CONTROL METHOD OF HYBRID POWER BATTERY CHARGER

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ABSTRACT

A power supply system and method for operating same. The power supply system is connectable to receive power from an adapter and supply power to a load. The power supply system includes a rechargeable battery, a buck mode circuit, and a boost mode circuit. A switching circuit switches between the buck mode circuit and boost mode circuit for supplying power to the load. If the power required by the load reaches a first predetermined level related to an adapter overload condition for a first predetermined time, the switching circuit disconnects said buck mode circuit from the load and connects the rechargeable battery and the boost mode circuit to said load. The first predetermined level may be established by a first predetermined percent of the current of a dynamic power management level established by the load, which is related to a power level below that which can be provided by the adapter.
FIG. 3B
STATE: IN BUCK MODE

100
INPUT CURRENT > 105% OF IDPM?

YES

SHUT DOWN CHARGER

104
WAIT MIN OF 100 US

NO

INPUT CURRENT STILL > 105% OF IDPM?

YES

START BOOST MODE

NO

FIG. 4

FIG. 6
CONTROL METHOD OF HYBRID POWER BATTERY CHARGER

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Patent Application Ser. No. 61/418,616, filed Dec. 1, 2010, and also claims the benefit of U.S. Provisional Patent Application Ser. No. 61/479,284, filed Apr. 26, 2011, both of which are assigned to the assignee hereof and incorporated herein by reference in their entireties.

FIELD

[0002] The various circuit embodiments described herein relate in general to battery charging and controlling circuits and methods, and, more specifically, to battery charging and controlling circuits and methods in which current can be drawn from both a charging adapter and the battery in response to a high load demand for current.

BACKGROUND

[0003] Rechargeable batteries, typically lithium-ion batteries, are widely used in consumer electronic devices, especially portable computers and mobile devices. Although examples of devices with which such batteries may be used are manifold, some recent examples include smartphone, notebook, tablet, and netbook computing devices, or the like, which have a CPU and memory that require operating power. When the device is not powered by the battery, an adapter is commonly used to power the device with which the battery is associated. At the same time, the adapter provides power to a charging circuit in the device to charge the battery. In such charging circuits, a synchronous switching buck converter is often used to control the charging current to the battery, while providing a substantially constant voltage to the load.

[0004] Traditionally, when the power required by the CPU and system load increase to reach the adapter power limit, the charge current can be reduced to zero, thereby giving a higher priority to power the system than to charge the battery. However, in certain conditions, if the CPU power demands are greater than those that can be met by the adapter, the adapter may crash. An example of such a condition is when the system is cold and the CPU power needed for application processing and speeding up data flow is much more than the power that the adapter can supply, even with zero charging current.

[0005] In the past, several solutions to the problem have been advanced. For example, one solution disables the CPU high current mode. This, however, lowers the system performance. Another solution uses an adapter with an increased current capability. This, however, increases the adapter cost. Yet another solution reduces the system bus voltage. This, however, is not a widely adopted battery charger solution, and is not suitable for a high power system. Still another solution is to add an additional boost converter and include a boost controller. This, however, requires at least a power MOSFET, diode, and other circuit components. The cost of this solution, however, is high and needs more space.

[0006] Thus, in order to solve the problem of operating a CPU at a high speed to improve the system performance, while not crashing the adapter, it has been suggested to use the battery and adapter to simultaneously power the system when power demands are high. One way in which this has been done has been to use a boost converter in the charging circuit to convert the battery power for delivery to the system. The charger can operate in a synchronous buck mode during the battery charging and in a boost mode when additional power to CPU and system is needed. This type of charging circuit is referred to herein as a "hybrid power battery charger."

[0007] What is needed is a system and method that uses the battery charger as a boost converter to boost battery voltage to adapter voltage and control method for achieving smooth mode transition between buck charging mode and boost supplement mode, and optimized efficiency.

SUMMARY

[0008] The proposed system and method described herein uses the existing battery charger configuration, but a control method is used that allows the charger to operate in a hybrid mode in which the charger operates in a buck mode during battery charging and in a boost mode during the battery discharging to supplement additional power to the system. This allows the CPU to operate at very high speed to realize its highest performance. In addition, the system does not need to increase the adapter current capability, thereby avoiding extra cost to the adapter. It realizes high power conversion efficiency, low total system cost, with a minimum space requirement.

[0009] Thus, according to one embodiment of a power supply system that is connectable to receive power from an adapter and supply power to a load, a rechargeable battery, a buck mode circuit, and a boost mode circuit are provided. A switching circuit is provided for switching between the buck mode circuit and boost mode circuit for supplying power to the load. If the power required by the load reaches a first predetermined level related to an adapter overload condition for a first predetermined time, the switching circuit disconnects said buck mode circuit from the load and connects the rechargeable battery and the boost mode circuit to said load. The first predetermined level may be established by a first predetermined percent of the current of a dynamic power management level established by the load, which may be related to a power level below that which can be provided by the adapter.

[0010] According to another embodiment of a power supply system connectable to a load, a power supply system having a rechargeable battery, a charging circuit, and an adapter connectable to receive power from a power supply source are provided. The charging circuit includes buck mode circuitry for selectively supplying power to the load in a normal operating mode and boost mode circuitry for selectively supplying power to the load in an adapter overload operating mode. Switching circuitry is provided for switching between the buck mode circuitry and the boost mode circuitry. If the power required by the load reaches an adapter overload condition, the charging circuit shuts down and waits a predetermined time. After the predetermined time, the charging circuit checks to determine whether the adapter overload condition still exists, and if the adapter overload is still exists, the charging circuit changes from the buck mode circuitry to the boost mode circuitry and connects the battery to the load to provide additional power to the load. The check to determine whether the adapter is still in the overload condition may be based, for example, on a system current.

[0011] According to an embodiment of a method for operating a charger circuit having a rechargeable battery, a buck mode circuit, and a boost mode circuit, the buck mode circuit is operated to provide power to a load in a normal operating...
mode. An input current to the charger circuit is sensed. If the input current exceeds a first predetermined percent of a current of a dynamic power management level established by the load, the charger circuit is shut down for a first predetermined time. If the input current continues to exceed the first predetermined percent of a current of a dynamic power management level established by the load after the first predetermined time, the boost mode circuit is started and the rechargeable battery is connected to provide power to the load.

**BRIEF DESCRIPTION OF THE DRAWINGS**

[0012] FIG. 1 is a block diagram of an example of a hybrid battery charger environment in which battery charging and controlling circuits and methods described herein may be employed.

[0013] FIG. 2 is an electrical schematic diagram illustrating an example of an embodiment of a charger circuit having a voltage boost function that may be used in the battery charging and controlling circuits and methods described herein.

[0014] FIG. 3A is a block diagram of an example of feedback amplifier, duty cycle, and driver circuits for implementing the battery charging and controlling circuits and methods of FIG. 2.

[0015] FIG. 3B is a block diagram of an example of start/stop control circuits for implementing the battery charging and controlling circuits and methods of FIG. 2.

[0016] FIG. 4 is a flow chart illustrating one embodiment of a method for operating the circuit of FIG. 2 to enter a boost mode of operation.

[0017] FIG. 5 is a flow chart illustrating one embodiment of a method for operating the circuit of FIG. 2 to exit a boost mode of operation.

[0018] And FIGS. 6A-6D are waveforms of various parameters versus time realized in the operation of the circuit of FIG. 2.

[0019] In the various figures of the drawing, like reference numbers are used to denote like or similar parts.

**DETAILED DESCRIPTION**

[0020] A block diagram of an example of a hybrid battery charger environment 10 is shown in FIG. 1. The hybrid battery charger environment 10 includes a system 12, which may be, for instance, a smartphone, notebook, tablet, netbook computing devices, or the like, which has a CPU 14 and a memory 16 that require operating power. The CPU 14 and memory 16 are part of the system load 18 for which the operating power is needed. The operating power to the system load is provided by a buck/boost charger system 20 and an associated rechargeable battery pack 22, in a manner described below in greater detail. The rechargeable battery pack 22 may be a lithium-ion battery pack, for example, although other rechargeable battery types may also be employed.

[0021] An adapter 24 is provided, which is optionally connectable to receive ac power, typically from an ac outlet, not shown, to convert the ac power to dc power to supply power to the buck/boost charger system 20 to power the system load 18 and to charge an associated rechargeable battery pack 22. For example, depending on the particular power requirements of a particular system load 18, a typical adapter may supply 90 W of power at about 20 V, thereby having the capability of supplying about 4.5 A current. The adapters, of course are load dependent, and may vary greatly from one application to another; however, one of the advantages of the hybrid battery charger of the type described herein is that the power requirements of the particular adapter needed can be reduced from that which would be required if the adapter alone is used to supply operating power to the system load 18. The adapter 24 may be supplied as a component that is external to the device or system that it is intended to supply power, and is selectively connectable thereto.

[0022] A switch 26 connects the battery pack 22 to the system load 18 when the adapter 24 is not connected to receive ac power so that system load 18 is powered by the rechargeable battery pack 22 directly. When the adapter 24 is connected to receive ac power, switch 26 is opened to disconnect the rechargeable battery pack 22 from system load so that system load is powered by the ac adapter directly. According to the embodiments described below, the rechargeable battery pack 22 can supply additional power to the system load 18 when the capabilities of the adapter 24 are exceeded. More specifically, when the power required by the system load 18 is more than the adapter 24 can provide, the buck/boost charger system 20 may call upon the rechargeable battery pack 22 to provide the additional power, for example by switching the rechargeable battery pack 22 into the system by, for instance, changing the buck converter charger to a boost converter. In addition, when the power required by the system load 18 is higher than that which can be provided by the adapter 24, the battery charge current is not only reduced to zero, but the buck/boost charger system 20 is operated in a boost mode so that the adapter and battery power the system simultaneously.

[0023] In one embodiment, if the power demanded by the system load 18 reaches an overload condition of the adapter 24 at or exceeding the maximum power limit of the adapter, the buck/boost charger system 20 immediately shuts down, and waits a predetermined period, referred to herein as a “deglitch time.” After the deglitch time, the buck/boost charger system 20 checks to determine whether the adapter 24 is still in an overload condition, based on the total system current. After the deglitch time, if the total system current is still higher than the maximum current limit of the adapter 24, the buck/boost charger system changes from buck mode to boost mode and allows the rechargeable battery pack 22 to provide additional power to the system load 18. As a result, the adapter 24 and the rechargeable battery pack 22 together provide sufficient system power, thereby avoiding an adapter crash and enabling the system load 18, including its CPU 14, to receive maximum available power for achieving its highest performance.

[0024] With reference now additionally to FIG. 2, an electrical schematic diagram is shown, illustrating an example of an embodiment of a charger circuit 30 having a voltage boost function that may be used to provide the battery charging and controlling circuits and methods described herein. The charger circuit 30 has a dynamic power management (DPM) circuit 32 that receives input power on input node 34 from an adapter 24 of the type described above which can be selectively connectable thereto.

[0025] The DPM loop 32 includes an input current sensing resistor 36, the nodes on either side of which being designated “ACP” and “ACN,” which are connected as inputs to the charger control loops 38, described below in greater detail. A pair of MOSFET devices 40 and 42 are connected to receive respective high-side and low-side driving voltages from the charger control loops 38, depending on whether the charger is
operating in buck or boost modes. An inductor 44 is connected to the rechargeable battery pack 22 by a charge current sensing resistor 46. The respective sides of the charge current sensing resistor 46 are designated “SRP” and “SRN,” and are connected as inputs to the charger control loops 38, as described in greater detail below. The output power from the charger circuit 30 is represented by the VBUS voltage shown between line 48 and the reference potential, or ground line 50, and by the current source I_{375} 52.

[0026] With reference now additionally to FIGS. 3A and 3B, respectively shown are the feedback amplifier 60, duty cycle and driver circuits 62, and boost stop and start control and circuit 64. The feedback amplifier 60 receives inputs ACP, ACN, SRP, and SRN respectively from the input current sensing resistor 36 and charge current sensing resistor 46, providing an input to the type III compensation circuit 66. The output from the compensation circuit 66 is applied to a control loop saturation determining circuit 68 and to a PWM circuit 70. The output from the control loop saturation determining circuit 68 is connected to the boost stop and start circuit 64, described below, and the output from the PWM circuit 70 is connected to the driver logic circuit 72.

[0027] The start boost and stop boost signals developed in the boost stop and start circuit 64 are also connected as inputs to the driver logic circuit 72. The outputs ISON and I.SON signals are connected to output drivers 74 and 76, which are level adjusted by BTST, PHASE and REGN and GND voltages to provide drive signals to the MOSFET devices 40 and 42 (FIG. 1) at the correct voltage levels.

[0028] The boost start and stop circuit 64 is shown in FIG. 3B, to which reference is now additionally made. The boost start and stop circuit 64 receives inputs representing the voltage difference between ACP and ACN. This voltage difference may be developed, for example, in the feedback amplifier 60 of FIG. 3A, with appropriate scaling.

[0029] With respect to the start boost mode, the voltage difference between ACP and ACN is compared to a reference voltage, for example 1.05xVREF ACN by comparator 80. VREF ACN represents a particular upper current level that is established by the host below which operation of the adapter should be held to avoid crashing the adapter. The comparator 80 has hysteresis so that momentary changes in the ACP-ACN voltage difference do not cause the comparator 80 to change state. The reference voltage is established such that if the voltage difference ACP-ACN developed across the input current sensing resistor 36 reaches a predetermined percentage of the power limit of the adapter 24, in this case 105%, the comparator 80 changes output state.

[0030] The output from the comparator 80 is connected to a delay circuit 82 which operates to shut down the charger and begin a predetermined delay, for example 170 μs in response to the change of state in the output of the comparator 80. If the voltage output from the comparator 80 returns to a low value before the predetermined delay, indicating that the boost mode is not required, the boost mode is not initiated and the charger is turned back on. However, after the expiration of the predetermined delay, the boost start output changes state, triggering the driver logic circuit 72 (FIG. 3A) to turn on the low-side MOSFET device 42 (FIG. 2) via the low-side driver 76 and high-side MOSFET device (FIG. 2) via the high-side driver 74.

[0031] With respect to the stop boost signal, four possible input signals can trigger the stop boost signal. The four signals are applied to an OR gate 83, the output of which being the stop boost signal that is applied to the driver logic circuit 72 (FIG. 3A). The first input signal is an immediate trigger developed by comparator 84 when the voltage difference ACP-ACN is less than a predetermined voltage, such as 10 mV. When this condition occurs, the boost mode is immediately shut down to prevent ACOV (system bus over voltage).

The second input signal is a trigger that occurs when the voltage difference ACP-ACN is a predetermined percentage below the VREF ACN voltage level. In the example illustrated, the percentage is 93%, and is established by the comparator 86. If the voltage difference ACP-ACN is a predetermined percentage below the VREF ACN voltage level, the output from the comparator 84 is not high, a 1 ms delay is timed by a timer 88 to trigger the stop boost output signal.

[0032] In addition, if the control loop is in saturation, determined in block 90, and if the voltage difference ACP-ACN is not a predetermined percentage below the VREF ACN voltage level, the stop boost output signal is triggered. Finally, a watchdog timer 92 is provided to assure that the boost mode does not remain engaged for a predetermined time, such as 175 seconds in the example shown.

[0033] The operation of the charger circuit 30 is illustrated in the flow diagram 99 of FIG. 4, to which reference is now additionally made. To enter boost mode for providing the power from both the adapter 24 and rechargeable battery pack 22 when the system power is higher than what the adapter can provide, a determination is made whether the input current is greater than 105% of IDPM, diamond 100. IDPM is the current threshold setting for the adapter so that at this threshold the charger will reduce charging current and even give discharging current to try to regulate adapter current at this threshold to avoid adapter overload. For example, if a 20 V, 90 W adapter can give 4.5 A current, and a system load is set to trigger at 4.1 A, when the adapter current is above 4.1 A, charging current is reduced to hold the adapter current at 4.1 A. If the adapter current is close to a limit such as 4.4 A, the controller in the system load will throttle to reduce CPU power, so that adapter will not see a current higher than 4.5 A and crash. The 4.1 A is referred to as the IDPM current (DPM dynamic power management current). Thus, the charging current is dynamically changed based on system current, so that the total adapter current is well regulated on or below the IDPM set point.

[0034] If the input current is not greater than 105% of IDPM, the determination is repeated. On the other hand, if the input current is greater than 105% of IDPM, then the charger is immediately shut down, box 102. A delay of a minimum of 100 μs, for example a typical delay may be 170 μs) is initiated, box 104. If the input current is still greater than 105% of IDPM, diamond 106, then the boost mode is started, box 108, if the other conditions are all met. If the input current is not greater than 105% of IDPM, then the process is reinitiated at diamond 100.

[0035] The conditions to trigger the exit from a boost mode are shown in the flowchart 120 in FIG. 5, to which reference is now additionally made. As described above with reference to FIG. 3A, four conditions are concurrently monitored. As shown in diamond 122, a determination is made by comparator 84 to determine whether the input current is above a predetermined level to prevent ACOV, or system bus over voltage. If the input current is less than the predetermined level, for example less than 10 mV for a 10 milliohm sensing resistor, the boost mode is immediately shut down, box 124.
[0036] If the need for boost mode voltage no longer exists, boost mode is also exited. Thus, a determination is made, diamond 126, by comparator 86 whether the input current is less than a predetermined percentage of IDPM, for example 93% in the embodiment illustrated. If it is, a de-glitch time, for example 1 ms, is timed, box 128, after which the boost mode is exited, box 124.

[0037] On the other hand, if the input current is greater than 93% of IDPM but is less than the input current regulation point of the integrator, diamond 130, if the loop integrator hit saturation (see control loop saturation determining circuit 68 in FIG. 3A and control loop saturation box 90 in FIG. 3B) then boost mode is exited, box 124. The delay time depends on the loop response.

[0038] Finally, if the watchdog timer 92 (See FIG. 3B) is enabled, if timer has expired and no charge voltage or current command are to be written, diamond 134, then the boost mode is exited, box 124. Of course, any of the conditions for entering the boost mode still exist, the circuit will reenter the boost mode.

[0039] Various waveforms seen in the operation of the charger circuit 30 of FIG. 2 are shown in FIGS. 6A-6D, to which reference is now additionally made. The system current, I_D2, is shown by waveform 140 in FIG. 6A, illustrating the increased system current in DPM mode. The adapter current, I_L2, is shown by waveform 142 in FIG. 6B, illustrating the operation of the adapter current at the adapter current limit. The battery charge current, I_CHG, is shown by waveform 144 in FIG. 6C, illustrating the drop in charge current due to regulation of the input current. And the constant output voltage is shown by waveform 146 in FIG. 6D.

[0040] One of the advantages of the embodiments described herein is that the existing battery charger topology can be used, but the control method of the embodiments may be used to allow the charger to operate in a buck mode during the battery charging and in a boost mode during the battery discharging for supplementing additional power to the system. Some of the benefits realized include allowing the CPU to operate at high speeds with the high performance, reducing the requirement for increased adapter current capability, eliminating extra cost for the adapter, enabling high power conversion efficiency, reducing the total system cost, and requiring minimum additional power system components.

[0041] Electrical connections, couplings, and connections have been described with respect to various devices or elements. The connections and couplings may be direct or indirect. A connection between a first and second electrical device may be a direct electrical connection or may be an indirect electrical connection. An indirect electrical connection may include interposed elements that may process the signals from the first electrical device to the second electrical device.

[0042] Although the invention has been described and illustrated with a certain degree of particularity, it should be understood that the present disclosure has been made by way of example only, and that numerous changes in the combination and arrangement of parts may be resorted to without departing from the spirit and scope of the invention, as hereinafter claimed.

1. A power supply system connectable to a load, said power supply system comprising:
   a. a rechargeable battery;
   b. a buck mode circuit;
   c. a boost mode circuit;
   and a switching circuit for switching between said buck mode circuit and boost mode circuit for supplying power to the load;
   wherein if the power required by the load reaches a first predetermined level related to an adapter overload condition for a first predetermined time, said switching circuit disconnects said buck mode circuit from said load and connects said rechargeable battery and said boost mode circuit to said load.

2. The power supply system of claim 1 wherein said first predetermined level is established by a first predetermined percent of the current of a dynamic power management level established by the load, which is related to a power level below that which can be provided by the adapter.

3. The power supply system of claim 2 wherein said first predetermined percent of the current of a dynamic power management level established by the load is about 105%.

4. The power supply system of claim 1 wherein if the power required by the load is below a second predetermined level related to the adapter overload condition for a second predetermined time and the boost mode circuit and rechargeable battery are connected to the load, said boost mode circuit and said rechargeable battery are disconnected from the load and said buck mode circuit is started.

5. The power supply system of claim 4 wherein if the power required by the load is below a third predetermined level related to the adapter overload condition and the boost mode circuit and rechargeable battery are connected to the load, said boost mode circuit and said rechargeable battery are disconnected from the load and said buck mode circuit is started, said third predetermined level being less than said second predetermined level.

6. In a power supply system connectable to a load, said power supply system having a rechargeable battery, a charging circuit, and an adapter connectable to receive power from a power supply source, said charging circuit comprising:
   a. buck mode circuitry for selectively supplying power to the load in a normal operating mode;
   b. boost mode circuitry for selectively supplying power to the load in an adapter overload operating mode;
   and switching circuitry for switching between said buck mode circuitry and boost mode circuitry;
   wherein if the power required by the load reaches an adapter overload condition, said charging circuit shuts down, and waits a predetermined time;
   wherein after the predetermined time, the charging circuit checks to determine whether the adapter overload condition still exists;
   wherein if the adapter overload is still exists, said charging circuit changes from said buck mode circuitry to said boost mode circuitry and connects said battery to the load to provide additional power to the load.

7. The power supply system of claim 6 wherein said check to determine whether the adapter is still in the adapter overload condition is based on a system current.

8. The power supply system of claim 6 wherein said adapter overload condition is sensed by a programmable current threshold circuit.

9. The power supply system of claim 6 further comprising an adapter over-voltage protection circuit to disable the boost mode circuitry to prevent said boost mode circuitry from generating too high of a voltage on the load.
10. The power supply system of claim 6 further comprising a watchdog timer configured to change from said boost mode circuitry to said buck mode circuitry after a preset time.

11. The power supply system of claim 6 further comprising a control loop saturation detecting circuit to stop a boost mode operation if a control loop saturates and an adapter current is above a predetermined level.

12. A method for operating a charger circuit having a rechargeable battery, a buck mode circuit, and a boost mode circuit, comprising:
   operating said buck mode circuit to provide power to a load in a normal operating mode;
   sensing an input current to said charger circuit;
   if said input current exceeds a first predetermined percent of a current of a dynamic power management level established by the load, shutting down the charger circuit for a first predetermined time;
   and if said input current continues to exceed the first predetermined percent of a current of a dynamic power management level established by the load after the first predetermined time, starting the boost mode circuit and connecting the rechargeable battery to provide power to the load.

13. The method of claim 12 wherein said first predetermined time is at least 100 μs.

14. The method of claim 12 wherein said dynamic power management level is an input current level established to operate said load in a manner to protect said adapter from an overload condition.

15. The method of claim 12 wherein if the input current is less than a first predetermined level, stopping said boost mode circuit, disconnecting said rechargeable battery from the load, and starting said buck mode circuit.

16. The method of claim 15 wherein said predetermined amount is less than about 1 A for a 10 milliohm sensing resistor.

17. The method of claim 15 wherein if the input current is above said first predetermined level and less than a second predetermined percent of the current of a dynamic power management level established by the load for a second predetermined time, stopping said boost mode circuit, disconnecting said rechargeable battery from the load, and starting said buck mode circuit.

18. The method of claim 17 wherein said second predetermined time is about 1 ms.

19. The method of claim 17 wherein said first predetermined amount is greater than 1 A for a 10 milliohm sensing resistor.

20. The method of claim 17 wherein said second predetermined percent is less than about 95 percent of the dynamic power management level established by the load.

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