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(54) Title: POWER SUPPLY INTERFACE FOR ELECTRIC TOOL POWERED BY A PLURALITY OF BATTERY PACKS

FIG. 5

(57) Abstract: An electric power tool (70; 100) is powered by a plurality of battery packs (10) connected in series. The electric power tool comprises a controller (152, 252) adapted to receive signals outputted from the integrated circuits located in each of the battery packs. A first voltage level-shifter (150b; 250b) is disposed between the controller of the electric power tool and one of the integrated circuits of the battery packs. The first voltage level-shifter is adapted to shift the voltage level of the signal outputted from the respective integrated circuit to the tool controller to an acceptable level for the controller.
DESCRIPTION

POWER SUPPLY INTERFACE FOR ELECTRIC TOOL
POWERED BY A PLURALITY OF BATTERY PACKS

CROSS-REFERENCE TO A RELATED APPLICATION
[0000] This application claims priority to U.S. Patent Application No. 12/888,101 filed on September 22, 2010 and to Japanese Patent Application No. 2010-029506 filed on February 12, 2010, the contents of both of which are hereby incorporated by reference into the present application.

TECHNICAL FIELD
[0001] The present invention relates to a power supply interface for an electric power tool powered by a plurality of battery packs.

DESCRIPTION OF RELATED ART
[0002] U.S. Patent No. 5,028,858 discloses an electric power tool that simultaneously uses two battery packs as a power source. In this electric power tool, the two battery packs are connected in series so that a high voltage is supplied to an electric motor of the electric power tool. As a result, a higher voltage output suitable for power-intensive operations can be generated, which output is higher than is possible when only one battery pack is used as the power source.

SUMMARY
[0003] Nowadays, many battery packs include not only one or a plurality of cells, but also integrated circuits capable of measuring the voltage and/or temperature of the cells. Further, in some battery packs, a CPU is installed in the integrated circuit and various control programs are executed. The integrated circuit of the battery pack may be electrically connected to a controller located inside the electric tool and to a controller located in a charger. The battery pack controller is capable of inputting/outputting a signal voltage to/from the controllers of the tool and the charger.

[0004] For example, in some battery packs, the integrated circuit is configured to output a signal voltage that shuts-off current flow when the discharge voltage of the cells falls below a permissible level! The outputted signal voltage is inputted to the controller of the electric tool,
which immediately stops the operation of the motor. As a result, the battery pack is prevented from being over-discharged. Such a function of monitoring the charge state or level of charge of the battery pack and automatically stopping the operation of the electric tool is called an "autostop function" or simply "autostop", and has already been put to practical use.

Accordingly, in an electric power tool that simultaneously uses two battery packs as the power source, the integrated circuit of each battery pack is electrically connected to the controller of the electric power tool and a signal voltage outputted from each integrated circuit is inputted in the control circuit of the electric tool. However, if the two battery packs are connected in series, the reference voltages (ground voltages) of the integrated circuits differ between the two battery packs, and thus the voltage levels of signals outputted by the integrated circuits also significantly differ from each other.

For example, assuming that two battery packs having a nominal voltage of 18 volts are connected in series, in the first battery pack positioned on a low-voltage side, the reference voltage of the integrated circuit is zero volts, which is equal to the reference or ground voltage of the controller of the electric tool. However, in the second battery pack positioned on a high-voltage side, the reference voltage of the integrated circuit is 18 volts above the reference or ground voltage of the controller of the electric tool, i.e. the reference or ground voltage of the second battery pack is 18 volts. Therefore, when a signal is outputted to the controller of the electric tool, the integrated circuit of the first battery pack outputs a zero volt signal as a low-level signal voltage, and the integrated circuit of the second battery pack outputs an 18 volt signal as its low-level signal voltage. As was noted above, the reference voltage of the controller of the electric tools is usually zero volts. Therefore, the signal voltage outputted from the second battery pack is too high to be useable by the controller of the electric tool, and thus cannot be inputted.

As described above, when a plurality of battery packs are connected in series in an electric tool powered by a plurality of battery packs, a signal voltage outputted from at least one of the integrated circuits cannot be directly inputted to the controller of the electric tool. Conversely, the signal voltage outputted by the controller of the electric tool cannot be directly inputted to at least one of the integrated circuits of the battery packs. As a result, communications between the integrated circuits of the battery packs and the controller of the electric tool are impossible as such and the above-described autostop function cannot be used.
[0008] In one aspect of the present teachings, the above-noted problem is overcome by the power supply interface of claim 1. By providing a voltage level-shifter or DC-to-DC converter between a controller of the electric tool and at least one of the integrated circuits of the battery packs, the voltage level of the signal that is outputted from the one of the integrated circuits to the controller of the electric tool is shifted to an acceptable level for the controller of the electric tool. As a result, even when the plurality of battery packs is connected in series, all of the signals outputted from the different integrated circuits can be inputted into the controller of the electric tool. Consequently, communications between the various integrated circuits of the battery packs and the controller of the electric tool are possible and the above-described autostop function can be implemented.

[0009] In an electric power tool according to one embodiment of the present teachings, it is preferred that a plurality of battery packs is connected in series and used as a power source. Each battery pack has an integrated circuit outputting a signal at a certain voltage, and the electric tool is provided with a controller configured to receive each signal outputted from the integrated circuits of battery packs as input signals. Further, the electric tool includes at least one voltage level-shifter or DC-to-DC converter disposed between the controller and the integrated circuit of at least one battery pack. The level-shifter is configured to shift or proportionally step-down or step-up the voltage level of the signal, which is outputted from the integrated circuit of the battery pack, to an acceptable level for the controller of the electric tool.

[0010] In such an electric tool, the integrated circuit of the battery pack and the controller of the electric tool can communicate, and the electric tool can employ a variety of functions, e.g., the aforementioned autostop function, for preventing the battery packs from being damaged.

[0011] The present teachings can be applied to any type of cordless electric power tool, including but not limited to electric power tools for processing metals, electric power tools for processing wood, electric power tools for processing stone, and electric power tools for gardening. Specific examples include, but are not limited to, electric drills, electric impact and screw drivers, electric impact wrenches, electric grinders, electric circular saws, electric reciprocating saws, electric jig saws, electric band saws, electric hammers, electric cutters, electric chain saws, electric planers, electric nailers (including electric rivet guns), electric staplers, electric shears, electric hedge trimmers, electric lawn clippers, electric lawn mowers,
electric brush cutters, electric blowers (leaf blowers), electric flashlights, electric concrete vibrators and electric vacuum cleaners.

[0012] In one embodiment of the present teachings, it is preferred that each battery pack comprises a plurality of lithium-ion cells and the nominal voltage of the battery packs is equal to or greater than 7.0 volts, more preferably equal to or greater than 12.0 volts and even more preferably equal to or greater than 18.0 volts. Over-discharging and overheating can cause significant damage to lithium-ion cells. Consequently, the present teachings are advantageous for preventing the lithium-ion cells from over-discharging and becoming overheated, thereby lengthening the service life of the battery packs.

[0013] In another embodiment, an electric power tool that normally operates at a rated voltage of 36 volts is preferably driven by two battery packs, each comprising a plurality of lithium-ion cells and each having a nominal voltage of 18 volts. In such an embodiment, the electric power tool having a higher output can be operated with the readily-available lower-voltage battery packs. Thus, the higher-voltage electric power tool (e.g., a 36 volt tool) can be used even if a corresponding high-voltage battery pack (i.e. a 36 volt battery pack) is not available to the user. Such an embodiment is also advantageous, because the lower-voltage battery pack (e.g., an 18 volt battery pack) can also be used with corresponding lower-voltage power tools (e.g., an 18 volt tool), thereby providing greater flexibility and convenience to the user.

[0014] The nominal voltage of a typical lithium-ion cell is 3.6 volts. Therefore, a battery pack having a nominal voltage of 18 volts includes at least five lithium-ion cells connected in series. The battery pack having a nominal voltage of 18 volts may also include, for example, ten lithium-ion cells, wherein five pairs of lithium-ion cells are connected in parallel, and the five pairs of parallel-connected lithium-ion cells are connected in series, whereby a voltage of 18 volts is output. In a similar manner, a battery pack having a nominal voltage of 18 volts can also include 15 or more lithium-ion cells by using such parallel- and series-connected cells. The higher the number of lithium-ion cells, the greater the capacity of the battery pack and consequently the smaller the electric current flowing in each lithium-ion cell during discharge of the battery due to a load being driven thereby.

[0015] In another aspect of the present teachings, a different problem of US Patent No. 5,028,858 is addressed. Specifically, if two or more battery pack interfaces are provided for
powering the power tool with two or more battery packs, one or more of the battery packs can be irreparably damaged if a reverse voltage is generated across the positive and negative battery electrode input terminals of the battery pack(s).

[0016] This problem is solved by the power supply interface of claim 16.

[0017] Additional embodiments of the present teachings are disclosed in the dependent claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] Fig. 1 shows a group of products according to one embodiment of the present teachings;

[0019] Fig. 2 shows a high-voltage electric power tool that simultaneously uses two low-voltage battery packs as a power source;

[0020] Fig. 3 is a top view illustrating the two low-voltage battery packs detached from the main body of the high-voltage electric tool of Fig. 2;

[0021] Fig. 4 is a bottom view illustrating the two low-voltage battery packs detached from the main body of the high-voltage electric tool of Fig. 2;

[0022] Fig. 5 is a schematic circuit diagram illustrating an electric circuit of the high-voltage electric tool of Fig. 2;

[0023] Fig. 6 is a modified example of the electric circuit of Fig. 5 having a bypass circuit added thereto;

[0024] Fig. 7 is a modified example of the electric circuit of Fig. 5, in which the position of the connection to the power supply circuit for the main controller has been changed;

[0025] Fig. 8 is a modified example of the electric circuit of Fig. 5, in which the position of the connection to the power supply circuit for the main controller has been changed and the bypass circuit has been added;

[0026] Fig. 9 shows two low-voltage battery packs connected to the main body of a high-
voltage electric tool via an adapter having a cord connecting a pack side unit with a main body side unit;

[0027] Fig. 10 shows the main body side unit of the adapter of Fig. 9 in greater detail;

[0028] Fig. 11 shows the pack side unit of the adapter of Fig. 9 in greater detail;

[0029] Fig. 12 is a schematic circuit diagram showing a representative electric circuit of the adapter of Figs. 9-11;

[0030] Fig. 13 is a modified example of the electric circuit of Fig. 12 having a bypass circuit added thereto;

[0031] Fig. 14 shows two low-voltage battery packs connected to the main body of a high-voltage electric tool via an integrated or one-piece adapter;

[0032] Fig. 15 shows an upper portion of the integrated adapter of Fig. 14 in greater detail;

[0033] Fig. 16 shows a lower portion of the integrated adapter of Fig. 14 in greater detail;

[0034] Fig. 17 shows a known low-voltage electric tool using one low-voltage battery pack as a power source;

[0035] Fig. 18 is a bottom view corresponding to Fig. 17 after the low-voltage battery pack has been detached from the main body of the low-voltage electric tool;

[0036] Fig. 19 shows the low-voltage battery pack in greater detail;

[0037] Fig. 20 shows a known high-voltage electric tool having one high-voltage battery pack as a power source;

[0038] Fig. 21 is a top view illustrating the high-voltage battery pack detached from the main body of the high-voltage electric tool, and
[0039] Fig. 22 is a bottom view illustrating the high-voltage battery pack detached from the main body of the high-voltage electric tool.

DETAILED DESCRIPTION OF THE INVENTION

[0040] Fig. 1 shows an exemplary, non-limiting group of cordless power tool products according to one embodiment of the present teachings. As shown in Fig. 1, the group of products includes two types of battery packs 10, 30, three types of electric power tools 50, 70, 100, and two types of adapters 200, 300. The "high-voltage" electric power tool 70 is normally intended to use a single "high-voltage" battery pack 30 as a power source. However, the adapters 200, 300 may serve to electrically connect a plurality of "low-voltage" battery packs 10 to a main body 72 of the electric power tool 70 so that the electric power tool 70 is supplied with the same or substantially the same voltage as the "high-voltage" battery pack 30.

[0041] In the present exemplary embodiment, the first battery pack 10 has a nominal voltage of 18 volts and the second battery pack 30 has a nominal voltage of 36 volts. For the sake of convenience in the following description, the first battery pack 10 having the nominal voltage of 18 volts will also be referred to as a "low-voltage battery pack 10" and the second battery pack 30 having the nominal voltage of 36 volts will also be referred to as a "high-voltage battery pack 30".

[0042] The low-voltage battery pack 10 comprises (at least) five lithium-ion cells connected in series. The high-voltage battery pack 30 comprises (at least) ten lithium-ion cells connected in series. The two types of battery packs 10, 30 are preferably rechargeable using a battery charger (not shown in the figures) after being used as power sources for the electric tools 50, 70, 100. Further, the two types of battery packs 10, 30 are preferably so-called "slide-type" battery packs that are attached by sliding into or onto corresponding engagement portions of the electric power tools 50, 70, 100, the adapters 200, 300 or the charger. Such battery packs 10, 30 have already been put to practical use. In particular, the low-voltage battery pack 10 with the nominal voltage of 18 volts has been widely used. However, the structure of the battery pack connection is not particularly limited and a wide variety of battery pack connection mechanisms known in the art also may be advantageously utilized with the present teachings.

[0043] The low-voltage battery pack 10 can incorporate, for example, ten lithium-ion cells, rather than five lithium-ion cells, as was discussed above in the Summary section. In this case,
the ten lithium-ion cells comprise five pairs of lithium-ion cells connected in parallel, and the
five pairs of parallel-connected lithium-ion cells are connected in series to output a voltage of 18 volts. Likewise, the high-voltage battery pack 30 can incorporate, for example, twenty lithium-ion cells, rather than ten lithium-ion cells. In this case, the twenty lithium-ion cells comprise ten pairs of lithium-ion cells connected in parallel and the ten pairs of parallel-connected lithium-ion cells are connected in series to output a voltage of 36 volts.

[0044] In the present exemplary embodiment, the "low-voltage" electric power tool 50 is designed to operate at a nominal voltage of 18 volts and the other two "high-voltage" electric tools 70, 100 are designed to operate at a nominal voltage of 36 volts. For the sake of convenience in the following description, the electric tool 50 operating at the nominal voltage of 18 volts will be referred to as a "low-voltage electric (power) tool 50", and the electric tools 70, 100 operating at the nominal voltage of 36 volts will be referred to as "high-voltage electric (power) tools 70, 100". As will be understood, however, the terms "low-voltage" and "high-voltage" are relative terms and are merely meant to indicate that two battery packs, which normally supply currents at different voltages, and two tools, which normally operate at different voltages, are contemplated by this aspect of the present teachings. It is not necessary that the high-voltage applications are twice the voltage of the low-voltage applications or, in fact, are any particular multiple thereof. For example, in certain applications of the present teachings, two low-voltage (e.g., 18-volt) battery packs 10 may be connected in series to a higher-voltage electric power tool that normally operates at a rated voltage that is not a multiple of the low-voltage battery packs 10, such as, e.g., 24 volts. In this case, voltage step-down circuitry is preferably provided either in the tool or in an adapter 200, 300 that connects the battery packs 10 to the tool.

[0045] As shown in Fig. 17 and Fig. 18, the low-voltage electric tool 50 is designed to normally use one low-voltage battery pack 10 as its sole power source. This low-voltage electric tool 50 is for example an electric impact driver and drives a tool chuck 54 in response to the operation of a main switch 58. A driver set, which is a tool, can be mounted on the tool chuck 54. Such a low-voltage electric tool 50 has already been put to practical use and has been widely sold together with the low-voltage battery pack 10 having the nominal voltage of 18 volts.

[0046] The main body 52 of the low-voltage electric tool 50 includes one battery interface 60. The battery interface 60 is configured to removably receive or attach the low-voltage battery
pack 10, and the low-voltage battery pack 10 can be slidably received or attached therein. The battery interface 60 has a pair of rails 62, a positive electrode input terminal 64a, a negative electrode input terminal 64b, and a latch receiving hole 68. A battery controller input/output terminal is also preferably provided, but is not shown in Fig. 18.

[0047] As shown in Fig. 19, the low-voltage battery pack 10 includes a connector 20 that can be slidingly inserted into the battery interface 60. The connector 20 includes a pair of rails 22, a positive electrode output terminal 24a, a negative electrode output terminal 24b, and an autostop terminal 26. When the low-voltage battery pack 10 is slidably attached to the battery interface 60, the positive electrode output terminal 24a of the low-voltage battery pack 10 is electrically connected to the positive electrode input terminal 64a of the main body 52, and the negative electrode output terminal 24b of the low-voltage battery pack 10 is electrically connected to the negative electrode input terminal 64b of the main body 52. In addition, the autostop terminal 26 is connected to the battery controller input/output terminal. As a result of this sliding connection, the low-voltage battery pack 10 is also physically connected to the main body 52 of the low-voltage electric tool 50 and the battery cells 16 (see e.g., Fig. 5) are electrically connected with the internal circuitry of the tool 50. Further, the low-voltage battery pack 10 has a latch member 12 that engages with the latch receiving hole 68 of the battery interface 60 and detachably affixes the low-voltage battery pack 10 to the battery interface 60. The latch member 12 can be released from the latch receiving hole 68 by operating a latch release button 14.

[0048] The two types of high-voltage electric tools 70, 100 will be explained below. The first high-voltage electric tool 70 is designed to be normally operated using one high-voltage battery pack 30 as the sole power source, as will now be explained with reference to Figs. 20, 21, and 22. The high-voltage electric tool 70 may be, e.g., an electric blower that includes a blower fan disposed in the main body 72 that is rotatably driven in response to the operation of a main switch 78. The electric blower 70 is an electric power tool normally used for gardening and cleaning-up purposes by propelling air from a tip 73a of a nozzle 73 to move debris, such as dead leaves. The high-voltage electric tool 70 operating at a nominal voltage of 36 volts has already been put to practical use together with the high-voltage battery pack 30 that outputs a nominal voltage of 36 volts.

[0049] Referring to Fig. 22, the main body 72 of the high-voltage electric tool 70 has one battery interface 80. The battery interface 80 is configured to removably attach to the high-
voltage battery pack 30, and the high-voltage battery pack 30 can be slidably received therein. The battery interface 80 includes a pair of rails 82, a positive electrode input terminal 84a, a negative electrode input terminal 84b, a battery controller input/output terminal 86 and a latch receiving hole 88.

[0050] The high-voltage battery pack 30 includes a connector 40 that can be slidingly inserted into the battery interface 80, as shown in Fig. 21. The connector 40 includes a pair of rails 42, a positive electrode output terminal 44a, a negative electrode output terminal 44b, and an autostop terminal 46. When the high-voltage battery pack 30 is attached to the battery interface 80, the positive electrode output terminal 44a of the high-voltage battery pack 30 is connected to the positive electrode input terminal 84a of the battery interface 80, and the negative electrode output terminal 44b of the high-voltage battery pack 30 is connected to the negative electrode input terminal 84b of the battery interface 80. Further, the autostop terminal 46, which is electrically connected to a controller of the battery pack 30 as will be discussed further below, is connected to the battery controller input/output terminal 86. As a result, the high-voltage battery pack 30 is electrically connected to the circuitry inside the main body 72 of the high-voltage electric tool 70. Further, the high-voltage battery pack 30 has a latch member 32 that engages with the latch receiving hole 88 of the battery interface 80 and detachable affixes the high-voltage battery pack 30 to the battery interface 80. The latch member 32 can be released from the latch receiving hole 88 by operating a latch release button 34.

[0051] The connectors 20, 40 of the low-voltage battery pack 10 and the high-voltage battery pack 30 may have basically the same or similar structures. However, the sizes of the connectors 20, 40 may differ, e.g., the spacing between the rails 22, 42 may differ. In this case, the low-voltage battery pack 10 cannot be attached to the battery interface 80 of the high-voltage electric tool 70, and the high-voltage battery pack 30 cannot be attached to the battery interface 60 of the low-voltage electric tool 50. In other words, due to the size differences in the connectors 20, 40, the battery interface 80 is a dedicated interface for the high-voltage battery pack 30, and the battery interface 60 is a dedicated interface for the low-voltage battery pack 10. Further, in another embodiment, the interfaces 60, 80 may be dedicated, in addition or in the alternative, based upon differences in the shapes of the connectors 20, 40.

[0052] Referring now to Figs. 2-4, the second high-voltage electric tool 100 is designed to be normally operated, on the other hand, by simultaneously using two low-voltage battery packs 10
as its power source. The high-voltage electric tool 100 also may be an electric blower having a blower fan rotatably supported in a main body 102 that is driven in response to the operation of a main switch 108. The electric blower 100 is basically identical to the above-described electric blower 70 in terms of functions and applications thereof.

[0053] In order to utilize current simultaneously supplied from two battery packs 10, the main body 102 of the high-voltage electric tool 100 includes a power supply interface 120 comprising two individual battery (pack) interfaces 130. Each battery interface 130 is configured to removably and, e.g., slidably, receive or attach one low-voltage battery pack 10. Each battery interface 130 includes a pair of rails 132, a positive electrode input terminal 134a, a negative electrode input terminal 134b, a battery controller input/output terminal 136 and a latch receiving hole 138. The battery interface 130 is substantially identical to the battery interface 60 of the above-described low-voltage electric tool 50 in terms of the respective structures. The two battery interfaces 130 are arranged side by side in the rear portion of the main body 102, and the low-voltage battery packs 10 can be inserted in the same direction. The two low-voltage battery packs 10 attached to the two battery interfaces 130 are connected in series and supply current to the circuitry of the main body 102 at about 36 volts.

[0054] The main body 102 of the high-voltage electric tool 100 also includes two indicators 160 respectively positioned above the two battery interfaces 130. Each indicator 160 comprises, e.g., one or more light-emitting diodes, or another means for visually communicating battery condition information to the tool user, such as but not limited to one or more incandescent lamps and/or a display, such as an LCD. In a preferred embodiment, one of the indicators 160 may indicate a charge state or level of charge of the low-voltage battery pack 10 attached to one battery interface 130, and the other indicator 160 may indicate the same condition (i.e., level of charge) or another condition of the low-voltage battery pack 10 attached to the other battery interface 130. More preferably, both indicators 160 indicate the charge state or the level of charge of the corresponding low-voltage battery pack 10. For example, the light-emitting diode can be illuminated when the charge state drops to a level at which recharging of the battery pack 10 is necessary. It is further preferred that each indicator 160 indicates the charge state of its corresponding low-voltage battery pack 10 at least in two levels, e.g., a yellow "low-charge warning" and red "immediately stop tool use" indication. A third green "tool operation permitted" LED also may be optionally provided, so that the tool user can receive visual confirmation that the battery is in a suitable condition for use. It is also preferred that one or
more indicators 160 communicate information concerning a possible battery temperature abnormality (e.g., overheating) of the corresponding low-voltage battery pack 10, instead of or in addition to the charge state of the corresponding low-voltage battery pack 10.

[0055] As shown in Fig. 2, the two indicators 160 are arranged side by side on a rear surface 102a of the high-voltage electric tool 100 and have the same indication direction (that is, the direction of illumination of the two light-emitting diodes is the same or substantially the same). Therefore, the user can see both indicators 160 simultaneously and can simultaneously recognize the respective charge states of the two low-voltage battery packs 10 in a convenient and reliable manner. Further, the indicators 160 are disposed above the corresponding battery interfaces 130. Therefore, for example, if the high-voltage electric tool 100 abruptly stops, the user can immediately and conveniently determine which of the low-voltage battery packs 10 has experienced a problem or abnormality. In addition or in the alternative to the rear surface 102a, the two indicators 160 could be disposed in other locations that can be simultaneously viewed by the user, such as an upper surface of the main body 102. More particularly, it is preferred that the two indicators 160 are disposed generally in the same plane, so that the user can simultaneously see the two indicators 160 from various different directions.

[0056] In addition or in the alternative, one or more indicators 160 can be also provided on an outer surface of each low-voltage battery pack 10, e.g. a surface of the battery pack 10 that faces rearward when the battery pack 10 is attached to the tool 100. As was already explained above, it is preferred that the two battery interfaces 130 are arranged side by side and can slidably receive the low-voltage battery packs 10 in the same direction. In such an embodiment, when the two low-voltage battery packs 10 are attached to the main body 102, the two indicators 160 will be positioned side by side in the same plane and the indication or illumination direction thereof will also be the same or substantially the same. As a result, even if the indicators 160 are disposed on the respective battery packs 10, the user can simultaneously view the two indicators 160 from various different directions.

[0057] An exemplary electric circuit for the high-voltage electric tool 100, as well as for the two low-voltage battery packs 10 serving as the power source for the tool 100, will be explained below with reference to Fig. 5. Each low-voltage battery pack 10 comprises five battery cells 16 connected in series and a battery controller 18, preferably a microprocessor. Each cell 16 is preferably a lithium-ion cell and the nominal voltage thereof is 3.6 volts. The five cells 16
connected in series are connected to the positive electrode output terminal 24a and negative electrode output terminal 24b, and current can flow across the two terminals 24a, 24b at a voltage of about 18 volts. As shown in Fig. 5, the negative electrode output terminal 24b of the upper low-voltage battery pack 10 is electrically connected to the positive electrode output terminal 24a of the lower low-voltage battery pack 10 via the terminals 134a and 134b, which are conductively connected by a wire. As a result, when the two low-voltage battery packs 10 are connected to the respective battery interfaces 130, the battery cells 16 of the two low-voltage (18 volt) battery packs 10 are connected in series and supply current to the circuitry of the main body 102 at a voltage of about 36 volts.

[0058] The battery controller 18 preferably comprises an integrated circuit that includes a CPU and can execute various programs stored therein. The battery controller 18 is electrically connected to each cell 16 and can measure the voltage of each cell 16. The battery controller 18 may be programmed to perform an algorithm, wherein the controller 18 determines the charge state or level of charge of each cell 16 based on the measured voltage of each cell 16, compares the measured voltage to a predetermined, stored threshold value and then outputs an autostop signal (AS signal) to the autostop terminal 26 when at least one cell 16 is determined to require recharging based upon the comparison step. In this case, the autostop signal may be a signal, e.g., indicating that a high impedance has been detected. In this embodiment, and all other embodiments disclosed herein, the autostop signal may preferably be a digital logic signal that is selected from one of two different voltage levels, i.e. a "1" or "0" digital signal that has a distinctly different voltage level signal as compared to a "battery normal" signal. However, it is also contemplated that the battery controller 18 may be an analog circuit or a mixed analog/digital circuit (e.g., a state machine) and the battery controller 18 may output analog signals (e.g., signals having more than two voltage levels) as the autostop signal. Naturally, the battery controller 18 is not limited to outputting only "autostop" signals, but may also be configured or programmed to output a wide variety of signals, e.g., representing one or more conditions of the battery, such as battery temperature, battery voltage, battery impedance, etc.

[0059] The main body 102 is provided with a motor 176 that drives the tool (in this exemplary embodiment, a blower fan). The two low-voltage battery packs 10 are connected in series with the motor 176 via a main switch 178. The main body 102 is provided with a speed adjusting circuit 190, a power FET 194, a gate-voltage-controlling transistor 192, and a voltage division circuit 196. The power FET 194 is connected in series with the motor 176 and can shut off the
electric current flowing to the motor 176. The speed adjusting circuit 190 performs pulse width modulation control for controlling the current flow through the power FET 194 and thus can adjust the rotational speed of the motor 176 in a manner well known in the power tool field. The gate-voltage-controlling transistor 192 is connected to the gate of the power FET 194 and, together with the voltage division circuit 196, can control the gate voltage of the power FET 194.

[0060] The main body 102 is also provided with a main controller 152, a power supply circuit 142 for the main controller 152, a shunt resistor 150 connected in series with the motor 176, a current detection circuit 148 that detects the electric current flowing to the motor 176 based on the voltage of the shunt resistor 150, and an autostop signal (AS signal) input/output circuit 144 that inputs/outputs autostop signals to/from the gate control transistor 192.

[0061] The main controller 152 is preferably an integrated circuit including a CPU and can execute various programs stored therein. For example, the main controller 152 may be programmed to perform the following algorithm. After receiving a voltage signal outputted by a current detection circuit 148 as an input signal, the main controller 152 compares the voltage signal to a pre-set, stored threshold/permissible value and then outputs an autostop signal to the gate-voltage-controlling transistor 192 via the autostop signal input/output circuit 144 when the electric current of the motor 176 exceeds the pre-set permissible value. In this case, the gate-voltage-controlling transistor 192 decreases the voltage coupled to the gate of the power FET 194 to the ground voltage, thereby shutting off the power FET 194. As a result, the motor 176 and the low-voltage battery pack 10 are electrically disconnected and an overload of the motor 176 and the low-voltage battery pack 10 may be prevented. A fuse 162 for preventing an excessive current from flowing between the motor 176 and the low-voltage battery pack 10 may also optionally be provided in the circuit path between the motor 176 and the low-voltage battery pack 10.

[0062] The main controller 152 is electrically connected to the battery controller input/output terminal (hereinafter "autostop terminal") 136 of the battery interface 130 and can receive a signal voltage (for example, an autostop signal) from the battery controller 18 as an input signal and can output a signal voltage (for example, a discharge protection cancellation signal) to the battery controller 18. In this case, because two low-voltage battery packs 10 are connected in series, the reference voltages (ground voltages) of the two low-voltage battery packs 10 differ from each other. More specifically, whereas the reference voltage of the low-voltage battery
pack 10 positioned at the low-voltage side (lower side in Fig. 5) will be referred to as a zero volt
ground, the reference voltage of the low-voltage battery pack 10 positioned at the high-voltage
side (upper side in Fig. 5) is 18 volts due to the series connection via terminals 24a, 134a, 134b,
24b. The reference voltage of the main body 102 is equal to the reference voltage of the low-
voltage battery pack 10 at the low-voltage side and is thus also zero volts. As a result, the levels
of the inputted and outputted signal voltages differ significantly between the main controller 152
of the main body 102 and the battery controller 18 of the upper low-voltage battery pack 10
positioned at the high-voltage side. Consequently, the signal voltages cannot be directly inputted
and outputted between the controllers 18, 152 unless a conversion (e.g., a step-down, step-up or
other voltage level shift) of the signal voltages is first performed.

[0063] To overcome this problem, the high-voltage electric tool 100 of the present embodiment
also includes two voltage level-shifters (e.g., DC-to-DC converters) 154b, 156b provided
between the battery controller 18 of the low-voltage battery pack 10 positioned at the high-
voltage side and the main controller 152 of the main body 102. One level-shifter 154b is
provided on a conductive path 154 that conducts a signal voltage from a first output terminal
157b of the main controller 152 to the battery controller 18 and raises, preferably proportionally
raises, the level of the signal voltage outputted by the main controller 152 to an acceptable or
readable level for the battery controller 18. The other level-shifter 156b is provided on a
conductive path 156 for conducting a signal voltage from an input terminal 157a of the battery
controller 18 to the main controller 152 and lowers, preferably proportionally lowers, the level of
the signal voltage outputted by the battery controller 18 to an acceptable or readable level for the
main controller 152. As a result, signals can be communicated (i.e. input and output) between
the battery controller 18 and the main controller 152 without any problem caused by the different
ranges of voltages at which the two controllers 18, 152 operate.

[0064] Further, cut-off switches 154a, 156a are also provided between each battery controller
18 and the main controller 152. One cut-off switch 154a is provided on the conductive path 154
for conducting the signal voltage from the main controller 152 to the battery controller 18, and
the other cut-off switch 156a is provided on the conductive path 156 for conducting a signal
voltage from the battery controller 18 to the main controller 152. The cut-off switches 154a,
156a are controlled by the main controller 152. When the main controller 152 determines that
the high-voltage electric tool 100 has not been used for a predetermined time, the main controller
152 switches off the cut-off switches 154a, 156a via a second output terminal 157c; thereby
electrically disconnecting the battery controllers 18 from the main controller 152. As a result, leakage current is prevented from flowing for too long of a time between the battery controllers 18 and the main controller 152, thereby preventing the low-voltage battery pack 10 from being excessively discharged. The cut-off switches 154a and 156b are electrically connected between the main controller 152 and respective battery controllers 18 via the respective wires 154, 156, through which a leakage current may flow.

[0065] It should be understood that the arrangement of the cut-off switch(es) of the present teachings is not limited to the arrangement shown in the present embodiment. For example, if there are a plurality of wires through which a leakage current may possibly flow between the main controller 152 and one battery controller 18, the cut-off switch(s) may be provided in one or some, but not all, of the conductive paths. In another alternative embodiment, in which a plurality of battery packs is connected to the main controller, the cut-off switch(s) may be provided between the main controller 152 and only one or some of the battery packs (e.g., only the first battery pack #1 or the second battery pack #2).

[0066] As described hereinabove, when the charge state of the cells 16 is detected as having decreased below a pre-determined threshold, the battery controller 18 outputs an autostop signal to the autostop terminal 26, which is electrically connected to the autostop terminal 136. The autostop signal outputted from the battery controller 18 is input into the main controller 152 via the conductive path 156: The main controller 152 receives the autostop signal from the battery controller 18 and outputs an autostop signal to the gate-voltage-controlling transistor 192. In this case, the autostop signal outputted by the main controller 152 is conducted to the gate of the gate-voltage-controlling transistor 192 via an autostop signal input/output circuit 144. As a result, the gate-voltage-controlling transistor 192 is turned on (i.e. becomes conductive), the power FET 194 is shut off, and current supply to the motor 176 is stopped. The low-voltage battery pack 10 is thus prevented from being over or excessively discharged.

[0067] In addition, when the main controller 152 receives the autostop signal from the battery controller 18, the indicator (LED of indication circuit) 160 is preferably illuminated. In this case, the main controller 152 selectively illuminates only the indicator 160 corresponding to the low-voltage battery pack 10 that has outputted the autostop signal. As a result, the user can immediately determine which low-voltage battery pack 10 requires charging.
As described herein above, the high-voltage electric tool 100 has two battery interfaces 130 configured to removably receive respective low-voltage battery packs 10 and can simultaneously use two low-voltage battery packs 10 as the power source. The two low-voltage battery packs 10 are connected in series to the motor 176 and supply a voltage of 36 volts to the motor 176. Thus, the high-voltage electric tool 100 with a rated voltage of 36 volts is driven by two low-voltage battery packs 10, each having a nominal voltage of 18 volts. The user can power the high-voltage electric tool 100 by using already available low-voltage battery packs 10, without having to purchase the high-voltage battery pack 30 and a charger therefor. Each low-voltage battery pack 10 also can be used individually as a sole power source for the low-voltage electric tool 50. Therefore, the user can effectively use the already available low-voltage battery packs 10 and the battery charger therefor.

Fig. 6 illustrates an example in which the electric circuit of the high-voltage electric tool 100 has been modified. In this modified example, two bypass circuits 158 are added to the circuit shown in Fig. 5. One bypass circuit 158 is provided for each respective low-voltage battery pack 10 connected with the main controller 152. Each bypass circuit 158 connects the positive electrode input terminal 134a with the negative electrode input terminal 134b for one battery pack 10 via a diode 158a. Thus, the bypass circuit 158 connects the positive electrode output terminal 24a with the negative electrode output terminal 24b of each low-voltage battery pack 10 via the diode 158a. In this embodiment, one bypass circuit 158 is provided for each of the battery packs 10 connected with the main controller 152. Note that the arrangement of the bypass circuit(s) of the present teachings is/are not limited to the above embodiment. For example, the bypass circuit may be provided between only some of the battery packs (e.g., only the first battery pack #1 or the second battery pack #2).

The anode of the diode 158a is connected to the negative electrode input terminal 134b, and the cathode of the diode 158a is connected to the positive electrode input terminal 134a. Therefore, electric current normally does not flow in the diode 158a, and the positive electrode output terminal 24a and the negative electrode output terminal 24b of the low-voltage battery pack 10 are electrically disconnected. However, when the low-voltage battery pack 10 becomes over-discharged and a reverse voltage is generated across the output terminals 24a, 24b of the low-voltage battery pack 10, electric current is caused to flow in the diode 158a. Thus, the output terminals 24a, 24b of the battery pack 10 become electrically connected via the bypass circuit 158. As a result, even if only one low-voltage battery pack 10 becomes over-discharged,
any damage caused to that low-voltage battery pack 10 can be minimized or even prevented. A fuse 158b also may be optionally provided in the bypass circuit 158. In this case, if a large current flows in the bypass circuit 158, the bypass circuit 158 will be physically disconnected by the fuse 158b, which has melted or otherwise broken the connection due to the excessive current. As a result, any damage caused to the low-voltage battery pack 10 can be minimized or prevented, for example, even when Zener breakdown occurs in the diode 158a. The fuse 158b is preferably accessible by the user so that it can be replaced, in case it is broken.

[0071] Fig. 7 illustrates another modified example of the electric circuit of the high-voltage electric tool 100. In this modified example, the attachment position of the power supply for the main controller 152 in the circuit shown in Fig. 5 has been changed. As shown in Fig. 7, the main switch 178 is inserted between the low-voltage battery pack 10 and the power supply circuit 142. Thus, when the main switch 178 is switched off, the current flow to the main controller 152 is simultaneously shut off. As a result, the main controller 152 can be prevented from unnecessarily consuming power in an inactive state of the high-voltage electric tool 100.

[0072] Fig. 8 illustrates another modified example of the electric circuit of the high-voltage electric tool 100. In this modified example, two bypass circuits 158 are added to the circuit shown in Fig. 7. The structure, functions, and effect of the bypass circuits 158 are same as described with reference to the embodiment shown in Fig. 6.

[0073] Two types of adapters (power supply interfaces) 200, 300 are also disclosed in the present teachings, namely a cored adapter 200 and an integrated adapter 300. The cored adapter 200 will be explained first with reference to Figs. 9, 10, and 11. The tool shown in Figs. 9 and 10 corresponds to the tool 70 shown in Figs. 19-22, which was described above and is incorporated herein by reference. As shown in Fig. 9, the adapter 200 is configured to connect a plurality of low-voltage battery packs 10 to the high-voltage electric tool 70. The adapter 200 is provided with a main body side unit 202 configured to be detachably attached to the main body 72 of the high-voltage electric tool 70, a pack side unit 206 configured to removably receive or attach a plurality of low-voltage battery packs 10, and an electric cord 204 that physically and electrically connects the main body side unit 202 to the pack side unit 206. An attachment hook 206a optionally may be provided on the pack side unit 206 to enable it to be attached to the user's clothing or belt or another article supported by the user's body, so that the adapter 200 and attached battery packs 10 can be conveniently carried during operation of the tool 70.
As shown in Fig. 10, the main body side unit 202 has an outer contour that generally conforms to the outer contour of the high-voltage battery pack 30. A connector (power tool interface) 220 is provided on the main body side unit 202 in the same manner as on the high-voltage battery pack 30. The connector 220 can be slidingly inserted into the battery interface 80 provided on the main body 72 of the high-voltage electric tool 70 at a voltage of about 36 volts. The adapter 200 enables the power voltage of the battery pack 80, which is connected to the input/output interface provided on the main body 72 of the high-voltage electric tool 70, to be changed to the power voltage of the battery pack 30. The adapter 200 is configured to be removably connected to the battery interface 80 on the main body side unit 202. The adapter 200 includes a pair of rails 222, a positive electrode output terminal 224a, a negative electrode output terminal 224b, and an autostop terminal 226. When the main body side unit 202 is attached to the battery interface 80, the positive electrode output terminal 224a of the main body side unit 202 is connected to the positive electrode input terminal 84a of the battery interface 80, and the negative electrode output terminal 224b of the main body side unit 202 is connected to the negative electrode input terminal 84b of the battery interface 80. Further, the autostop terminal 226 is connected to the battery controller input/output (autostop) terminal 86. As a result, the main body side unit 202 is electrically connected to the internal circuitry of the main body 72 of the high-voltage electric tool 70. Further, the main body side unit 202 has a latch member 212 that is engaged with the latch receiving hole 88 (see Fig. 22) of the battery interface 80 and is configured to detachably affix the main body side unit 202 to the battery interface 80. This engagement of the latch receiving hole 88 with the latch member 212 can be released by the latch release button 214.

As shown in Fig. 11, the pack side unit 206 includes two battery interfaces 230. Each battery interface 230 can removably receive or attach one low-voltage battery pack 10, and the low-voltage battery pack 10 can be slidably received thereby. The battery interface 230 has a pair of rails 232, a positive electrode input terminal 234a, a negative electrode input terminal 234b, a battery controller input/output (autostop) terminal 236 and a latch receiving hole 238. With respect to the structure, the battery interface 230 is substantially identical to the battery interface 60 of the low-voltage electric tool 50 explained hereinabove with respect to Figs. 17 and 18 and incorporated herein by reference. The two battery interfaces 230 are arranged side by side on the lower surface of the pack side unit 206 and the low-voltage battery packs 10 are respectively inserted therein in the same direction. The two low-voltage battery packs 10 attached to the pack side unit 206 are connected in series to the positive electrode output terminal 224a and the negative electrode output terminal 224b of the connector 220. As a result, the two low-voltage battery packs 10 supply current to the internal circuitry of the main body 72 of the high-voltage electric tool 70 at a voltage of about 36 volts. The adapter 200 enables the power
tool 70 having the battery interface 80 dedicated for the high-voltage battery pack 30 to be connected to the low-voltage battery packs 10 and to be driven thereby. In addition, the autostop terminal 26 of the battery pack 10 is connected to the autostop terminal 236 of the pack side unit 206.

[0076] As shown in Fig. 11, the pack side unit 206 also includes two indicators 260. The two indicators 260 are respectively positioned above the two battery interfaces 230. Each indicator 260 is for example a light-emitting diode, but may be any other device that is capable of visually communicating information about the status of the attached battery pack 10, such as one or more incandescent lamps or one or more LCDs. The teachings concerning the indicator 160 discussed above with respect to the embodiment of Figs. 2-4 are equally applicable to the present embodiment and thus the above-teachings concerning the indicator 160 are incorporated herein. Thus, for example, one indicator 260 may indicate a charge state or level of charge of the low-voltage battery pack 10 attached to one battery interface 230, and the other indicator 260 may indicate the same condition (level of charge) or another condition of the low-voltage battery pack 10 attached to the other battery interface 230. Each indicator 260 preferably indicates at least the charge state of its corresponding low-voltage battery pack 10. For example, the light-emitting diode can be illuminated when the charge state drops below a level at which recharging becomes necessary. Like the indicator 160, it is again preferred that the indicator 260 indicates the charge state of its corresponding low-voltage battery pack 10 at least in two levels. Also similar to the indicator 160, it is again preferred that the indicator 260 indicates a temperature abnormality of its corresponding low-voltage battery pack 10, instead of or in addition to the charge state thereof.

[0077] The two indicators 260 are preferably arranged side by side on one surface of the pack side unit 206 and have the same or substantially the same indication direction (that is, the same or substantially the same illumination direction of light-emitting diodes). Therefore, the user can see the two indicators 260 simultaneously and can simultaneously recognize the charge states of the two low-voltage battery packs 10. Further, the indicators 260 are preferably disposed above the corresponding battery interfaces 230. Therefore, for example, if the high-voltage electric tool 70 abruptly stops, the user can immediately determine which low-voltage battery pack 10 has experienced a problem or abnormality. The two indicators 260 can be also disposed, for example, on the main body side unit 202, rather than on the pack side unit 206. The two indicators 260 can be also arranged in other locations that can be simultaneously viewed by the
user. It is preferred that the two indicators 260 are disposed in the same plane, so that the user
can simultaneously see the two indicators 260 from various directions.

[0078] Similar to the indicator 160, the indicator 260 can be also provided in each low-voltage
battery pack 10. As has already been explained above, the two battery interfaces 230 are
arranged side by side and can receive the low-voltage battery packs 10 in the same direction.
Therefore, when the two low-voltage battery packs 10 are attached to the pack side unit 206, the
two indicators 260 are positioned side by side in the same plane and the direction of illumination
is also the same. The user can thus simultaneously view the two indicators 260 from various
directions.

[0079] An exemplary electric circuit of the adapter 200 will be explained below with reference
to Fig. 12. As will be readily understood from a comparison of Fig. 12 with Fig. 5, the circuit of
the adapter 200 is substantially identical to a part of the circuit disposed in the main body 102 of
the above-described high-voltage electric tool 100. More specifically, a combination of the
circuit of the main body 72 of the high-voltage electric tool 70 and the circuit of the adapter 200
shown in Fig. 12 is substantially identical to the circuit of the main body 102 of the high-voltage
electric tool 100 shown in Fig. 5 (however, the power FET 246 is absent in Fig. 5).

[0080] First, the circuit of the main body 72 of the high-voltage electric tool 70 shown in Fig.
12 will be explained. The main body 72 of the high-voltage electric tool 70 is provided with a
motor 76, a main switch 78, a speed adjusting circuit 90, a power FET 94, a gate-voltage-
controlling transistor 92, and a voltage division circuit 96. The configurations of these
components may be identical to those of the motor 176, main switch 178, speed adjusting circuit
190, power FET 194, gate-voltage-controlling transistor 192, and voltage division circuit 196 of
the main body 102 of the high-voltage electric tool 100 described above with reference to Figs.
5-8 and therefore an explanation thereof is not necessary here. Two low-voltage battery packs
10 are thus connected in series to the motor 76 via the adapter 200.

[0081] The adapter 200 is provided with a main controller 252, a power source circuit 242, a
shunt resistor 250, a current detection circuit 248, an autostop signal input/output circuit 244, and
a fuse 262. The main controller 252 is electrically connected to two indicators 260. The
configurations of these components may be identical to those of the main controller 152, power
source circuit 142, shunt resistor 150, current detection circuit 148, autostop signal input/output
circuit 144, indicator 160, and fuse 162 in the main body 102 of the high-voltage electric tool 100 and therefore an explanation thereof also is not necessary here.

[0082] The adapter 200 is further provided with a power FET 246 between a negative electrode input terminal 234b connected to the low-voltage battery pack 10 and a negative electrode output terminal 224b connected to the high-voltage electric tool 70. Thus, two low-voltage battery packs 10 are electrically connected to the motor 76, and a discharge current produced by the two series-connected low-voltage battery packs 10 flows through this circuit. The main controller 252 is connected to the gate of the power FET 246 and can control the power FET 246. For example, the main controller 252 may shut off the power FET 246 when the output voltage of the current detection circuit 248 exceeds a predetermined value.

[0083] The functions of the power FET 246 will be explained below. When the adapter 200 is detached from the high-voltage electric tool 70, the connector 220 of the adapter 200 is exposed. When the two low-voltage battery packs 10 are attached to the adapter 200 in this state, a voltage of about 36 volts is generated across the positive electrode output terminal 224a and the negative electrode output terminal 224b in the connector 220. The positive electrode output terminal 224a and the negative electrode output terminal 224b are disposed in a slot of the adapter 200 as shown in Fig. 10. Therefore, foreign matter is generally prevented from coming into contact with the two output terminals 224a, 224b. However, the possibility of the foreign matter coming into contact with the two output terminals 224a, 224b cannot be completely excluded. For example, if the two output terminals 224a, 224b were to be short circuited by foreign matter, a very large current flow could be generated inside the low-voltage battery pack(s) 10 or adapter 200. In the circuit according to the present embodiment, the power FET 246 is provided inside the adapter 200 so that, after the adapter 200 has been removed from the high-voltage electric tool 70, if very large current is detected, the circuit and thus the current flow can be cut off by the power FET 246.

[0084] The main controller 252 is electrically connected to an autostop terminal 236 of the battery interface 230 and can receive an input signal voltage (for example, an autostop signal) from the battery controller 18 and can output a signal voltage (for example, a discharge protection cancellation signal) to the battery controller 18. Cut-off switches 254a, 256a are provided, respectively, in a conductive path 254 that conducts the signal voltage from the main controller 252 to the battery controller 18 and in a conductive path 256 that conducts a signal
voltage from the battery controller 18 to the main controller 252. Further, level-shifters 254b, 256b are also provided in the conductive paths 254, 256, respectively, in order to adjust the voltage of signals output from the battery controller 18 of the low-voltage battery pack 10 that is positioned on the high-voltage side, as was discussed above with respect to the exemplary level shifters 154b, 156b of Figs. 5-8. Thus, the cutoff switches 154a, 156a and level shifters 154b, 156b described above with respect to the high-voltage electric tool 100 may be used without modification in the present embodiment and therefore an explanation thereof is not necessary here.

[0085] As described hereinabove, by using the adapter 200, the high-voltage electric tool 70 (which is designed to normally attach only one battery pack at the battery interface 80) can be operated with two low-voltage battery packs 10. By connecting the two low-voltage battery packs 10 in series to the motor 76, it is possible to supply a voltage of about 36 volts to the motor 76. As a result, the high-voltage electric tool 70 with a rated voltage of 36 volts can be driven by two low-voltage battery packs 10, each having a nominal voltage of 18 volts. Thus, the high-voltage electric tool 70 can be operated using already available low-voltage battery packs 10, without the need to purchase a high-voltage battery pack 30 that supplies a nominal voltage of 36 volts or the charger therefor. Each low-voltage battery pack 10 can also be individually used as the sole power source for the low-voltage electric tool 50, which operates with an 18 volt battery pack.

[0086] Fig. 13 illustrates a modified example of the electric circuit of the adapter 200. In this modified example, two bypass circuits 258 are added to the circuit shown in Fig. 12. One bypass circuit 258 is provided for each respective low-voltage battery pack 10. The bypass circuit 258 includes a diode 258a and a fuse 258b. These bypass circuits 258 may be identical to the bypass circuits 158 of the high-voltage electric tool 100 described above with respect to Figs. 6 and 8 and therefore an explanation thereof is not necessary here.

[0087] Another (integrated) adapter 300 will be explained below with reference to Figs. 14, 15, and 16. The tool shown in Figs. 14-16 corresponds to the tool 70 shown in Figs. 19-22, which was described above and is incorporated herein by reference. As shown in Fig. 14, the adapter 300 also serves to connect a plurality of low-voltage battery packs 10 to the high-voltage electric tool 70. Similar to the adapter 200, the adapter 300 also enables the power tool 70 having the battery interface 80 designed to receive the high-voltage battery pack 30 to be connected to the
low-voltage battery packs 10 and to be driven thereby. In contrast with the above-described adapter 200, the entire circuitry for this adapter 300 is contained within one housing. That is, the portions, which correspond to the main body side unit 202 and pack side unit 206 of the above-described adapter 200, are integrated into a single housing. The electric circuitry of the adapter 300 may be functionally identical to the circuitry of the above-described adapter 200 shown in Fig. 12 or Fig. 13.

[0088] As shown in Fig. 15, the connector 220 may be provided at or on the upper surface or upper portion 301 of the adapter 300 in the same manner as the connector 220 of the cored adapter 200 shown in Fig. 10. Thus, the connector 220 can be slidingly inserted into the battery interface 80 provided on the main body 72 of the high-voltage electric tool 70. The connector 220 includes a pair of rails 222, a positive electrode output terminal 224a, a negative electrode output terminal 224b, and an autostop terminal 226. The structures of connectors 220 in the two types of adapters 200, 300 may be substantially identical. Thus, when the connector 220 of the adapter 300 is attached to the battery interface 80, the positive electrode output terminal 224a of the adapter 300 is electrically connected to the positive electrode input terminal 84a of the battery interface 80, and the negative electrode output terminal 224b of the adapter 300 is electrically connected to the negative electrode input terminal 84b of the battery interface 80. As a result, the adapter 300 is electrically connected to the circuitry contained in the main body 72 of the high-voltage electric tool 70. In addition, the autostop terminal 86 is connected to the autostop terminal 226.

[0089] As shown in Fig. 16, two battery interfaces 230 are provided on the lower surface or lower portion 302 of the adapter 300 in the same manner as the battery interfaces 230 of the cored adapter 200 shown in Fig. 11. Each battery interface 230 can removably receive or attach one low-voltage battery pack 10, and the low-voltage battery pack 10 can be slidally received thereby. The battery interface 230 has a pair of rails 232, a positive electrode input terminal 234a, a negative electrode input terminal 234b, and a latch receiving hole 238. The structures of the battery interfaces 230 of the two types of adapters 200, 300 may be substantially identical. The two battery interfaces 230 are arranged side by side on the lower surface of the pack side unit 206 and the low-voltage battery packs 10 are respectively inserted therein in the same direction. The two low-voltage battery packs 10 attached to the adapter 300 are connected in series to the positive electrode output terminal 224a and the negative electrode output terminal 224b of the connector 220. As a result, the two low-voltage battery packs 10 supply current to
the circuitry contained in the main body 72 of the high-voltage electric tool 70 at a voltage of about 36 volts. In addition, the autostop terminal 26 of the battery pack 10 is connected to the autostop terminal 236 of the adapter 300.

[0090] As shown in FIG. 15, the adapter 300 is also provided with two indicators 260. The two indicators 260 are disposed on the rear surface 300a of the adapter 300. The two indicators 260 are respectively positioned above the two battery interfaces 230. Each indicator 260 comprises, e.g., a light-emitting diode or another light source, such as an incandescent light, or a display device such as an LCD, as was described above with reference to the indicator 260 of the corded adapter 200 and the indicator 160 of the embodiment of Figs. 2-4, which description is again incorporated herein by reference. Thus, similar to the above embodiments, the indicator 260 may indicate a charge state of the low-voltage battery pack 10 attached to one battery interface 230, and the other indicator 260 may indicate the same or a different condition of the low-voltage battery pack 10 attached to the other battery interface 230. The two indicators 260 are preferably arranged side by side on the rear surface 300a of the adapter 300. Therefore, the user can see the two indicators 260 simultaneously and can simultaneously recognize the respective charge states or other indicated condition(s) of the two low-voltage battery packs 10. Further, the indicators 260 are preferably disposed above the corresponding battery interfaces 230. Therefore, for example, if the high-voltage electric tool 70 abruptly stops, the user can immediately determine which low-voltage battery pack 10 is experiencing a problem or abnormality.

[0091] As described hereinabove, by using the adapter 300, the high-voltage electric tool 70 can be operated using two low-voltage battery packs 10. By connecting the two low-voltage battery packs 10 in series to the motor 76, it is possible to supply a voltage of about 36 volts to the motor 76. As a result, the high-voltage electric tool 70 with a rated voltage of 36 volts can be driven by two low-voltage battery packs 10, each having a nominal voltage of 18 volts. Thus, the high-voltage electric tool 70 can be powered using already available low-voltage battery packs 10, without the need to purchase a high-voltage battery pack 30 having a nominal voltage of 36 volts or a charger therefor. Each low-voltage battery pack 10 can be also individually used as the sole power source for the low-voltage electric tool 50.

[0092] In the present description, the representative example of the low-voltage electric tool 50 is an electric drill, and the representative example of the high-voltage electric tools 70, 100 is an
electric blower (leaf blower). However, the present teachings are not particularly limited to these types of electric tools and can be widely applied to a variety of types of electric tools, as was described above in the Summary section.

Specific embodiments of the present teachings are described above, but these embodiments merely illustrate some representative possibilities for utilizing the present teachings and do not restrict the claims thereof. The subject matter set forth in the claims includes variations and modifications of the specific examples set forth above.

The technical elements disclosed in the specification or the drawings may be utilized separately or in other combinations that are not expressly disclosed herein, but will be readily apparent to a person of ordinary skill in the art. Furthermore, the subject matter disclosed herein may be utilized to simultaneously achieve a plurality of objects or to only achieve one object, which object(s) may not be explicitly recited in the present disclosure.

Although the present teachings have been described with respect to a preferred usage of lithium-ion cells, the present teachings are, of course, applicable to any type of battery chemistry or technology, including but not limited to nickel-cadmium, nickel-metal-hydride, nickel-zinc, lithium iron phosphate, etc.

Further, although the representative electric power tool 100 and the adapters 200, 300 were illustrated as providing a serial connection of two battery packs 10, the battery interface 80 of the tool 100 or the adapters 200, 300 may, of course, be modified to connect three or more battery packs 10 in series and/or in parallel. Moreover, the first battery packs 10 are not all required to have the same nominal voltage and in certain applications of the present teachings, one first battery pack 10 could have a first nominal voltage, e.g., of 12 volts, and one first battery pack 10 could have a second nominal voltage, e.g., of 18 volts, i.e. the first and second nominal voltages of the two battery packs 10 are different. In this case, it is preferable that the first battery interfaces 130, 230 are configured differently, so as to be able to ensure that only the appropriate battery pack is attachable thereto. In addition or in the alternative, the main controller 152 of the tool 70, 100 or the main controller 252 of the adapter 200, 300, and its supporting circuitry, may be configured to recognize battery packs having different nominal voltages and process signals outputted from the respective CPUs of the battery packs appropriately.
[0097] The adapters 200, 300 may be modified to only provide a voltage level-shifting function and the tool motor controlling function may be performed by an integrated circuit, e.g., a microprocessor, located in the main body 72, 100 of the tool 70, 100. For example, the adapters 200, 300 are not required to include the main controller 252 and instead may include, e.g., only the level-shifters 254b, 256b and/or the cut-off switches 254a, 256a. Naturally, the adapters 200, 300 may also include the diode(s) 258a, the fuse(s) 258b and the indicators 260. In such embodiments, the functions of the main controller 252 are performed by circuitry located in the main body 72, 100 of the tool 70, 100. In this case, the level-shifters 254b, 256b preferably supply appropriate voltage-adjusted signals from the battery pack controllers 18 to the processor located in the main body 72, 102.

[0098] Additional embodiments of the present teachings include, but are not limited to:

1. An electric power tool adapted to be powered by at least a first battery pack and a second battery pack connected in series, wherein each battery pack comprises an integrated circuit, the electric power tool comprising:

   a controller adapted to receive signals respectively outputted from the integrated circuits of the first and second battery packs, wherein the integrated circuit of the first battery pack outputs a first signal at a first voltage level and the integrated circuit of the second battery pack outputs a second signal at a second voltage level different from the first voltage level; and

   a first level-shifter disposed between the controller and the integrated circuit of the first battery pack, the first level-shifter being adapted to shift the first voltage level of the first signal to the second voltage level that is usable by the controller.

2. The electric power tool as in embodiment 1, further comprising:

   a second level-shifter disposed between the controller and the integrated circuit of the first battery pack, the second level-shifter being adapted to shift the second voltage level of a signal outputted from the controller to the first voltage level that is usable by the integrated circuit of the first battery pack.

3. The electric power tool as in embodiment 1 or 2, further comprising:

   at least one cut-off switch disposed between the controller and the integrated circuit of the first battery pack, the cut-off switch being adapted to cut off an electrical connection between
the controller and the integrated circuit of the first battery pack.

4. The electric power tool as in embodiment 3, wherein the at least one cut-off switch is controllable by the controller.

5. The electric power tool as in embodiments 1-4, further comprising:
   at least one bypass circuit comprising a diode that electrically connects a positive electrode and a negative electrode of one of the battery packs.

6. The electric power tool as in embodiment 5, wherein the at least one bypass circuit further comprises a fuse.

7. An electric power tool adapted to be powered by a plurality of battery packs connected in series, the electric tool comprising:
   at least one bypass circuit comprising a diode that electrically connects a positive electrode and a negative electrode of one of the battery packs.

8. The electric power tool as in embodiment 7, wherein the at least one bypass circuit further comprises a fuse.

9. An adapter adapted for detachably connecting a plurality of battery packs to a main body of an electric power tool, wherein each battery pack comprises an integrated circuit and the adapter is detachable from the main body of the electric power tool, the adapter comprising:
   a controller adapted to receive signals respectively outputted from the integrated circuit of the first and second battery packs, wherein the integrated circuit of the first battery pack outputs a first signal at a first voltage level and the integrated circuit of the second battery pack outputs a second signal at a second voltage level different from the first voltage level; and
   a first level-shifter disposed between the controller and the integrated circuit of the first battery pack, the first level-shifter being adapted to shift the first voltage level of the first signal to the second voltage level that is usable by the controller.

10. The adapter as in embodiment 9, further comprising:
   a second level-shifter disposed between the controller and the integrated circuit of the first battery pack, the second level-shifter being adapted to shift the second voltage level of a
signal outputted from the controller to the first voltage level that is usable by the integrated circuit of the first battery pack.

11. The adapter as in embodiments 9 or 10, further comprising:
   at least one cut-off switch disposed between the controller and the integrated circuit of the first battery pack, the cut-off switch being adapted to cut off an electrical connection between the controller and the integrated circuit of the first battery pack.

12. The adapter as in embodiment 11, wherein the at least one cut-off switch is controlled by the controller.

13. The adapter as in embodiments 9-12, further comprising:
   at least one bypass circuit comprising a diode that electrically connects a positive electrode and a negative electrode of one of the battery packs.

14. The adapter as in embodiment 13, wherein the at least one bypass circuit further comprises a fuse.

15. An adapter adapted for connecting a plurality of battery packs to a main body of an electric power tool, the adapter being detachable from the main body of the electric power tool, the adapter comprising:
   at least one bypass circuit comprising a diode that electrically connects a positive electrode and a negative electrode of one of the battery packs.

16. The adapter as in embodiment 15, wherein the at least one bypass circuit further comprises a fuse.
CLAIMS:

1. A power supply interface (120; 200; 300) for an electric power tool (70; 100) comprising:
   a first battery pack interface (130; 230) adapted to detachably attach a first battery pack (10) and comprising a first positive battery electrode input terminal (134a; 234a), a first negative battery electrode input terminal (134b; 234b) and a first battery controller interface terminal (136; 236),
   a second battery pack interface (130; 230) adapted to detachably attach a second battery pack (10) and comprising a second positive battery electrode input terminal (134a; 234a), a second negative battery electrode input terminal (134b; 234b) and a second battery controller interface terminal (136; 236), the first negative battery electrode input terminal being electrically connected in series with the second positive battery electrode input terminal, wherein the first positive battery electrode input terminal is electrically connectable with the second negative battery electrode input terminal via a load (M) of the electric power tool, and
   a first DC-to-DC converter (156b; 256b) electrically connected with the first battery controller interface terminal and adapted to proportionally step down a voltage of a first signal received at the first battery controller interface terminal.

2. A power supply interface (120; 200; 300) as in claim 1, further comprising:
   a second DC-to-DC converter (154b; 254b) electrically connected with the first battery controller interface terminal (136; 236) and adapted to proportionally step up a voltage of a second signal received at the second DC-to-DC-converter to be supplied to the first battery controller interface terminal.

3. A power supply interface (120; 200; 300) as in claim 2, further comprising:
   a first switch (156a; 256a) electrically connected between the first battery controller interface terminal (136; 236) and the first DC-to-DC converter (156b; 256b) and
   a second switch (154a; 254a) electrically connected between the first battery controller interface terminal and the second DC-to-DC converter (154b; 254b), wherein the first and second switches are controllable such that:
   the first battery controller interface terminal is electrically connected with the first DC-to-DC converter when the first signal is being input at the first battery controller interface terminal and
the first battery controller interface terminal is electrically connected with the second
DC-to-DC converter when the second signal is being input at the first DC-to-DC converter.

4. A power supply interface (120; 200; 300) as in any preceding claim, further comprising:
a first battery pack (10) attached to the first battery pack interface (130; 230) and
comprising a first controller (18) having an output terminal (26) electrically connected to the first
battery controller interface terminal (136; 236), the first controller being adapted to output an
autostop signal as the first signal to the first battery controller interface terminal when the first
controller determines that the first battery pack is experiencing an abnormality or requires
recharging, and

a second battery pack (10) attached to the second battery pack interface (130; 230) and
comprising a second controller (18) having an output terminal (26) electrically connected to the
second battery controller interface terminal (136; 236), the second controller being adapted to
output an autostop signal to the second battery controller interface terminal when the second
battery controller determines that the second battery pack is experiencing an abnormality or
requires recharging.

5. A power supply interface (120; 200; 300) as in any preceding claim, further comprising:
a first diode (158a; 258a) having an anode electrically connected to the first positive
battery electrode input terminal (134a; 234a) and a cathode electrically connected to the first
negative battery electrode input terminal (134b; 234b), the first diode having the property that it
becomes conductive when a reverse voltage is generated across the first positive battery
electrode input terminal and the first negative battery electrode input terminal, and

a second diode (158a; 258a) having an anode electrically connected to the second
positive battery electrode input terminal (134a; 234a) and a cathode electrically connected to the
second negative battery electrode input terminal (134b; 234b), the second diode having the
property that it becomes conductive when a reverse voltage is generated across the second
positive battery electrode input terminal and the second negative battery electrode input terminal.

6. A power supply interface (120; 200; 300) as in any preceding claim, further comprising
a fuse (158b; 258b) electrically connected between the first negative battery electrode input
terminal (134b; 234b) and the second positive battery electrode input terminal (134a; 234a).

7. The power supply interface (120; 200; 300) as in any preceding claim, wherein the load
(M) has a rated voltage (e.g., 14 or 36 volts) that is at least substantially equal to twice the nominal voltage (e.g., 7 or 18 volts, respectively) of the first and second battery packs (10).

8. The power supply interface (120; 200; 300) as in any preceding claim, wherein the first and second battery packs (10) have a prescribed nominal voltage and the first and second battery pack interfaces (130; 230) are constructed to prevent attachment of a battery pack having a nominal voltage different from the prescribed nominal voltage of the first and second battery packs.

9. A power supply interface (120; 200; 300) as in any one of claims 2-8, further including a controller (152; 252) comprising:

- an input terminal (157a; 257a) electrically connected to the first DC-to-DC converter (156b; 256b),
- a first output terminal (157b; 257b) electrically connected to the second DC-to-DC converter (154b; 254b), and
- a second output terminal (157c; 257c) electrically connected to the first and second switches (154a, 156a; 254a, 256a), the controller being adapted to cause the first switch to conduct when the first signal is received at the first battery controller interface terminal (136; 236) and to cause the second switch to conduct when the controller outputs the second signal at the first output terminal.

10. A power supply interface (200; 300) as in any preceding claim, further comprising a housing having a first portion (206; 302) with the first and second battery pack interfaces (230) disposed on a surface thereof, wherein the housing further comprises a second portion (202; 301) with a power tool interface (220) disposed on a surface thereof, the power tool interface comprising:

- a positive battery electrode output terminal (224a) electrically connected to the first positive battery electrode input terminal (234a), and
- a negative battery electrode output terminal (224b) electrically connected to the second negative battery electrode input terminal (234b),

wherein the power tool interface is adapted to be detachably attachable to a battery pack interface (80) of the electric power tool (70).

11. The power supply interface (200; 300) as in claim 10, wherein the first and second
battery pack interfaces (230) are physically configured differently than the power tool interface (80).

12. The power supply interface (200; 300) as in claim 10 or 11, wherein the first and second battery pack interfaces (230) each have a first set of parallel rails (232) adapted to slidably receive a battery pack (10) and the power tool interface (220) has a second set of parallel rails (222) adapted to slidably engage the battery pack interface (80) of the electric power tool (70), wherein the first set of parallel rails has a different spacing than the second set of parallel rails.

13. A power supply interface (200) as in any one of claims 10-12, wherein the first portion (206) of the housing is connected to the second portion (202) of the housing via an electric cord (204).

14. A power supply interface as in any one of claims 10-13, further comprising an attachment device (206a) disposed on the first portion (206), the attachment device being adapted to attach to an article worn by a user and/or to a body part of the user.

15. A power tool (100) comprising:
   
an electric load (M) disposed within a tool housing (102), and

   the power supply interface (120) of any one of claims 1-8, wherein the first and second battery pack interfaces (130) are disposed on a surface of the tool housing and the first positive battery electrode input terminal (234a) and the second negative battery electrode input terminal (234b) are selectively electrically connectable to the electric load.

16. A power supply interface (120; 200; 300) for an electric power tool (70; 100) comprising:
   
a first battery pack interface (130; 230) adapted to detachably attach a first battery pack (10) and comprising a first positive battery electrode input terminal (134a; 234a) and a first negative battery electrode input terminal (134b; 234b),

   a second battery pack interface (130; 230) adapted to detachably attach a second battery pack (10) and comprising a second positive battery electrode input terminal (134a; 234a) and a second negative battery electrode input terminal (134b; 234b), the first negative battery electrode input terminal being electrically connected in series with the second positive battery electrode input terminal, wherein the first positive battery electrode input terminal is electrically
connectable with the second negative battery electrode input terminal via a load (M) of the
electric power tool,

5 a first diode (158a; 258a) having an anode electrically connected to the first positive
battery electrode input terminal and a cathode electrically connected to the first negative battery
electrode input terminal, the first diode having the property that it becomes conductive when a
reverse voltage is generated across the first positive battery electrode input terminal and the first
negative battery electrode input terminal, and

a second diode (158a; 258a) having an anode electrically connected to the second
positive battery electrode input terminal and a cathode electrically connected to the second
negative battery electrode input terminal, the second diode having the property that it becomes
conductive when a reverse voltage is generated across the second positive battery electrode input
terminal and the second negative battery electrode input terminal.

17. A power supply interface (120; 200; 300) as in claim 16, further comprising a fuse
(158b; 258b) electrically connected between the first negative battery electrode input terminal
(134b; 234b) and the second positive battery electrode input terminal (134a; 234a).

18. The power supply interface (120; 200; 300) as in claim 16 or 17, wherein the load (M)
has a rated voltage (e.g., 14 or 36 volts) that is at least substantially equal to twice the nominal
voltage (e.g., 7 or 18 volts, respectively) of the first and second battery packs (10).

19. The power supply interface (120; 200; 300) as in any one of claims 16-18, wherein the
first and second battery packs (10) have a prescribed nominal voltage and the first and second
battery pack interfaces (130; 230) are constructed to prevent attachment of a battery pack having
a nominal voltage different from the prescribed nominal voltage of the first and second battery
packs.

20. A power supply interface (120; 200; 300) as in any one of claims 16-19, further
comprising a housing having a first portion (206; 302) with the first and second battery pack
interfaces (230) disposed on a surface thereof, wherein the housing further comprises a second
portion (202; 301) with a power tool interface (220) disposed on a surface thereof, the power tool
interface comprising:

a positive battery electrode output terminal (224a) electrically connected to the first
positive battery electrode input terminal (234a), and
a negative battery electrode output terminal (224b) electrically connected to the second
negative battery electrode input terminal (234b),
wherein the power tool interface is adapted to be detachably attachable to a battery pack interface (80) of the power tool (70).

21. The power supply interface (200; 300) as in claim 20, wherein the first and second battery pack interfaces (230) are physically configured differently than the power tool interface (80).

22. The power supply interface (200; 300) as in claim 20 or 21, wherein the first and second battery pack interfaces (230) each have a first set of parallel rails (232) adapted to slidably receive a battery pack (10) and the power tool interface (220) has a second set of parallel rails (222) adapted to slidably engage the battery pack interface (80) of the electric power tool (70), wherein the first set of parallel rails has a different spacing than the second set of parallel rails.

23. A power supply interface (200) as in any one of claims 20-22, wherein the first portion (206) of the housing is physically and electrically connected to the second portion (202) of the housing via an electric cord (204).

24. A power supply interface (200) as in any one of claims 20-23, further comprising an attachment device (206a) disposed on the first portion (206), the attachment device being adapted to attach to an article worn by a user and/or to a body part of the user.

25. A power supply interface (200; 300) as in any one of claims 20-24, further comprising a power FET (246) electrically connected between one of (i) the positive battery electrode output terminal (224a) and the first positive battery electrode input terminal (234a) and (ii) the negative battery electrode output terminal (224b) and the second negative battery electrode input terminal (234b), the power FET being adapted to shut-off current flow to the load (M) of the power tool (70) in case a short-circuit is detected.

26. A power tool (100) comprising:
an electric load (M) disposed within a tool housing (102), and
the power supply interface (120) of any one of claims 16-19, wherein the first and second battery pack interfaces (130) are disposed on a surface of the tool housing and the first
positive battery electrode input terminal (234a) and the second negative battery electrode input terminal (234b) are selectively electrically connectable to the electric load.
FIG. 18

Prior Art
FIG. 19

Prior Art
A. CLASSIFICATION OF SUBJECT MATTER

INV. H02J7/00 B23B45/02

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H02J B23B B25B B25F

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

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
<th>Relevant to claim No.</th>
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<td>DE 10 2008 040061 Al (BOSCH GMBH ROBERT [DE]) 7 January 2010 (2010-01-07) figure 1 claim 7</td>
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