifying operation.

16. The power source apparatus according to claim **15**, wherein the open and close means is composed of a semiconductor switch, and the rectifying means is composed of a parasitic diode of the semiconductor switch.

17. The power source apparatus according to claim **15**, wherein the open and close means is composed of an electromagnetic relay which is connected in parallel to the rectifying means.

18. The power source apparatus according to claim **14**, wherein the open circuit voltage and the internal resistance of the lead-acid battery and the open circuit voltage and the internal resistance of the secondary battery are determined so that the open circuit voltage of the secondary battery is lower than the subtracted voltage of the lead-acid battery at the lower limit side from the equal voltage point in the use range of SOC of the secondary battery, where the subtracted voltage of the lead-acid battery is obtained by subtracting the barrier voltage of the rectifying means from the open circuit voltage of the lead-acid battery.

19. The power source apparatus according to claim **18**, wherein the open circuit voltage and the internal resistance of the lead-acid battery and the open circuit voltage and the internal resistance of the secondary battery are determined so that a range at the upper limit side from the equal voltage point in the use range of SOC of the secondary battery is wider than a lower part at the lower limit side from the equal voltage point in the use range of SOC of the secondary battery.

20. The power source apparatus according to claim **15**, further comprising protection control means capable of protecting the secondary battery from overcharge by limiting a charging capacity to the secondary battery and of protecting the secondary battery from over discharge by limiting a discharging capacity from the secondary battery so that the residual capacity of the secondary battery is within the use range of the secondary battery,

wherein the protection control means limits the charging capacity to the secondary battery or the discharging capacity from the secondary battery by using the voltage drop suppression means.

21. The power source apparatus according to claim **15**, further comprising protection control means capable of protecting the secondary battery from overcharge by controlling a charging capacity to the secondary battery and protecting the secondary battery from over discharge by controlling a discharging capacity from the secondary battery so that the residual capacity of the secondary battery is within the use range of the secondary battery,

wherein the protection control means outputs an instruction signal which instructs the constant voltage control means to decrease the set voltage in order to control the charging capacity to the secondary battery.

22. The power source apparatus according to claim **14**, wherein the secondary battery is a battery of non-aqueous electrolyte.

23. The power source apparatus according to claim **22**, wherein the secondary battery is comprised of a positive electrode made of positive electrode active material, a negative electrode made of negative electrode active material, and an electrolyte, the negative electrode active material is one of carbon, graphite, lithium-doped carbon or graphite, lithium titanium oxide, silicon-containing alloy, and tin-containing alloy, and the positive electrode active material is lithium metal composite oxide or activated carbon.

24. The power source apparatus according to claim **23**, wherein the negative electrode active material is made of lithium titanium oxide.

25. The power source apparatus according to claim **14**, wherein the secondary battery is comprised of a plurality of battery cells electrically connected in series, and further comprising cell equalizing means capable of detecting a voltage of each of the battery cells and of equalizing a residual capacity of each of the battery cells based on the detected voltage of each of the battery cells.

26. The power source apparatus according to claim **14**, wherein the power source apparatus is mounted to a vehicle with an idle stop function capable of automatically stopping and restarting the operation of the internal combustion engine.

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