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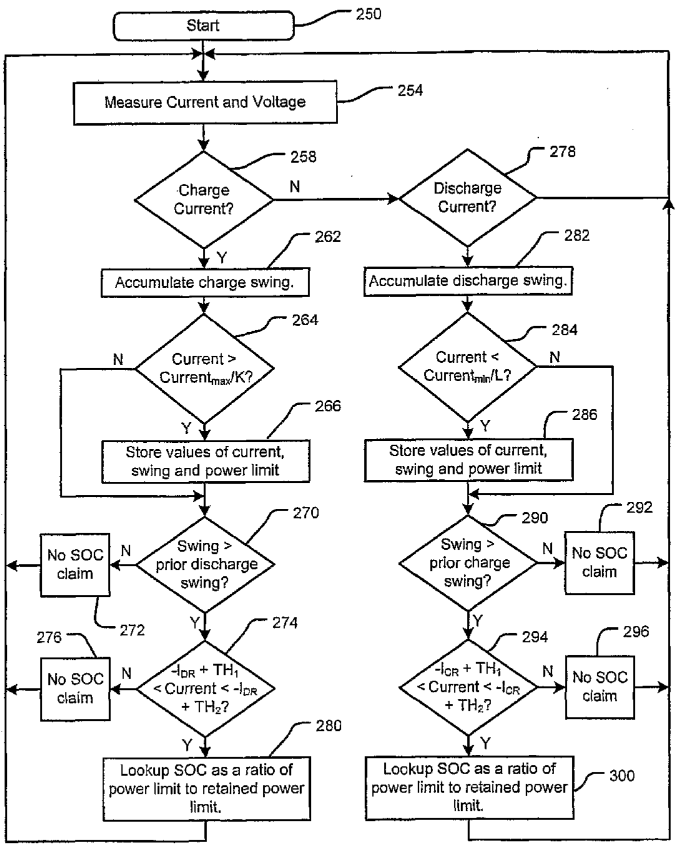
(54) Title: BATTERY STATE OF CHARGE ESTIMATOR



(57) Abstract: A battery control module for a battery system comprises a voltage measuring module that measures battery voltage and a current measuring module that measures battery current. A state of charge (SOC) module that communicates with the current and voltage measuring modules and that estimates SOC.

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BATTERY STATE OF CHARGE ESTIMATOR

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 60/559,921, filed on April 6, 2004, U.S. Patent Application Serial No. 11/081,979 filed on March 16, 2005, U.S. Patent Application Serial No. 11/081,980 filed on March 16, 2005 and Serial No. 11/081,978 filed on March 16, 2005. The disclosures of the above applications are incorporated herein by reference in their entirety.

FIELD OF THE INVENTION

[0002] The present invention relates to battery systems, and more *particularly to state of charge tracking systems for battery systems.*

BACKGROUND OF THE INVENTION

[0003] Battery systems may be used to provide power in a wide variety applications. Exemplary transportation applications include hybrid electric vehicles (HEV), electric vehicles (EV), Heavy Duty Vehicles (HDV) and Vehicles with 42-volt electrical systems. Exemplary stationary applications include backup power for telecommunications systems, uninterruptible power supplies (UPS), and distributed power generation applications.

[0004] Examples of the types of batteries that are used include nickel metal hydride (NiMH) batteries, lead-acid batteries and other types of batteries. A battery system may include a plurality of battery subpacks that are connected in series and/or in parallel. The battery subpacks may include a plurality of batteries that are connected in parallel and/or in series.

[0005] The maximum and/or minimum power that can be delivered by batteries, battery subpacks and/or battery systems varies over time as a function of a temperature of the batteries, battery state of charge (SOC) and/or battery age. Therefore, accurate estimation of battery SOC is important to the determination of maximum and minimum power.

[0006] The energy that can be provided by or sourced to a battery is a function of state of charge. When the battery state of charge is known and targeted during operation, an optimal ratio can maintained between the ability to accept amp-hours in charge and to provide amp-hours in discharge. As this optimal ratio can be maintained, there is a reduced need to oversize the battery system to assure adequate power assist and regeneration energy.

[0007] For example in transportation applications such as HEVs or EVs, it is important for the powertrain control system to know the maximum and/or minimum power limit of the battery system. The powertrain control system typically receives an input request for power from an accelerator pedal. The powertrain control system interprets the request for power relative to the maximum power limit of the battery system (when the battery system is powering the wheels). The minimum power limits may be relevant during recharging and/or regenerative braking. Exceeding the maximum and/or minimum power limits may damage the batteries and/or the battery system and/or reduce the operational life of the batteries and/or the battery system. Being able to estimate the battery SOC accurately has been somewhat problematic – particularly when the battery system includes NiMH batteries.

SUMMARY OF THE INVENTION

[0008] A battery control module for a battery system comprises a voltage measuring module that measures battery voltage and a current measuring module that measures battery current. A state of charge (SOC) module communicates with the current and voltage measuring modules and estimates SOC based on relaxation voltage.

[0009] In other features, the SOC module enables the SOC estimation when a qualified charge swing follows a discharge swing and relaxation. The SOC module enables the SOC estimation when a qualified discharge swing follows a charge swing and relaxation. The SOC module accumulates charge swing during charging and identifies the qualified charge swing when the accumulated charge swing is within a charge swing window. The SOC module accumulates discharge swing during discharging and identifies the qualified discharge swing when the accumulated discharge swing is within a discharge swing window.

[0010] In still other features, the SOC module monitors rest periods during which the battery is neither charging nor discharging. The SOC module enables the SOC estimation when the rest period is greater than a threshold. The SOC module enables SOC estimation during charging when a first period between the qualified charge swing and the prior discharge swing and relaxation is less than a predetermined allowed time. The SOC module enables SOC estimation during charging when a second period between the qualified discharge swing and the prior charge swing and relaxation is less than a predetermined allowed time.

[0011] A battery control module for a battery system comprises a voltage measuring module that measures battery voltage and a current measuring module that measures battery current. A state of charge (SOC) module communicates with said current and voltage measuring modules and estimates SOC based on a power limit ratio.

[0012] In other features, the SOC module accumulates charge swing during charging, identifies maximum current during the charge swing and stores the maximum charge current, a charge swing and a charge power limit. The SOC module accumulates discharge swing during discharging, identifies maximum current during the discharge swing and stores the maximum discharge current, a discharge swing and a discharge power limit. The SOC module determines whether the charge swing is greater than a negative of a retained discharge swing.

[0013] In other features, the SOC module determines whether the maximum current is approximately equal to a negative of a retained discharge current. The SOC module includes a lookup table. The SOC module looks up the SOC as a function of the power limit ratio when the charge swing is greater than the retained discharge swing and the maximum current is approximately equal to the negative of the retained discharge current. The SOC module determines whether the discharge swing is greater than a negative of a retained charge swing.

[0014] In yet other features, the SOC module determines whether the maximum current is approximately equal to a negative of a retained charge current. The SOC module includes a lookup table. The SOC module looks up the SOC as a function of the power limit ratio when the discharge swing is greater than the retained charge swing and the maximum current is approximately equal to the negative of the retained charge current.

[0015] A battery control module for a battery system comprises a voltage measuring module that measures battery voltage and a current measuring module that measures battery current. A state of charge (SOC) module communicates with the current and voltage measuring modules and estimates SOC when an accumulated charge swing during charge is greater than or equal to an accumulated discharge swing during a prior discharge and a negative of a charge current is within a predetermined window of a negative of a retained discharge current during the prior discharge.

[0016] In other features, the SOC module estimates SOC when an accumulated discharge swing during discharge is greater than or equal to an accumulated charge swing during a prior charge and a negative of a discharge current is within a predetermined window of a negative of a retained charge current during the prior charge.

[0017] A battery control module for a battery system comprises a voltage measuring module that measures battery voltage and a current measuring module that measures battery current. A state of charge (SOC) module communicates with the current and voltage measuring modules and estimates SOC when an accumulated discharge swing during discharge is greater than or equal to an accumulated charge swing during a prior charge and a negative of a discharge current is within a predetermined window of a negative of a retained charge current during the prior charge.

[0018] Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating the preferred embodiment of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0020] FIG. 1 is a functional block diagram of a battery system including battery subpacks, battery control modules and a master control module;

[0021] FIG. 2 is a more detailed functional block diagram of a battery control module;

[0022] FIG. 3 is an equivalent circuit of a battery;

[0023] FIG. 4 is a graph of battery current as a function of time;

[0024] FIGs. 5A and 5B are flowcharts illustrating steps of a relaxation voltage approach for estimating state of charge;

[0025] FIG. 6 is a graph of battery current as a function of time with charge and discharge swing and charge and discharge events shown; and

[0026] FIG. 7 is a flowchart illustrating a power ratio approach of estimating battery state of charge.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0027] The following description of the preferred embodiment(s) is merely exemplary in nature and is in no way intended to limit the invention, its application, or uses. For purposes of clarity, the same reference numbers will be used in the drawings to identify the same elements. As used herein, the term module or device refers to an application specific integrated circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and memory that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable components that provide the described functionality. As used herein, the term current swing refers to current integrated over a duration during which the charge (polarity) is in one direction. Charge swing may be expressed in units of Amp-seconds or A-s.

[0028] An exemplary system that can be used to calculate the SOC will be shown, although skilled artisans will appreciate that other systems may be used. Referring now to FIG. 1, an exemplary embodiment of a battery system 10 is shown to include M battery subpacks 12-1, 12-2, ..., and 12-M (collectively battery subpacks 12). The battery subpacks 12-1, 12-2, ..., and 12-M include N series connected batteries 20-11, 20-12, ..., and 20-NM (collectively batteries 20). Battery control modules 30-1, 30-2, ... and 30-M (collectively battery control modules 30) are associated with each of the battery subpacks 12-1, 12-2, ... and 12-M, respectively. In some embodiments, M is equal to 2 or 3, although additional or fewer subpacks may be used. In some embodiments, N is equal to 12-24, although additional and/or fewer batteries may be used.

[0029] The battery control modules 30 sense voltage across and current provided by the battery subpacks 12. Alternatively, the battery control modules 30 may monitor one or more individual batteries 20 in the battery subpacks 12 and appropriate scaling and/or adjustment is performed. The battery control modules 30 communicate with a master control module 40 using wireless and/or wired connections. The master control module 40 receives the power limits from the battery control modules 30 and generates a collective power limit. The SOC can be calculated for each module, in groups and/or collectively. The battery control module 30 may be integrated with the master control module 40 in some embodiments.

[0030] Referring now to FIG. 2, some of the elements of the battery control modules 30 are shown. The battery control modules 30 include a voltage and/or current measuring module 60 that measures voltage across the battery subpack 12 and/or across one or more individual batteries 20 in the battery subpack 12. The battery control modules 30 further include a battery state of charge (SOC) module 68 that periodically calculates the SOC of the batteries 20 in the battery subpacks 12. In one implementation, the SOC module 68 uses a power ratio estimation and/or V_0 approach, as will be described below. In another implementation, the SOC module 68 uses a relaxation voltage SOC estimation approach, as will be described below. The SOC module 68 may employ a lookup table 70, formulas and/or other methods.

[0031] A power limit module 72 calculates a maximum current limit $I_{\lim}$, voltage limit V_{lim}, and/or power limit P_{lim} for the battery subpack 12 and/or one or more batteries 20 in the battery subpack 12, as will be described further below. The limits may be maximum and/or minimum limits. A contactor control module 74 controls one or more contactors (not shown) that are associated with the control and/or connection of the batteries 20 in the battery subpacks 12. A clock circuit 76 generates one or more clock signals for one or more modules within the battery control module 30.

[0032] Referring now to FIG. 3, an equivalent circuit for the battery 20 is shown where R_0 represents ohmic resistance of the battery, V_P represents the polarization voltage, V_0 represents the open circuit or relaxation voltage, I represents battery current and V represents battery voltage. V and I are measured values. R_p varies with temperature, duration of applied current and SOC. V_0 and R_0 vary primarily with SOC. V_P is equal to measured current I times R_p. Using the equivalent circuit and Kirchoff's voltage rules for the battery 20, $V = V_0 + V_P + IR_0$.

[0033] Relaxation voltage is relatively insensitive to temperature and current demand and is a good indicator of SOC. A set of specialized current pulses can be used to condition the battery to yield SOC dependent relaxation voltages. This approach is referred to herein as relaxation voltage SOC estimation.

[0034] Referring now to FIG. 4, battery current is shown as a function of time. Current that is greater than zero, for example at 100-1, 100-2, 100-3, and 100-4, is charging current. Current that is less than zero, for example at 102-1, 102-2, and 102-3, is discharging current. The areas under the curve between points 106 and 108 and points 110 and 112 are defined as a charge swing in A-s. The area under the current curve between points 108 and 110 is defined as a discharge swing in A-s.

[0035] Referring now to FIGs. 5A and 5B, steps of a method for implementing a relaxation voltage SOC estimation approach are shown. The relaxation voltage estimation approach monitors battery current for a pair of power pulses, checks relaxation voltage after each and determines SOC using the lookup table 70. The relaxation voltage approach was derived based on the observation of voltage responses to pulses throughout a range operating of temperatures, such as -15°C to 45°C. The relaxation voltages were affected by swing amplitudes, pulse amplitudes and whether the battery was brought from top of charge or bottom of charge.

[0036] In FIGs. 5A and 5B, control begins with step 150. In step 152, the current and voltage are measured. In step 154, control determines whether the measured current is charge current (current > zero or a predetermined threshold). If step 154 is true, control accumulates charge swing and resets discharge swing in step 156. In step 158, control sets a rest variable equal to zero. In step 162, control determines whether the accumulated charge swing is within a predetermined window. The window may include upper and lower thresholds. In some implementations, the upper and lower thresholds are between 10% and 100% of battery capacity, although other values may be used. If not, control disables SOC lookup after charge in step 163 and returns to step 152.

[0037] If step 162 is true, control continues with step 164 and determines whether last swing and relaxation occurred in discharge. As used herein, relaxation refers to battery voltage asymptotically approaching the relaxation voltage. If not, control continues with step 163. If step 164 is true, control enables SOC lookup after charge in step 166.

[0038] If step 154 is false, control continues with step 174. In step 174, control determines whether the measured current is discharge current (current < zero or a predetermined threshold). If step 174 is true, control accumulates discharge swing and resets charge swing in step 176. In step 178, control sets the rest variable equal to zero. In step 182, control determines whether the accumulated discharge swing is within a predetermined window. The window may include upper and lower thresholds that may be similar to the accumulated charge swing thresholds or different therefrom. If not, control disables SOC lookup after discharge in step 183 and returns to step 152.

[0039] If step 182 is true, control continues with step 184 and determines whether last swing and relaxation occurred in charge. If not, control continues with step 183. If step 184 is true, control enables SOC lookup after discharge in step 186.

[0040] If step 174 is false, control continues in FIG. 5B with step 200 and increments the rest variable. In step 202, control determines whether rest time is adequate by comparing rest time to a threshold. In some implementations, approximately 120 seconds is used as a threshold, although other values may be used. If step 202 is true, control determines whether allowable time is less than a threshold time Th_{time} in step 204. In some implementations, allowable time is equal to 240 seconds, although other values may be used. Exceeding this value tends to indicate that the pulses were not controlled enough for an SOC estimation.

[0041] If step 204 is true, control continues with step 206 and determines whether SOC lookup after charge is enabled. If step 206 is true, control looks up SOC as a function of relaxation voltage in step 208 and disables SOC lookup after charge in step 210 and control returns to step 152. If step 206 is false, control continues with step

212 and determines whether SOC lookup after discharge is enabled. If step 212 is true, control looks up SOC as a function of relaxation voltage in step 214 and disables SOC lookup after discharge in step 216 and control returns to step 152. If steps 202, 204 or 212 are false, control returns to step 152.

[0042] The power ratio SOC estimation approach monitors power pulse pairs. The method calculates the ratio of power capabilities in charge and discharge when the swings of the pulse pairs are approximately equal. The SOC is a function of the power ratio and is determined by a lookup table. The algorithm was derived while attempting to use inputs of current and voltage to solve for relaxation voltage V_0.

[0043] The voltage equation as the maximum or minimum power is held to a voltage limit is $V_{\lim} = V_0 + V_P + I_{\lim} R_0$. Substitution of the calculation for $V_0 + V_P$ from a prior sampling interval into the equation for $V_{\lim}$ yields $V_{\lim} = (V - IR_o) + I_{\lim} R_o$. In this case, we are assuming that $V_0 + V_P$ for the current sampling interval is approximately equal to $V_0 + V_P$ of the prior sampling interval (in other words, $V_0 + V_P \cong V_{t=i-1} - I_{t=i-1} R_0$). This approximation is valid if the sampling interval is sufficiently small since the battery and ambient conditions are very similar. For example in some implementations, a sampling interval 10ms<T<500ms may be used, although other sampling intervals may be used. In one embodiment, T=100ms. Sampling intervals of 1 second have been used successfully. If the sampling interval is determined to be excessive in duration then R_o would be increased as a constant or as a temperature dependent variable.

[0044] Solving for $I_{\lim}$ yields the following:

$$I_{\lim} = \frac{V_{\lim} - V_{t=i-1} + I_{t=i-1} R_0}{R_0}.$$

Therefore, since $P_{\lim} = V_{\lim} I_{\lim}$,

$$P_{\lim} = V_{\lim} \left(\frac{V_{\lim} - V_{t=i-1} + I_{t=i-1} R_0}{R_0} \right).$$

[0045] At the time that power limit is established for a charge or discharge swing and measured current, the measured current and voltage values are stored. When the current is reversed, the swing amplitude passes the negative of the retained swing, and the current is approximately equal to the magnitude of the retained current, a power limit calculation is performed.

[0046] The power ratio is calculated by taking $P_{\lim}$ in charge divided by $-P_{\lim}$ in discharge for adjacent cycles. Even though V_0 and V_p are no longer in the equation, their contributions are reflected in current and voltage measurements, which are functions of both the polarization build up and V_0. The polarization voltage V_p during a charge swing is approximately equal to the polarization voltage V_p during a discharge swing of approximately equal magnitude. Using this approximation, the power ratio SOC estimation is used to remove V_p from the calculation. The use of the power limit ratio has the effect of adding consideration of the low discharge power at low SOC and the low charge acceptance at high SOC to the stated charge determination.

[0047] In FIG. 6, the battery current is shown. The present invention monitors charge and discharge swing and declares charge and discharge events under certain circumstances. A charge swing event occurs when the charge swing is greater than a charge swing threshold. A discharge event occurs when a discharge swing is greater than a discharge swing threshold. The thresholds may be related to or based on a prior charge or discharge event. For example, a charge swing threshold may be set equal to the absolute value of a prior discharge event. A discharge swing threshold may be set equal to the absolute value of a prior charge event. Still other approaches may be used to determine the charge and discharge thresholds. As used herein, the term claim refers to situations when a charge or discharge event is followed by a discharge or charge claim and when other conditions described below are met. The occurrence of discharge event is determined independently from the occurrence of the discharge claim, to different criteria. The algorithm looks for both simultaneously. For example, the claim point occurs at the time that the area discharge swing is equal to the previous charge swing. The event point occurs when the ratio current vs. discharge current MIN is roughly equal to the ratio current at charge event vs. charge current MAX. This would be the case if L = K in FIG. 7. In some implementations, L and K are between 1 and 2, although other values may be used.

[0048] Referring now to FIG. 7, the power ratio SOC estimation method according to the present invention is shown in further detail. Control begins with step 250. In step 254, control measures current and voltage. In step 258, control determines whether there is a charge current. Charge current is defined by positive current above zero or a predetermined positive threshold. If step 258 is true, control continues with step 262 and accumulates charge swing. In step 264, control determines whether the current during the charge swing passes a maximum value and is greater than $Current_{max}/K$. When step 264 is true, control stores values of current, charge swing and power limit in step 266. If not, control continues past step 266 to step 270. In step 270, control determines whether the swing is greater than the prior discharge swing. If not, control does not make an SOC claim in step 272 and control continues with step 254.

[0049] If step 270 is true, control determines whether the current is approximately equal to a retained discharge current $-I_{DR}$ (in other words within upper and lower thresholds thereof) in step 274. If step 274 is false, control does not make an SOC claim in step 276 and control continues with step 254. If step 274 is true, control looks up SOC as a ratio of power limit to retained power limit in step 280.

[0050] If step 258 is false, control continues with step 278 and determines whether discharge current is present. Discharge current is present when discharge current is less than zero or a predetermined negative threshold. If step 278 is false, control returns to step 254. If step 278 is true, control continues with step 282 and accumulates discharge swing. In step 284, control determines whether the current during the discharge swing passes a minimum value and is less than $Current_{min}/L$. When step 284 is true, control stores values of current, the discharge swing and power limit in step 286. If not, control continues past step 286 to step 290. In step 290, control determines whether the discharge swing is greater than the prior charge swing. If not, control does not make an SOC claim in step 292 and control continues with step 254.

[0051] If step 290 is true, control determines whether the current is approximately equal to a retained charge current $-I_{CR}$ (in other words within upper and lower thresholds thereof) in step 294. If step 294 is false, control does not make an SOC claim in step 296 and control continues with step 294. If step 294 is true, control looks up SOC as a ratio of power limit to retained power limit in step 300.

[0052] Those skilled in the art can now appreciate from the foregoing description that the broad teachings of the present invention can be implemented in a variety of forms. Therefore, while this invention has been described in connection with particular examples thereof, the true scope of the invention should not be so limited since other modifications will become apparent to the skilled practitioner upon a study of the drawings, the specification and the following claims.

CLAIMS

What is claimed is:

1. A battery control module for a battery system, comprising:

a voltage measuring module that measures battery voltage;

a current measuring module that measures battery current; and

a state of charge (SOC) module that communicates with said current and voltage measuring modules and that estimates SOC based on relaxation voltage.

2. The battery control module of Claim 1 wherein said SOC module enables said SOC estimation when a qualified charge swing follows a discharge swing and relaxation.

3. The battery control module of Claim 1 wherein said SOC module enables said SOC estimation when a qualified discharge swing follows a charge swing and relaxation.

4. The battery control module of Claim 2 wherein said SOC module accumulates charge swing during charging and identifies said qualified charge swing when said accumulated charge swing is within a charge swing window.

5. The battery control module of Claim 3 wherein said SOC module accumulates discharge swing during discharging and identifies said qualified discharge swing when said accumulated discharge swing is within a discharge swing window.

6. The battery control module of Claim 1 wherein said SOC module monitors rest periods during which said battery is neither charging nor discharging.

7. The battery control module of Claim 6 wherein said SOC module enables said SOC estimation when said rest period is greater than a threshold.

8. The battery control module of Claim 2 wherein said SOC module enables SOC estimation during charging when a first period between said qualified charge swing and said prior discharge swing and relaxation is less than a predetermined allowed time.

9. The battery control module of Claim 3 wherein said SOC module enables SOC estimation during charging when a second period between said qualified discharge swing and said prior charge swing and relaxation is less than a predetermined allowed time.

10. A method for operating a battery control module for a battery system, comprising:

measuring battery voltage;

measuring battery current; and

estimating state of charge (SOC) based on relaxation voltage, said battery voltage and said battery current.

11. The method of Claim 10 further comprising enabling said SOC estimation when a qualified charge swing follows a discharge swing and relaxation.

12. The method of Claim 10 further comprising enabling said SOC estimation when a qualified discharge swing follows a charge swing and relaxation.

13. The method of Claim 11 further comprising:

accumulating charge swing during charging; and

identifying said qualified charge swing when said accumulated charge swing is within a charge swing window.

14. The method of Claim 12 further comprising:

accumulating discharge swing during discharging; and

identifying said qualified discharge swing when said accumulated discharge swing is within a discharge swing window.

15. The method of Claim 10 further comprising monitoring rest periods during which said battery is neither charging nor discharging.

16. The method of Claim 15 further comprising enabling said SOC estimation when said rest period is greater than a threshold.

17. The method of Claim 11 further comprising enabling SOC estimation during charging when a first period between said qualified charge swing and said prior discharge swing and relaxation is less than a predetermined allowed time.

18. The method of Claim 12 further comprising enabling SOC estimation during charging when a second period between said qualified discharge swing and said prior charge swing and relaxation is less than a predetermined allowed time.

19. A battery control module for a battery system, comprising:

a voltage measuring module that measures battery voltage;

a current measuring module that measures battery current; and

a state of charge (SOC) module that communicates with said current and voltage measuring modules and that estimates SOC based on a power limit ratio.

20. The battery control module of Claim 19 wherein said SOC module accumulates charge swing during charging, identifies a maximum current divided by K during said charge swing and stores said charge current, a charge swing and a charge power limit.

21. The battery control module of Claim 19 wherein said SOC module accumulates discharge swing during discharging, identifies a minimum current divided

by L during said discharge swing and stores said discharge current, a discharge swing and a charge power limit.

22. The battery control module of Claim 20 wherein said SOC module determines whether said charge swing is greater than a negative of a retained discharge swing.

23. The battery control module of Claim 22 wherein said SOC module determines whether said charge current is approximately equal to a negative of a retained discharge current.

24. The battery module of Claim 20 wherein said SOC module includes a lookup table and wherein said SOC module looks up said SOC as a function of said power limit ratio when said charge swing is greater than a negative of said retained discharge swing and said charge current is approximately equal to a negative of said retained discharge current.

25. The battery control module of Claim 21 wherein said SOC module determines whether said discharge swing is greater than a negative of a retained charge swing.

26. The battery control module of Claim 25 wherein said SOC module determines whether said discharge current is approximately equal to a negative of a retained charge current.

27. The battery module of Claim 26 wherein said SOC module includes a lookup table and wherein said SOC module looks up said SOC as a function of said power limit ratio when said discharge swing is greater than a negative of said retained charge swing and said discharge current is approximately equal to a negative of said retained charge current.

28. A method for operating a battery control module for a battery system, comprising:

measuring battery voltage;

measuring battery current; and

estimating SOC based on a power limit ratio, said battery voltage and said battery current.

29. The method of Claim 28 further comprising:

accumulating charge swing during charging;

identifying a charge current equal to a maximum current divided by K during said charge swing; and

storing said charge current, a charge swing and a charge power limit.

30. The method of Claim 28 further comprising:

accumulating discharge swing during discharging;

identifying a discharge current equal to a minimum discharge current divided by L during said discharge swing; and

storing said discharge current, a discharge swing and a discharge power limit.

31. The method of Claim 29 further comprising determining whether said charge swing is greater than a negative of a retained discharge swing.

32. The method of Claim 31 further comprising determining whether said charge current is approximately equal to a negative of a retained discharge current.

33. The battery module of Claim 29 further comprising looking up said SOC as a function of said power limit ratio when said charge swing is greater than a negative of said retained discharge swing and said charge current is approximately equal to a negative of said retained discharge current.

34. The method of Claim 30 further comprising determining whether said discharge swing is greater than a negative of a retained charge swing.

35. The method of Claim 34 further comprising determining whether said discharge current is approximately equal to a negative of a retained charge current.

36. The battery module of Claim 35 further comprising looking up said SOC as a function of said power limit ratio when said discharge swing is greater than a negative of said retained charge swing and said minimum current is approximately equal to a negative of said retained charge current.

37. A battery control module for a battery system, comprising:

a voltage measuring module that measures battery voltage;

a current measuring module that measures battery current; and

a state of charge (SOC) module that communicates with said current and voltage measuring modules and that estimates SOC when an accumulated charge swing during charge is greater than or equal to a negative of an accumulated discharge swing during a prior discharge and a charge current is within a predetermined window of a negative of a retained discharge current during said prior discharge.

38. The battery control module of Claim 37 wherein said SOC module estimates SOC when an accumulated discharge swing during discharge is greater than or equal to a negative of an accumulated charge swing during a prior charge and a discharge current is within a predetermined window of a negative of a retained charge current during said prior charge.

39. The battery control module of Claim 37 wherein said SOC module calculates a power limit during charging, calculates a power limit ratio based on said

power limit during charging and a retained power limit during said prior discharge, and estimates SOC based on a power limit ratio.

40. The battery control module of Claim 38 wherein said SOC module calculates a power limit during discharging, calculates a power limit ratio based on said power limit during discharging and a retained power limit during said prior charge, and estimates SOC based on a power limit ratio.

41. The battery control module of Claim 37 wherein said SOC module accumulates said charge swing during charging until a maximum charge current divided by K is reached and stores said charge current and said charge swing as said accumulated charge swing.

42. The battery control module of Claim 38 wherein said SOC module accumulates said discharge swing during discharging until a minimum discharge current divided by L is reached and stores said minimum discharge current as said discharge current and said discharge swing as said accumulated discharge swing.

43. The battery module of Claim 39 wherein said SOC module includes a lookup table and wherein said SOC module looks up said SOC as a function of said power limit ratio.

44. The battery module of Claim 40 wherein said SOC module includes a lookup table and wherein said SOC module looks up said SOC as a function of said power limit ratio.

45. A battery control module for a battery system, comprising:

a voltage measuring module that measures battery voltage;

a current measuring module that measures battery current; and

a state of charge (SOC) module that communicates with said current and voltage measuring modules and that estimates SOC when an accumulated discharge swing during discharge is greater than or equal to a negative of an accumulated charge swing during a prior charge and a discharge current is within a predetermined window of a negative of a retained charge current during said prior charge.

46. The battery control module of Claim 45 wherein said SOC module estimates SOC when an accumulated charge swing during charge is greater than or equal to a negative of an accumulated discharge swing during a prior discharge and a charge current is within a predetermined window of a negative of a retained discharge current during said prior discharge.

47. The battery control module of Claim 46 wherein said SOC module calculates a power limit during charging, calculates a power limit ratio based on said

power limit during charging and a retained power limit during said prior discharge, and estimates SOC based on a power limit ratio.

48. The battery control module of Claim 45 wherein said SOC module calculates a power limit during discharging, calculates a power limit ratio based on said power limit during discharging and a retained power limit during said prior charge, and estimates SOC based on a power limit ratio.

49. The battery control module of Claim 46 wherein said SOC module accumulates said charge swing during charging until a maximum charge current divided by K is reached and stores said maximum charge current as said charge current and said charge swing as said accumulated charge swing.

50. The battery control module of Claim 45 wherein said SOC module accumulates said discharge swing during discharging until a minimum discharge current divided by L is reached and stores said minimum discharge current as said discharge current and said discharge swing as said accumulated discharge swing.

51. The battery module of Claim 47 wherein said SOC module includes a lookup table and wherein said SOC module looks up said SOC as a function of said power limit ratio.

52. The battery module of Claim 48 wherein said SOC module includes a lookup table and wherein said SOC module looks up said SOC as a function of said power limit ratio.

53. A method for operating a battery control module for a battery system, comprising:

measuring battery voltage;

measuring battery current; and

estimating state of charge (SOC) when an accumulated charge swing during charge is greater than or equal to a negative of an accumulated discharge swing during a prior discharge and a charge current is within a predetermined window of a negative of a retained discharge current during said prior discharge.

54. The method of Claim 53 further comprising estimating said SOC when an accumulated discharge swing during discharge is greater than or equal to a negative of an accumulated charge swing during a prior charge and a discharge current is within a predetermined window of a negative of a retained charge current during said prior charge.

55. The method of Claim 53 further comprising:

calculating a power limit during charging;

calculating a power limit ratio based on said power limit during charging and a retained power limit during said prior discharge; and

estimating SOC based on a power limit ratio.

56. The method of Claim 54 further comprising:

calculating a power limit during discharging;

calculating a power limit ratio based on said power limit during discharging and a retained power limit during said prior charge; and

estimating SOC based on a power limit ratio.

57. The method of Claim 53 further comprising:

accumulating said charge swing during charging until a maximum charge current divided by K is reached; and

storing said charge current and said charge swing as said accumulated charge swing.

58. The method of Claim 54 further comprising:

accumulating said discharge swing during discharging until a minimum discharge current divided by L is reached; and

storing said discharge current and said discharge swing as said accumulated discharge swing.

59. The method of Claim 55 wherein said SOC module includes a lookup table and wherein said SOC module looks up said SOC as a function of said power limit ratio.

60. The method of Claim 56 wherein said SOC module includes a lookup table and wherein said SOC module looks up said SOC as a function of said power limit ratio.

61. A method for operating a battery control module for a battery system, comprising:

measuring battery voltage;

measuring battery current; and

estimating state of charge (SOC) when an accumulated discharge swing during discharge is greater than or equal to a negative of an accumulated charge swing during a prior charge and a discharge current is within a predetermined window of a negative of a retained charge current during said prior charge.

62. The method of Claim 61 further comprising estimating said SOC when an accumulated charge swing during charge is greater than or equal to a negative of an accumulated discharge swing during a prior discharge and a charge current is within a

predetermined window of a negative of a retained discharge current during said prior discharge.

63. The method of Claim 62 further comprising:

calculating a power limit during charging;

calculating a power limit ratio based on said power limit during charging and a retained power limit during said prior discharge; and

estimating SOC based on a power limit ratio.

64. The method of Claim 61 further comprising:

calculating a power limit during discharging;

calculating a power limit ratio based on said power limit during discharging and a retained power limit during said prior charge; and

estimating SOC based on a power limit ratio.

65. The method of Claim 62 further comprising:

accumulating said charge swing during charging until a maximum charge current divided by K is reached; and

storing said charge current and said charge swing as said accumulated charge swing.

66. The method of Claim 61 further comprising:

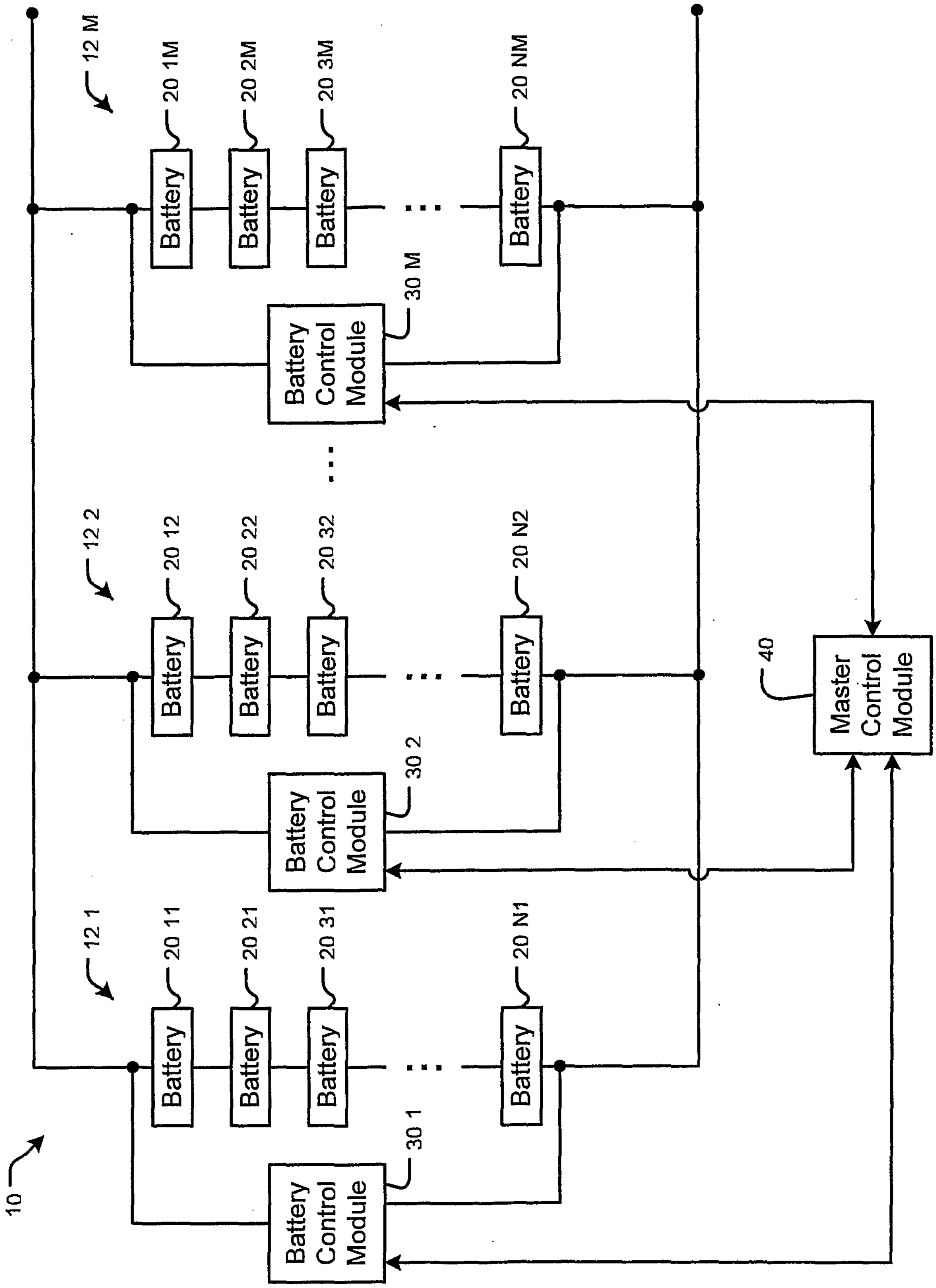
accumulating said discharge swing during discharging until a minimum discharge current divided by L is reached; and

storing said discharge current and said discharge swing as said accumulated discharge swing.

67. The method of Claim 62 wherein said SOC module includes a lookup table and wherein said SOC module looks up said SOC as a function of said power limit ratio.

68. The method of Claim 63 wherein said SOC module includes a lookup table and wherein said SOC module looks up said SOC as a function of said power limit ratio.

FIG. 1


10
12 1
12 2
12 M
20 11
20 21
20 31
20 N1
20 12
20 22
20 32
20 N2
20 1M
20 2M
20 3M
20 NM
Battery
30 1
30 2
30 M
Battery Control Module
40
Master Control Module

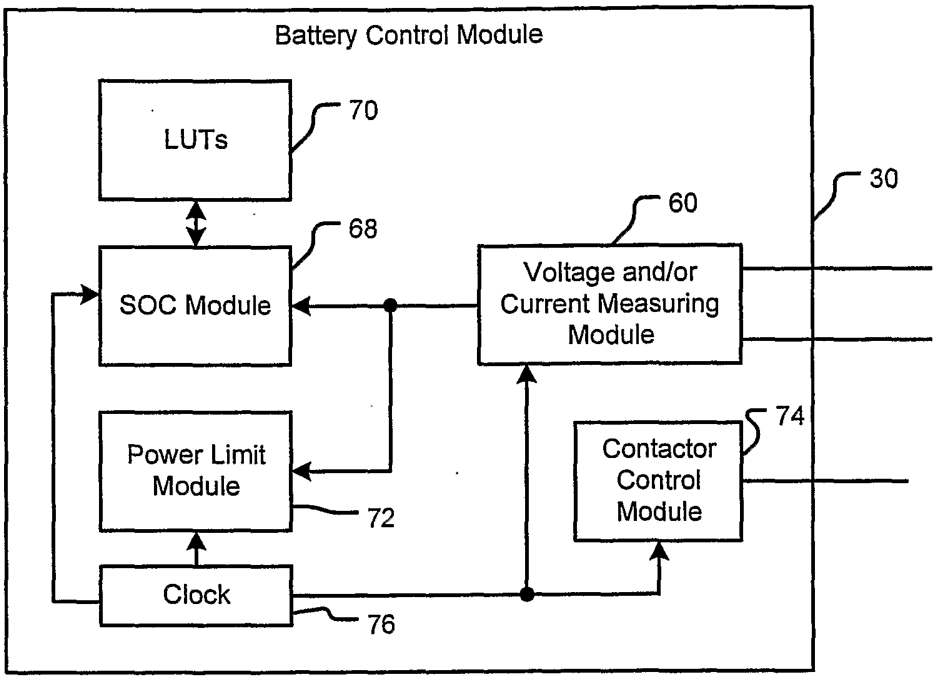

Battery Control Module
LUTs
70
30
60
68
SOC Module
Voltage and/or Current Measuring Module
Power Limit Module
74
Contactor Control Module
72
Clock
76

FIG. 2

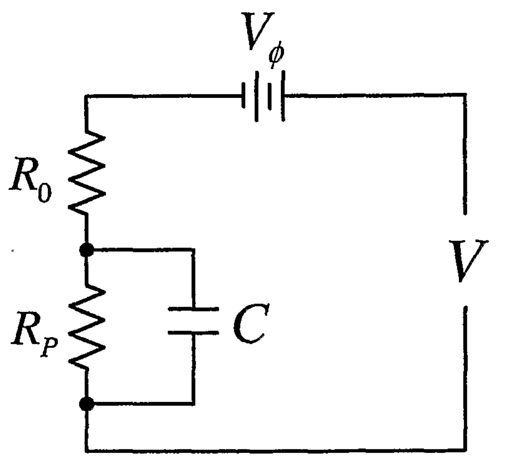
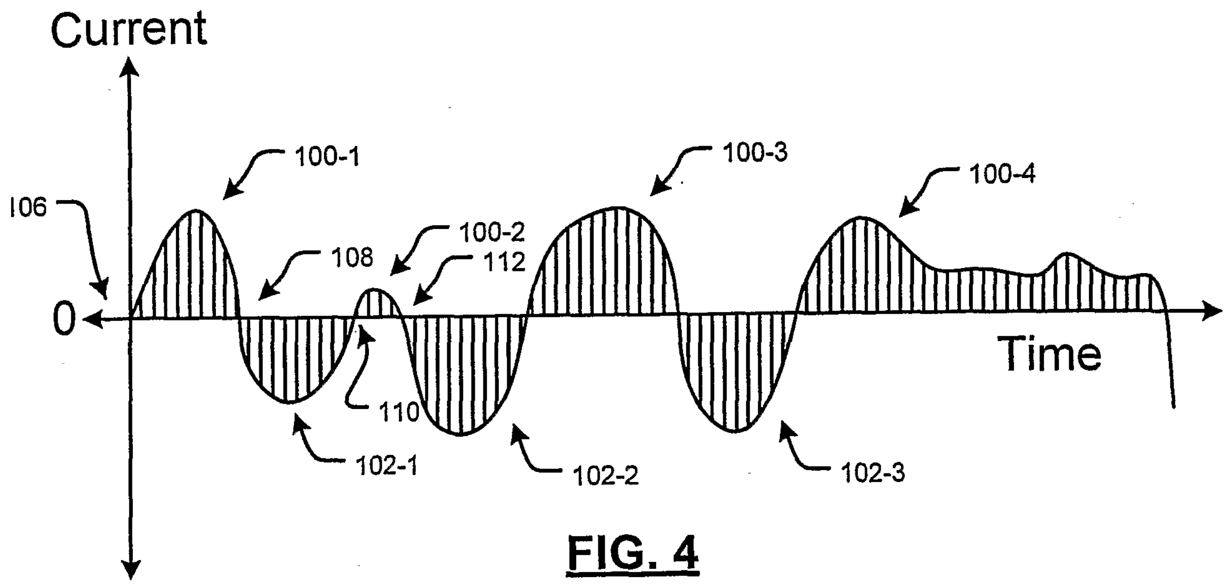
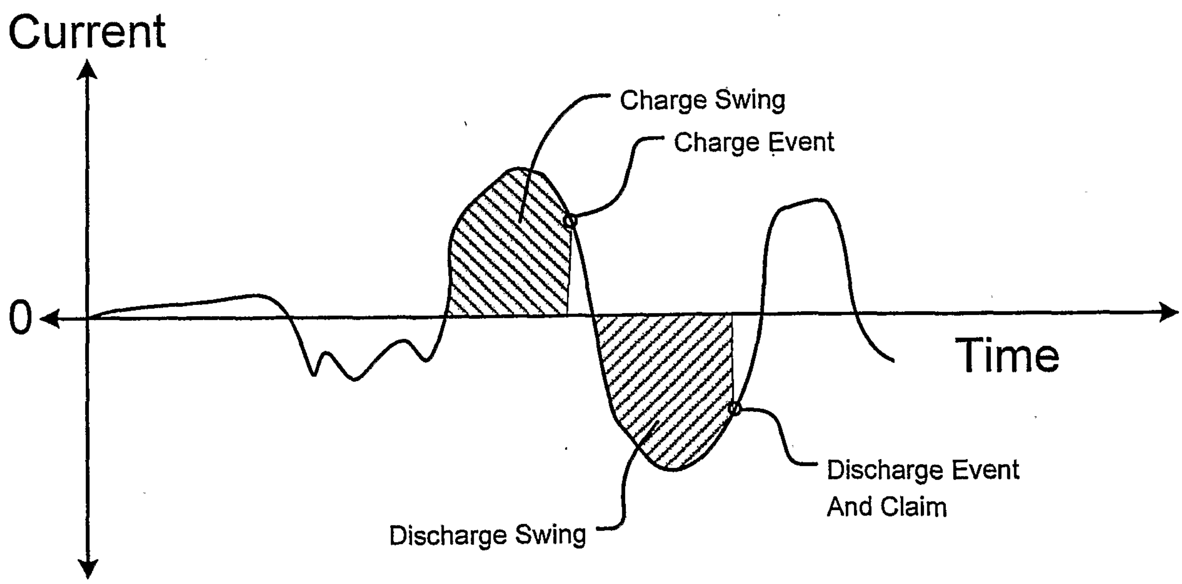

V_ϕ
R_0
V
R_P
C

FIG. 3



Current
0
Time
106
100-1
108
100-2
112
110
100-3
100-4
102-1
102-2
102-3

FIG. 4



Current
0
Time
Charge Swing
Charge Event
Discharge Event
And Claim
Discharge Swing

FIG. 6

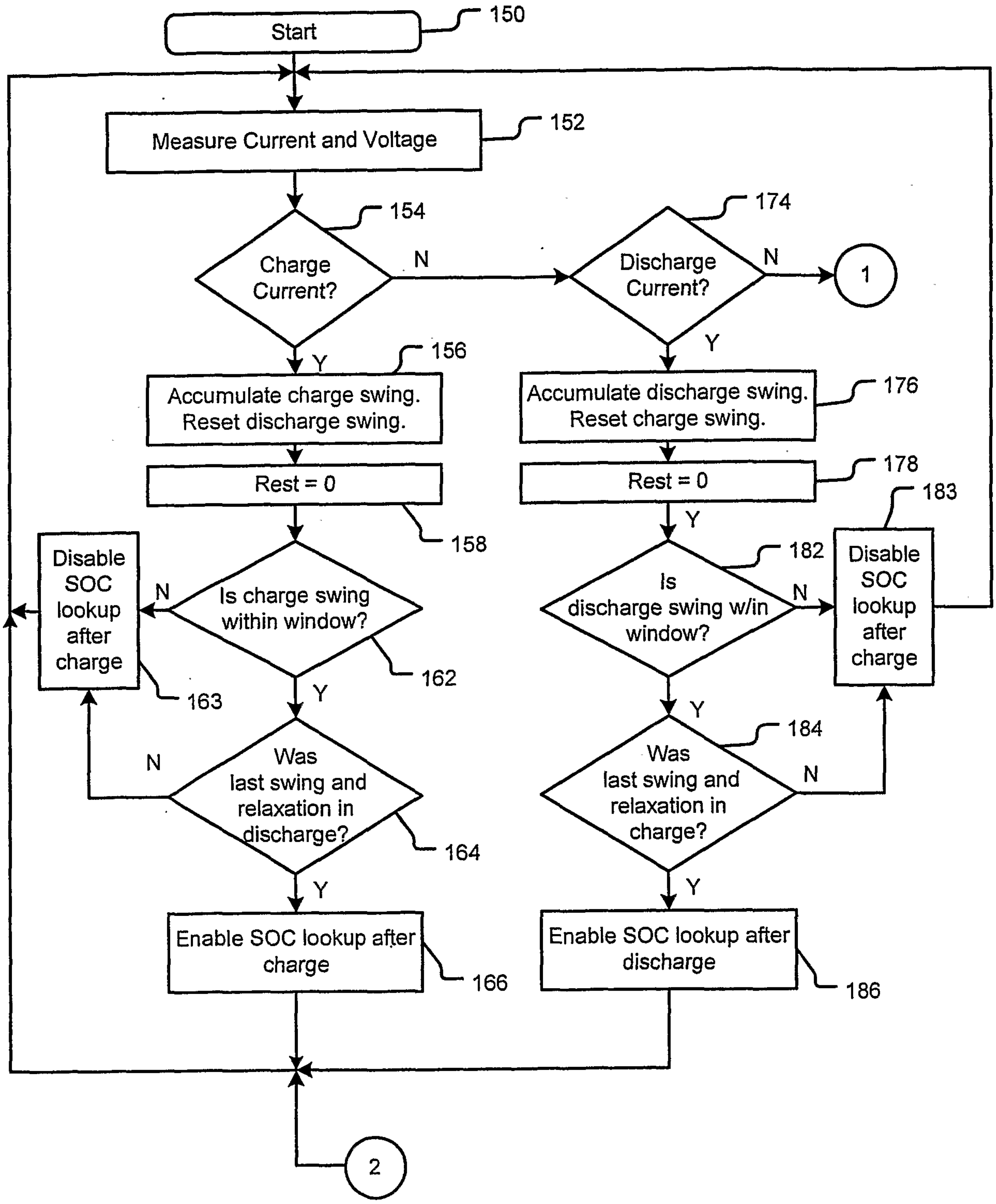

Start
150
Measure Current and Voltage
152
Charge Current?
154
N
Discharge Current?
174
N
1
Y
Accumulate charge swing. Reset discharge swing.
156
Y
Accumulate discharge swing. Reset charge swing.
176
Rest = 0
158
Rest = 0
178
Y
Disable SOC lookup after charge
163
N
Is charge swing within window?
162
Y
Is discharge swing w/in window?
182
N
Disable SOC lookup after charge
183
Y
N
Was last swing and relaxation in discharge?
164
Y
Was last swing and relaxation in charge?
184
N
Y
Enable SOC lookup after charge
166
Enable SOC lookup after discharge
186
2

FIG. 5A

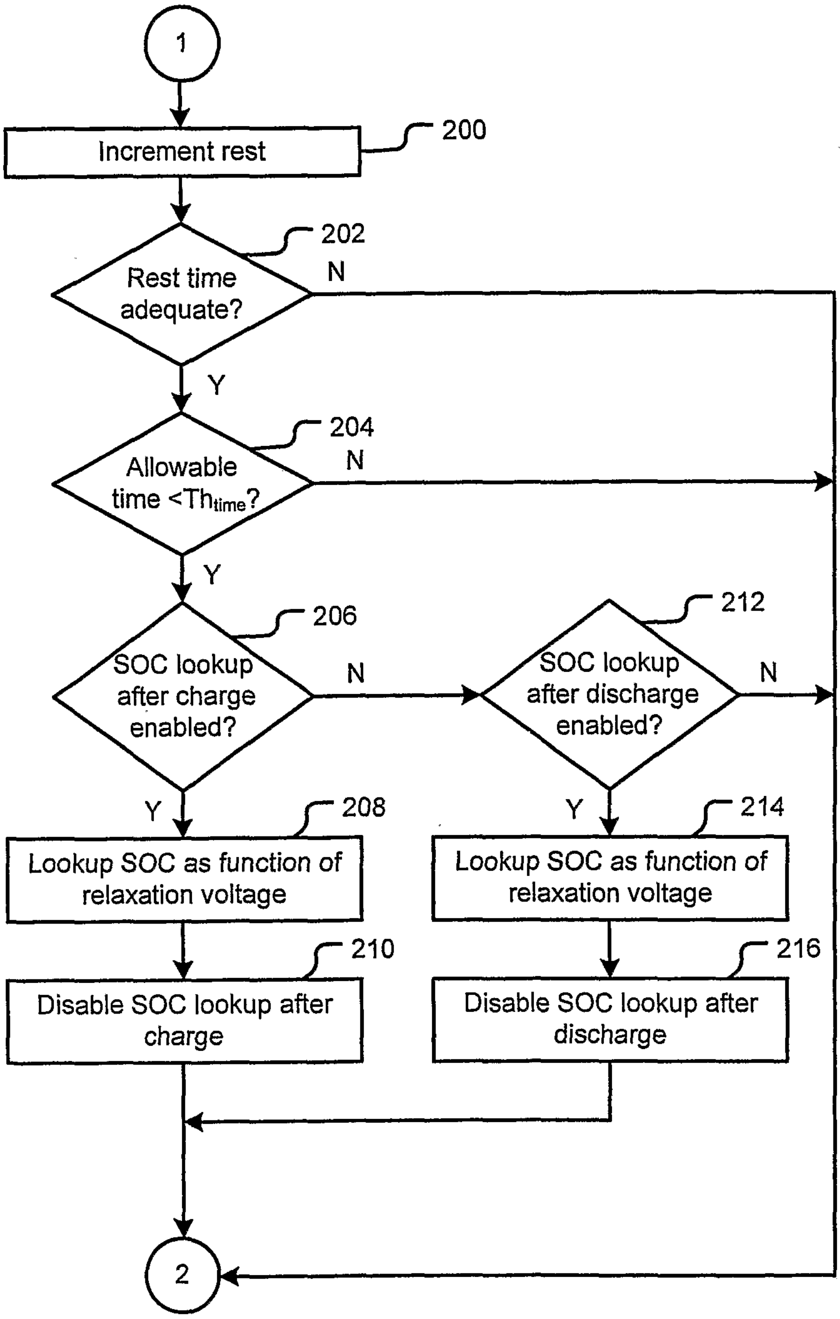

1
Increment rest
200
Rest time adequate?
202
N
Y
Allowable time <Th$_{time}$?
204
N
Y
SOC lookup after charge enabled?
206
N
SOC lookup after discharge enabled?
212
N
Y
Lookup SOC as function of relaxation voltage
208
Y
Lookup SOC as function of relaxation voltage
214
Disable SOC lookup after charge
210
Disable SOC lookup after discharge
216
2

FIG. 5B

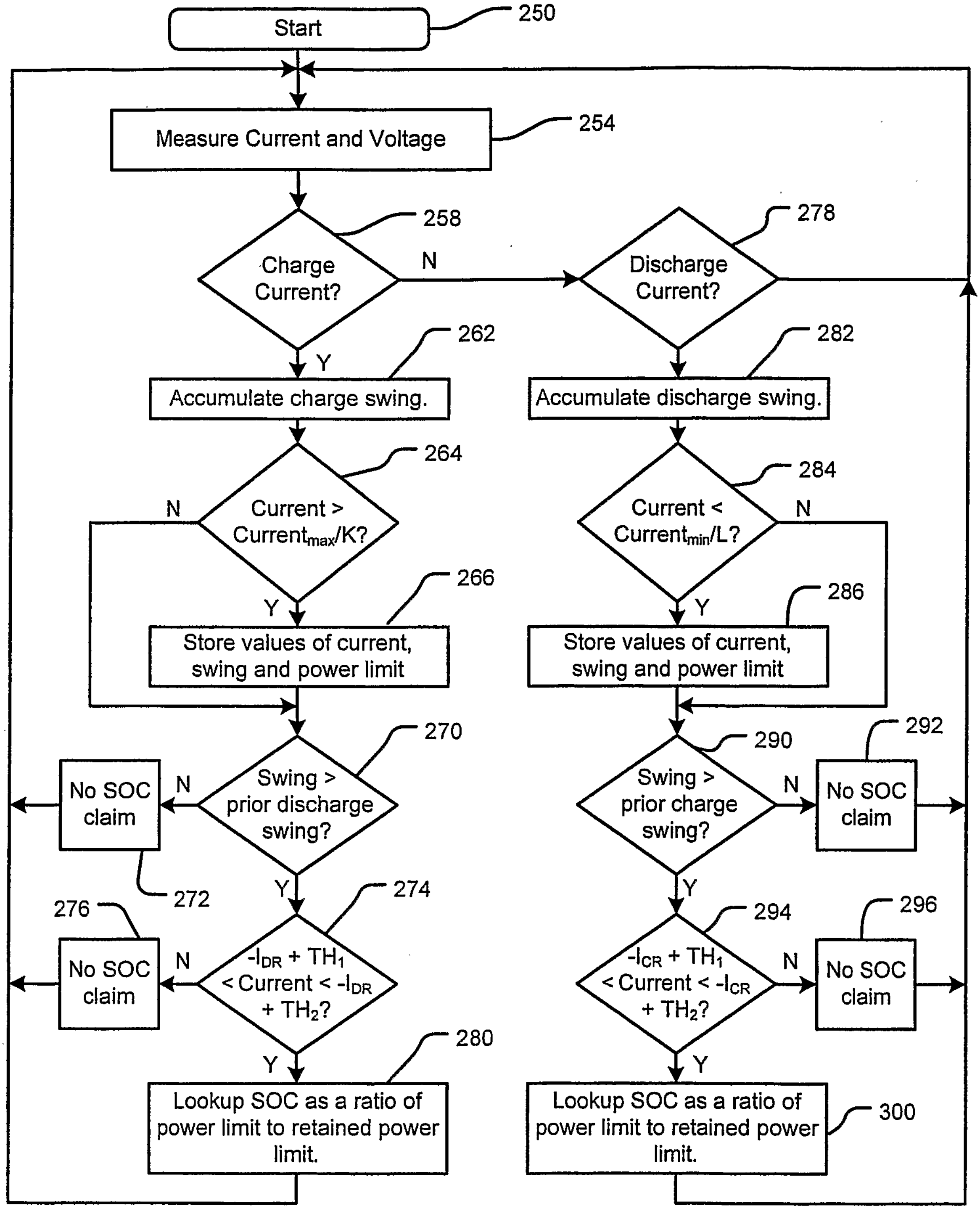

Start
250
Measure Current and Voltage
254
Charge Current?
258
N
Y
Discharge Current?
278
262
Accumulate charge swing.
282
Accumulate discharge swing.
Current > Current$_{max}$/K?
264
N
Y
Current < Current$_{min}$/L?
284
N
Y
266
Store values of current, swing and power limit
286
Store values of current, swing and power limit
Swing > prior discharge swing?
270
N
Y
No SOC claim
272
Swing > prior charge swing?
290
N
Y
No SOC claim
292
$-I_{DR} + TH_1 < Current < -I_{DR} + TH_2$?
274
N
Y
276
No SOC claim
$-I_{CR} + TH_1 < Current < -I_{CR} + TH_2$?
294
N
Y
No SOC claim
296
Lookup SOC as a ratio of power limit to retained power limit.
280
Lookup SOC as a ratio of power limit to retained power limit.
300

FIG. 7

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2005/011761

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01R31/36

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC, COMPENDEX, IBM-TDB

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 560 468 A (GLOBE-UNION INC; C&D/CHARTER HOLDINGS, INC) 15 September 1993 (1993-09-15) abstract; figures 1,2,4 page 2, line 1 - line 9 page 4, line 31 - line 42 page 5, line 33 - page 7, line 15 page 11, line 55 - page 12, line 33 page 12, line 39 - page 13, line 12 page 14, line 9 - line 14; claims 1,4,6-11,15 -----	1-18
X	US 2002/113594 A1 (SATAKE SHUJI) 22 August 2002 (2002-08-22) abstract; figures 2,7 paragraphs ‘0013!, ‘0014!, ‘0055!, ‘0058! - ‘0062!, ‘0091! -----	1-18
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 August 2005	9. 09. 2005

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Binger, B

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2005/011761

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2003/112011 A1 (GUIHEEN JAMES V ET AL) 19 June 2003 (2003-06-19) abstract; claims 1,7; figure 1 paragraphs ‘0006!, ‘0013!, ‘0016! - ‘0018!, ‘0021!, ‘0026!, ‘0027!, ‘0030!	1-18
X	US 6 160 380 A (TSUJI ET AL) 12 December 2000 (2000-12-12) column 5, line 38 - column 6, line 8; figures 1,2,6,7,12 column 6, line 20 - column 7, line 29	19-21, 28-30
X	EP 1 220 413 A (TOYOTA JIDOSHA KABUSHIKI KAISHA; NIPPON SOKEN, INC) 3 July 2002 (2002-07-03) paragraphs ‘0081! - ‘0085!; figures 4,22a	19,28
X	EP 1 085 592 A (MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD) 21 March 2001 (2001-03-21) paragraphs ‘0012!, ‘0023!, ‘0025!, ‘0037! - ‘0042!; figure 1	19,28
A		37,45, 53,61
A	US 5 412 323 A (KATO ET AL) 2 May 1995 (1995-05-02) column 2, line 25 - line 57 column 6, line 41 - line 66 column 21, line 28 - line 67; claim 1	37,45, 53,61

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2005/011761

Box II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [ ] Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. [ ] Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. [X] As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest.

[X] No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-18

State of charge based on relaxation voltage

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2. claims: 19-36

State of charge based on power limit ratio

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3. claims: 37-68

State of charge when an accumulated charge/discharge swing during charge/discharge is greater than or equal to a negative of an acculmulated discharge/charge swing during a prior discharge/charge and a charge/discharge current is within in a predetermined window of a negative of a retained discharge/charge current during said prior discharge/charge

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2005/011761

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
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			DE	69328513	D1	08-06-2000
			DE	69328513	T2	31-08-2000
			EP	0560468	A1	15-09-1993
			ES	2145026	T3	01-07-2000
			JP	6052903	A	25-02-1994
US 2002113594	A1	22-08-2002	JP	2002234408	A	20-08-2002
			GB	2373864	A ,B	02-10-2002
US 2003112011	A1	19-06-2003	US	6586130	B1	01-07-2003
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			EP	1336113	A2	20-08-2003
			JP	2004515195	T	20-05-2004
			WO	0242786	A2	30-05-2002
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			JP	3543645	B2	14-07-2004
			JP	11218567	A	10-08-1999
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			JP	2001078365	A	23-03-2001
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			JP	2001097150	A	10-04-2001
			JP	3475894	B2	10-12-2003
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			EP	1220413	A1	03-07-2002
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			WO	0118938	A1	15-03-2001
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			EP	1085592	A2	21-03-2001
			US	6278257	B1	21-08-2001
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			JP	4229030	A	18-08-1992
			JP	2927003	B2	28-07-1999
			JP	4236136	A	25-08-1992
			JP	4198762	A	20-07-1992
			JP	3036000	B2	24-04-2000
			JP	4164269	A	09-06-1992
			US	5280231	A	18-01-1994
			DE	69132790	D1	06-12-2001
			DE	69132790	T2	23-05-2002
			EP	0464748	A2	08-01-1992