Method and apparatus for controlling energy transfer between an energy bus and a battery system based upon battery operating condition

BACKGROUND OF THE INVENTION

1. Field of Invention

This invention relates to battery power systems and more particularly to apparatus, methods, media and signals for controlling energy transfer between an energy bus and a system of batteries.

2. Description of Related Art

With the increasing interest in electric vehicles, hybrid electric vehicles and use of battery back-up systems, the need for battery power systems is similarly increasing. Many applications require the use of a series string of rechargeable batteries. The ability of any individual battery in such a string to accept a load or to accept a charge current depends on the individual battery. Various factors affect the ability of a battery to receive or deliver charge and such factors may include operating conditions of the battery such as temperature and state of charge, for example. Other factors such as storage time, float voltage, float life, minimum voltage, number of cycles, depth of discharge and capacity also play a role. Consequently, the operating conditions of each individual battery affect the ability of the entire battery system to deliver or receive charge.

Most systems that deliver or receive charge from a battery system treat the battery system as a single source supply where voltage and current demands or impositions on the battery system are calculated for the performance of the system as a whole. Some systems monitor voltages at each battery and adjust the overall system voltage or current based on differences in voltage so as not to place excessive strain on any given battery. Voltage, however, is a very crude and inaccurate measure of a battery's ability to deliver or receive charge and thus, provides only limited information with which to control the

overall system, resulting in somewhat inefficient operation of the battery system.

Thus, there is a need for efficient management of energy flow to and from a battery system. More accurate control of load and charging current is needed to maximize energy efficiency.

SUMMARY OF THE INVENTION

Example embodiments of the present invention addresses the above need by providing an apparatus, method, media and signal for controlling energy transfer between an energy bus and a system of batteries, in which a control signal generator operable to receive an extreme voltage representation representing a voltage of a battery exhibiting an extreme voltage among voltages of all batteries in the system, and a representation of a reference voltage derived from an operating parameter associated with the battery exhibiting the extreme voltage, is operable to produce a control signal for use in changing the amount of energy transfer between the energy bus and the battery system in response to the aforementioned representations. The control signal may be used by a load/charging device such as a motor/generator to control the flow of energy from and to the system of batteries.

Effectively, using the system and methods described above, the voltage of any given battery relative to the voltage of other batteries in the battery system determines whether or not a battery is selected for more careful analysis based on an operating parameter of that battery. This operating parameter may be used to determine a reference voltage which is used in conjunction with the voltage of the selected battery to produce a control signal such as a current change signal and/or a voltage change signal. Thus, a battery's relative voltage performance is used to invoke an investigation of its operating conditions to determine how best to adjust the charge or discharge current or more generally to adjust the energy flowing to or from the battery system as a whole.

In accordance with one aspect of the invention, there is provided an apparatus for controlling energy transfer between an energy bus and a system of batteries, the apparatus comprising: an accessor for accessing an extreme voltage representation representing a voltage of a battery exhibiting an extreme voltage among voltages of all batteries in the system and reference voltage representation derived from an operating parameter associated with said battery exhibiting said extreme voltage; and a control signal generator in communication with said accessor and operable to produce a control signal for use in changing the amount of energy transfer between the energy bus and the system in response to said representation of a reference voltage and said extreme voltage representation.

The apparatus may include a voltage extremity processor operable to produce the representation of the voltage extremity and may include memory accessible by the voltage extremity processor, for receiving and storing representations of voltages of batteries in the system. The voltage extremity processor may be configured to determine which of the representations represents the extreme voltage, and this may be done by employing a sorter to sort the representations of voltages.

The apparatus may further comprise a reference voltage processor operable to produce the representation of the reference voltage. This reference voltage processor may be operable to receive a representation of an operating parameter such as temperature of the battery exhibiting the extreme voltage. The reference voltage processor may have a look-up table interface operable to employ the temperature representation as an index to a look-up table relating reference voltages to temperature. The particular look-up table used may be selected as a function of state of charge of the battery having the extreme voltage. The look-up table interface may include an input operable to receive a representation of state of charge, for example, or the apparatus may include a

state of charge processor operable to produce a representation of state of charge.

The look-up table interface may be able to employ the temperature representation as an index to a look-up table relating optimal charging voltages to temperature and/or a look-up table relating lowest permissible battery voltages to temperature, for example.

The apparatus may further comprise memory for receiving and storing a representation of voltage and a representation of temperature for each battery in the system and alternatively or in addition, the apparatus may include a device for producing the representation of voltage and the representation of temperature for each battery in the system.

The apparatus may employ an associator operable to associate respective voltage and temperature representations with corresponding batteries.

The apparatus may include a selector operable to select, as the temperature representation for use by the reference voltage processor, a temperature representation associated with a battery with which the extreme voltage is associated.

The control signal generator may have a difference processor operable to find a mathematical difference between the reference voltage and the extreme voltage and may be operable to produce a current change value indicative of a change in current available from the system of batteries and/or it may be operable to produce a voltage change value indicative of a desired change in voltage to be applied to the system of batteries. In addition, the control signal generator may be operable to produce a target bus voltage as a function of a previous target bus voltage and the voltage change value.

The apparatus may include an energy flow determiner operable to determine whether or not energy transfer is to the energy bus or to the battery system. The energy flow determiner may cooperate with the control signal generator or may be integrated therein, for example, to cause the control signal generator to produce a current change signal when energy is flowing to the bus and to produce a voltage change signal when energy is flowing to the battery system.

The apparatus may also include a bypass controller operable to produce a bypass activation signal for activating a bypass circuit on any battery having a voltage greater than a reference value, when there is no change in the direction of current flow through the battery system. The bypass controller may also produce a bypass circuit de-activation signal for de-activating a bypass circuit on any battery having an activated bypass circuit when there is a change in the direction of current flow in the system unless any battery has a voltage greater than the reference value.

In accordance with another aspect of the invention, there is provided a method for controlling energy transfer between an energy bus and a system of batteries, the method comprising: producing a control signal for use in changing the amount of energy transfer between the energy bus and the system of batteries in response to: a representation of a reference voltage determined from an operating parameter of a battery exhibiting a voltage extremity in the system of batteries; and a representation of said voltage extremity.

In accordance with yet another aspect of the invention, there is provided a

computer readable medium encoded with codes for directing a processor circuit to control energy transfer between an energy bus and a system of batteries, by: producing a control signal for use in changing the amount of energy transfer between the energy bus and the system of batteries in response to a representation of a reference voltage determined from an operating parameter of a battery exhibiting a voltage extremity and a representation of said voltage extremity.

In accordance with a further aspect of the invention, there is provided a signal for transmitting codes for directing a processor circuit to control energy transfer between an energy bus and a system of batteries, the signal being encoded with codes for directing the processor circuit to produce a control signal for use in changing the amount of energy transfer between the energy bus and the system of batteries in response to a representation of a reference voltage determined from an operating parameter of a battery exhibiting a voltage extremity and a representation of said voltage extremity.

In accordance with another aspect of the invention, there is provided an apparatus for controlling energy transfer between an energy bus and a system of batteries, the apparatus comprising a processor circuit operable to produce a control signal for use in changing the amount of energy transfer between the energy bus and the system of batteries, in response to a representation of a reference voltage determined from an operating

parameter of a battery exhibiting a voltage extremity and a representation of said voltage extremity.

In accordance with another aspect of the invention, there is provided an apparatus for controlling energy transfer between an energy bus and a system of batteries, the apparatus comprising: means for accessing an extreme voltage representation representing a voltage of a battery exhibiting an extreme voltage among voltages of all batteries in the system; means for accessing a representation of a reference voltage derived from an operating parameter associated with said battery exhibiting said extreme voltage; and means in communication with said means for accessing an extreme voltage representation and said means for accessing a representation of a reference voltage, for producing a control signal for use in changing the amount of energy transfer between the energy bus and the system in response to said representation of a reference voltage and said extreme voltage representation.

Other aspects and features of the present invention will become apparent to those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

In drawings which illustrate embodiments of the invention,

Figure 1 is a schematic representation of a system employing an apparatus according to first embodiment of the invention.

Figure 2 is a block diagram of a processor circuit of the apparatus shown in Figure 1.

Figure 3 is a schematic representation of a data structure formed in a random access memory of the processor circuit shown in Figure 2.

Figure 4 is a flow chart showing a main routine executed by the processor circuit shown in Figure 2.

Figure 5 is a flow chart showing a load control routine executed by the processor circuit shown in Figure 2.

Figure 6 is a flow chart of a charting control routine executed by the processor shown in Figure 2.

Figure 7 is a flow chart of an voltage extremity processor routine executed by the processor shown in Figure 2.

Figure 8 is a flow chart of a bypass control routine executed by the processor circuit shown in Figure 2.

DETAILED DESCRIPTION

Referring to Figure 1, a generic battery-powered power system according to a first embodiment of the invention is shown generally at **10**. This power system **10** may be used in an electric vehicle, a hybrid electric vehicle, a stationary power back-up system or the like. Generally, the power system **10** involves a system of batteries shown generally at **12** connected to an energy bus **13** which may include high current capacity cables **15** and **17** for example, connected to a load/charger device **18**. The system of batteries **12** may include a series string of rechargeable batteries such as lead acid or gel cell batteries, for example. The lead acid batteries may be valve regulated lead acid (VRLA) batteries, for example.

Where the power system **10** is used in an electric vehicle, the load/charger device **18** may be a combination controller/motor/generator unit capable of receiving data words representing control parameters for adjusting field current of the motor/generator to control the amount of power drawn or provided to the battery system **12**. The controller of the combination may be a programmable inverter/charger, for example which may be connected to a motor/generator unit to supply current thereto and receive current therefrom. For example, the controller may be of the type available from Ecostar Electric Drive Systems of Dearborn, Michigan, USA for use in electric drive systems for automotive and stationary power applications. The motor generator unit may be of the type available from UQM Technologies, Inc. of Golden, CO, USA.

In general, the system of batteries **12** may operate in a supply mode to supply or transfer energy to the energy bus **13** for conduction to the load/charger device **18** or the battery system **12** may operate in a charge mode in which

the system of batteries receives energy from the energy bus, the energy being supplied by the load/charger device **18**.

The power system **10** further includes a battery data acquisition system shown generally at **14**, and a controller shown generally at **16**. Generally, the battery data acquisition system **14** produces a representation of voltage and a representation of a battery operating parameter such as temperature, for each battery in the battery system **12** and it may also provide a measure of the magnitude and direction of current flow on the energy bus **13**.

The data acquisition system **14** may include a plurality of sensor units **28**, **30**, **32**, and **34**, for example, each sensor unit being associated with a respective corresponding battery **20**, **22**, **24** and **26**. The data acquisition system **14** may further include a battery data interface shown generally at **36**.

The sensor units may be of the type available from eXtend Computer & Instrument Inc. of Michigan, U.S.A., for example. Generally, these sensor units **28**, **30**, **32** and **34** are operable to measure voltage across respective batteries **20** to **26** and include sensors for measuring an operating parameter of each respective battery. In this embodiment, the operating parameter sensed by the sensors is case temperature of the battery.

Measured data obtained by the sensors is transmitted by corresponding sensor units over an isolated, single wire digital network, to the battery data interface **36**. Each sensor unit draws its operating power from the system of batteries to which it is connected. Measurement of battery data may be invoked at a selected sensor unit, in response to receiving a command transmitted on the digital network from the battery data interface **36**.

In this embodiment, each sensor unit **28**, **30**, **32** and **34** has a built-in bypass circuit **31**, **33**, **35** and **37**, respectively, which, as will be explained below, can be used to continually balance/equalize batteries within the battery system **12**.

Control of the bypass circuits **31**, **33**, **35** and **37** is provided by signals received over the same single wire digital network used to receive commands from and transmit measured data to the battery data interface **36**.

In this embodiment the battery data interface **36** is of the type supplied by eXtend Computer & Instrument, Inc. of Michigan USA. This interface **36** may have a serial or parallel communications port through which communications with the controller **16** may be effected. The battery data interface **36** also has a terminal for connection to the single wire digital network to which the battery sensor units **28**, **30**, **32**, and **34** are connected, for bi-directional communication with the battery sensor units. The battery data interface **36** may also have a current sensor input operable to be used with a current shunt (not shown) to acquire information relating to the magnitude of current flow and direction on the energy bus **13**.

The battery data interface **36** is operable to be controlled by the controller **16** such that the controller can communicate with the battery data interface to send a request for information and receive the requested information in response, or to control the bypass circuits **31**, **33**, **35** and **37** of certain sensor units **28**, **30**, **32** and **34**, respectively. Such communications are effected by sending a command message or messages from the controller **16** to the battery data interface **36**. In response, the battery data interface **36** interprets the command message and communicates with one or more individual sensor units **28**, **30**, **32** or **34** to control it or acquire any requested information and sends back a response message to the controller **16** with the requested information or an indication of the status of the sensor unit. Requested information may include voltage and operating condition such as temperature of any battery of the battery system **12** and the magnitude and direction of current flow in the battery system, for example.

It will be appreciated that every battery **20**, **22** **24** and **26** in the battery system **12** may operate at a different voltage, depending upon various factors such as

operating conditions and state of charge, for example. Some batteries will have higher voltages relative to others while other batteries will have lower voltages relative to others. Usually, one battery will have a higher voltage than all the rest and one battery will have a lower voltage than all the rest. This higher voltage and this lower voltage may be referred to as voltage extremities, or extreme voltages among the voltages of all of the batteries in the battery system **12**. The battery with the lowest voltage is, of course, the battery with the low voltage extreme while the battery with the highest voltage is the battery with the high voltage extreme. In accordance with the invention claimed herein, these voltage extremes are important in determining how to control energy flow to and from the energy bus **13**, depending upon the direction of energy flow on the energy bus, as will be appreciated below.

In general, the controller **16** is operable to receive from the data acquisition system **14** representations of voltage and representations of at least one operating parameter for each battery and is operable to store these representations in respective arrays **19** and **21**. The representations may be in the form of data "words" or "bytes", for example.

In this embodiment, the controller **16** has functional blocks **23** and **25** that act as a voltage extremity processor and a reference voltage processor respectively that operate on the voltage and operating parameter representations to produce an extreme voltage representation representing the voltage of the battery exhibiting an extreme voltage and to produce a representation of a reference voltage derived from an operating parameter associated with the battery exhibiting the extreme voltage. This extreme voltage representation and reference voltage representation are received in respective memory locations. The controller further includes an accessor **27** that accesses the extreme voltage representation and the reference voltage representation and passes them to a control signal generator **29** that produces a control signal for use by the load/charger device **18**, in changing the amount of energy transfer between the energy bus and the battery system

12 in response to the representation of the voltage extremity and the representation of the reference voltage.

The controller **16** may be implemented by discrete components or more preferably by a processor circuit such as a programmable controller, for example.

Referring to Figures **1** and **2**, a suitable processor circuit for use as the controller **16** is shown generally at **51**. In this embodiment, the processor circuit **51** includes an input interface **60** having inputs shown generally at **62** for receiving voltage and operating parameter values for each respective battery in the battery system **12**. In the embodiment shown, the input interface **60** is seen to have a separate pair of inputs for each battery but it will be appreciated that voltage and operating parameter information may be received serially from the data acquisition system, in which case there may be a single input for receiving voltage and temperature values for each battery, for example. For illustrative purposes, the input interface **60** also includes a user input **64** for receiving user information and also includes a current input **66** for receiving a value indicative of the direction and magnitude of current flowing in the system, such as described above, from the data acquisition system **14**. Alternatively, the current value may be derived from a current transformer on one of the supply conductors from the battery system to the load/charger, for example.

The processor circuit **51** further includes a main processor circuit **70**, program memory **72**, random access memory (RAM) **74** and battery information non-volatile memory **76**. In this embodiment, the battery information non-volatile memory **76** is operable to store tables **77** representing optimal charging voltage vs. temperature and lowest permissible battery voltage vs. temperature and may further store tables representing storage time vs. temperature, float voltage vs. temperature, minimum voltage vs. state of charge, cycles to failure vs. percent depth of discharge and battery capacity

tables of percent capacity vs. temperature, for example. This information may be inputted into the battery information non-volatile memory **76** by the user or may be pre-stored in this memory to provide libraries of the above-mentioned tables for a plurality of different types of batteries, for example. Then, on receiving user input identifying the type of battery with which the controller **16** is to be used, the appropriate library of tables may be selected and activated for use in producing the control signal.

In this embodiment, the main processor circuit **70** is also in communication with a media interface **78** operable to read a computer readable medium such as a CD-ROM **80**, for example. The CD-ROM **80** may provide the above-mentioned libraries of information for each type of battery, for example, and/or may provide codes operable to be stored in the program memory **72** defining functions executed by the main processor circuit **70** for producing the control signal, in accordance with an embodiment of a method according to the invention.

In addition, in the embodiment shown, the main processor circuit **70** is in communication with an external communications interface **81** operable to provide for communications on a network, for example, and such network may include the internet, for example. Thus, the external communications interface **81** may provide for receipt of library information mentioned above via the internet or may be operable to receive programs as mentioned above in a computer data signal received from the internet, for storage in the program memory **72**.

The main processor circuit **70** is further in communication with an output interface **82** which has an output **84** for providing signals to the battery data interface **36** shown in Figure **1** to cause the battery data interface to sample or interrogate the sensor units **28** to **34** shown in Figure **1** to acquire voltage and operating parameter information which will ultimately be received at the input interface **60**, shown in Figure **2**. In addition, the output interface **82** provides

the control signal for use in changing the amount of energy transfer between the energy bus **13** and the battery system **12** in response to the representation of a reference voltage and the representation of the voltage extremity. This control signal may appear at an output **86** in the form of a target bus voltage control signal for controlling bus voltage during the charging mode and/or may appear as an output **88** in the form of a current change control signal for controlling current in the system during the supply mode. It will be appreciated that the output interface **82** may alternatively provide a single output in place of outputs **86** and **88** for issuing commands identifying whether the output signal represents the target bus voltage signal and/or the current change control signal, as the control signal for controlling the load/charger charger **18** shown in Figure **1**, the commands also including these signals.

Referring to Figure **3**, the random access memory (RAM) **74** may be arranged to include an operating parameter array **90**, a voltage parameter array **92**, a control parameter array **94** and an output parameter array **96**. The RAM **74** may also include a reference value field **98**.

In general, the operating parameter array **90** and the voltage parameter array store a representation of operating parameter (such as temperature) and a representation of voltage, respectively, for each battery in the battery system **12**.

The operating parameter array **90** may store number pairs representing an operating parameter and battery identification respectively. Thus, when the operating parameter array **90** is loaded with data, given any battery identification, the corresponding operating parameter can be obtained. Similarly, the voltage parameter array **92** stores number pairs representing voltage and battery identification. Thus, given a voltage value, a corresponding battery may be identified. As will be more fully explained below, when both arrays are loaded, the main processor circuit **70** uses a

given voltage value to find the operating parameter representation associated with the battery associated with the given voltage value.

The operating parameter array includes a battery type id field **100**, a load control constant field **102**, a charge control constant field **104**, and a current direction field **106**. The battery type id field **100** may be loaded with information received from the user, such as an indication of the type of batteries in the battery system **12**. The load control constant field **102** and charge control constant field **104** hold fixed values dependent upon the type of batteries employed in the battery system **12**. The current direction field **106** stores a value received from the battery data acquisition system **14** shown in Figure **1**, representing current direction on the energy bus **13**.

The output parameter array **96** may include a current change output value field **120** and a voltage change output value field **122**, which may act as representations of the output signal produced by the signal generator.

Referring to Figures **1** and **2**, the program memory **72** is programmed with blocks of codes **138**, **140**, **142**, **144**, **146** and **200**, which direct the main processor circuit **70** to execute functional blocks that implement a set of routines including a main routine, a load control routine, a charge control routine, a voltage extremity processor routine, a lookup table interface and a bypass routine respectively. Various subsets of this set of routines cooperate to act as the voltage extremity processor **23**, the reference voltage processor **25**, the accessor **27** and the control signal generator **29**, shown in Figure **1**. The program memory **72** may include further sets of codes (not shown) for establishing communications with the battery data interface **36** shown in Figure **1** and for executing various functions for interfacing with the media interface **78**, and the external communications interface **81**, for example.

Referring to Figures **1**, **2** and **4** the main routine is shown generally at **138**. The main routine **138** begins with a first block **139** that directs the main

processor circuit **70** to dispatch a data request command to the battery data interface **36** shown in Figure **1**, to cause it to acquire voltage and temperature representations from the sensor units **28-34**. Block **141** directs the main processor circuit **70** to wait for data to be returned from the battery data interface **36**. As the data is returned, it may be stored, for example in a temporary storage area (not shown) in the RAM **74**. If a representation of current direction is returned, it may be stored in the current direction field in the RAM **74**, for example.

Block **143** of the main routine, in cooperation with the RAM **74** and processor circuit **70**, acts as an associator for associating respective voltage and temperature representations with corresponding batteries.

When the requested data has been returned, block **143** directs the main processor circuit **70** to extract the voltage and temperature representations stored in temporary memory and store them in the operating parameter and voltage parameter arrays **90** and **92** shown in Figure **3**, such that these representations are associated with corresponding batteries. In the embodiment shown such association is achieved by storing temperature and battery id values as number pairs in the operating parameter array **90** and by storing voltage and battery id values as number pairs in the voltage parameter array **92**. Alternatively, the operating parameter and voltage parameter values may be associated with corresponding batteries by storing both representations and the battery id for each battery in a separate record, for example. It will be appreciated that various other ways of associating these representations with batteries are possible and within the scope of this invention. Also, the intermediate step of storing the voltage and temperature values in temporary memory may be omitted with these values being stored directly in the indicated arrays with battery ids as they are received.

Block **145** then directs the main processor circuit **70** to determine the direction of current flow, from the current direction value returned from the battery data interface **36** and stored in the control parameter array **94** of the RAM **74**.

Block **147** then directs the main processor circuit **70** to invoke the appropriate control routine, that is, the load control routine shown in Figure **5** or the charge control routine shown in Figure **6** depending on whether the current direction value indicates that current flow is to the energy bus **13** from the battery system **12** or to the battery system **12** from the energy bus **13**, respectively. In the embodiment shown, when the current direction value indicates that energy is flowing from the battery system **12** to the energy bus **13**, i.e., the battery system **12** is operating in the supply mode, the load control routine **140** shown in Figure **5** is invoked to produce a current change signal. Similarly, in the embodiment shown, when the current direction value indicates that energy is flowing to the battery system **12** from the energy bus **13**, i.e., the battery system is operating in the charge mode, the charge control routine **142** shown in Figure **6** is invoked to produce a voltage change signal. Block **147** of the main routine **138**, in conjunction with the main processor circuit **70** thus cooperate to act as an energy flow determiner operable to determine whether or not energy transfer is to the energy bus **13** or to the battery system **12**.

Block **149** then directs the main processor circuit **70** to invoke the bypass routine shown in Figure **8** to activate or de-activate bypass circuits **31**, **33**, **35** and **37** in certain sensor units.

Referring to Figure **5**, the load control routine **140** is executed when energy is flowing from the battery system **12** to the energy bus **13** and begins by block **150** directing the processor to set active an extreme id flag (not shown) to indicate that the lowest voltage measured across any battery of the battery system **12** shown in Figure **1** is to be taken as the extreme voltage for use in calculations. Block **152** then directs the main processor circuit **70** to call the

voltage extremity processor routine shown at **144** in Figure **7**. Referring to Figures **2**, **3** and **7**, the voltage extremity processor routine **144** begins with a first block **156** which directs the main processor circuit **70** to access the voltage parameter array **92** to determine which of the voltage representations represents the extreme voltage, in this instance, the lowest voltage. To do this, block **156** acts as a sorter to sort the voltage parameter array **92** shown in Figure **3** in ascending order. This causes the lowest measured voltage value to appear as the first value in the array. Next, block **158** directs the main processor circuit **70** to address the voltage parameter array **92** to read the battery identification associated with the lowest voltage value to identify the battery exhibiting the extreme voltage value. Block **160** then directs the main processor circuit **70** to act as a selector operable to select as the temperature representation for use by the reference voltage processor a temperature representation associated with a battery with which the extreme voltage is associated. To do this, the main processor circuit **70** finds the corresponding operating parameter value for the identified battery, by referring to the operating parameter array **90** using the battery identification associated with the lowest voltage value as an index into that array. On finding the corresponding operating parameter of the number pair associated with the identified battery, block **162** directs the main processor circuit to store the extreme voltage representation and the located operating parameter value in memory to enable it to be passed to the calling routine, in this instance, the load control routine **140**.

Referring back to Figures **2**, **3** and **5**, armed with the extreme voltage value and the operating parameter value, block **164** of the load control routine **140** directs the main processor circuit **70** to act as the reference voltage processor **25** shown in Figure **1** and use the operating parameter value received from the voltage extremity processor routine **144**, i.e., temperature to find a corresponding lowest permissible voltage for the battery exhibiting the extreme voltage value. To do this, the main processor circuit **70** employs the lookup table interface **146** to access the minimum voltage table stored in the

battery information non-volatile memory **76**, using the operating parameter value (temperature) as an index to that table. This look-up causes a lowest permissible voltage value V_{lp}, which acts as a reference voltage, to be stored in memory, for access by the load control routine.

The lookup table interface **146** may direct the main processor circuit **70** to access the battery information non-volatile memory **76** configured as part of the processor circuit **51**. It will be appreciated that the battery data memory need not be part of the processor circuit **51**, but rather may be a remote memory device containing a database of the indicated tables. In this case, the lookup table interface may include further functions such as communications beyond what it might normally include where the battery data memory is directly accessible by the main processor circuit **70**, for dealing with error correction and handshaking and the like. In general, the database containing the indicated tables may be located anywhere and the lookup table interface may include appropriate communications functions to gain access to the required tables.

Referring to Figure **5**, blocks **166** and **168** then direct the main processor circuit **70** to act as the accessor **27** and control signal generator **29** of Figure **1**. Block **166** directs the main processor circuit **70** to access the extreme voltage representation and the reference voltage representation stored in memory and to produce a control signal for use in changing the amount of energy transfer between the energy bus and the system in response to the representation of a reference voltage and the representation of the voltage extremity. To do this the main processor circuit **70** is directed to calculate a current change control value as the difference between the lowest permissible voltage value and the extreme voltage value multiplied by the load control constant (a) stored in the corresponding field **102** of the RAM **74**. In doing so, the main processor circuit **70** acts as a difference processor operable to find a mathematical difference between the reference voltage and the extreme voltage. The main processor circuit **70** causes this mathematical difference to

be multiplied by the load control constant (a) to produce a current change control signal indicative of a change in current drawn from the system. Block **168** then directs the main processor circuit **70** to cause this current change control value to be represented as a current change control signal at the output **88** shown in Figure **2**, for receipt by the load/charger device **18** shown in Figure **1**.

The effect of the load control routine **140** is to decrease the load on the battery system **12** when the voltage across any battery is below a minimum permissible battery voltage.

Referring to Figure **6**, the charge control routine **142** begins with a first block **170** that directs the main processor circuit **70** shown in Figure **2** to set the extreme id flag to indicate that the highest voltage measured across any battery in the system is to be taken as the extreme voltage value. Then, block **172** directs the main processor circuit **70** to call the voltage extremity processor routine shown in Figure **7** to obtain the extreme voltage representation and the output parameter representation and store these representations in memory, for access by the remainder of the charging control routine **142**. It should be noted that at block **156** when the charging control routine calls the voltage extremity processor routine **144** shown in Figure **7**, the voltage parameter array **92** shown in Figure **3** is sorted in descending order, to cause the first entry in the array to be the highest voltage value.

Referring back to Figure **6**, given the extreme voltage value and the operating parameter value associated with the battery exhibiting the extreme voltage value, block **174** directs the main processor circuit **70** to find an optimal charging voltage value using the operating parameter. This is done by causing the main processor circuit **70** to use the lookup table interface **146** to refer to the battery information non-volatile memory **76** and specifically the optimum voltage vs. temperature table stored therein, to find a corresponding

optimal voltage value V_{opt}, using the operating parameter value (temperature) as an index to the table. Blocks **176**, **178** and **180** then direct the main processor circuit **70** to act as the accessor **27** and control signal generator **29** shown in Figure **1**.

Block **176** then directs the main processor circuit **70** to access the extreme voltage representation and the reference voltage representation stored in memory and to produce a control signal for use in changing the amount of energy transfer between the energy bus and the system in response to the representation of a reference voltage and the representation of the voltage extremity. To do this the main processor circuit **70** is directed to calculate a voltage change value as a function of the difference between the optimal voltage value V_{opt} and the extreme voltage value. In doing so, the main processor circuit **70** again acts as a difference processor operable to find a mathematical difference between the reference voltage and the extreme voltage. In this embodiment, the result produced by the action as a difference processor is multiplied by the charge control constant (b) stored in the corresponding field **104** in the RAM **74** shown in Figure **3** to produce a voltage change value indicative of a desired change in voltage across the battery system **12**.

Block **178** then directs the main processor circuit **70** to calculate a target bus voltage value as the sum of the voltage change value and the previous bus voltage value. The previous bus voltage value may be found by taking the sum of the voltage values stored in the voltage parameter array **92** shown in Figure **3**.

Block **180** then directs the main processor circuit **70** to cause this new bus voltage value to be represented as a signal at the output **86** shown in Figure **2** for use by the load/charger device **18** shown in Figure **1**.

The effect of the charge control routine **142** is to decrease the main bus voltage, i.e., the total voltage impressed upon the battery system **12** until no battery in the system has a voltage higher than the highest optimal voltage permitted for any given battery.

Performance of the above system can be enhanced by selecting a lowest permissible voltage vs. temperature table and an optimum charge voltage table as a function of the state of charge of the battery exhibiting the voltage extremity. Thus, the lookup table interface **146** may provide access to a plurality of lowest permissible voltage vs. temperature tables and a plurality of optimum charge voltage vs. temperature tables, each associated with a different state of charge. The lookup table interface **146** may have an input operable to receive a representation of the state of charge of the battery and given such representation it can select the appropriate table accordingly.

Information about the state of charge of a battery in the battery system **12** can be obtained from a variety of sources including a routine such as shown at **201** in Figure **2** operable to run on the main processor circuit **70** to gather information about the use of the battery, for example, and to produce a measure of the state of charge. For example, such a routine might keep track of the accumulated time and depth of discharge and the accumulated time and amount of charge and the temperatures at which these events occur and it might use one of the tables stored in the battery data memory to produce a percent discharge value. The above mentioned lookup tables may then be indexed by percent of discharge so that percent of discharge can be used by the lookup table interface to select an appropriate table for use in producing the reference voltage value. Thus, state of charge information may be an input to blocks **164** and **174** of Figures **5** and **6**, respectively. A routine causing the main processor circuit **70** to perform a state of charge determination function may be regarded as a state of charge processor.

Alternatively, state of charge information may be received from an external source such as through the external communication interface, or through the user input, for example.

Referring to Figure **8**, the bypass routine **200** is the final routine called by the main routine **138** and directs the main processor circuit **70** to control the bypass circuits **31**, **33**, **35** and **37** on the sensor units **28**, **30**, **32** and **34**, respectively, shown in Figure **1**. This provides for continuous balancing and equalization of energy flow from batteries in the battery system **12**.

The bypass routine begins with a first block **202** that directs the main processor circuit **70** to calculate a reference value, such as the mean battery voltage, for example, from the voltage values stored in the voltage parameter array **92** shown in Figure **3**. This reference value is stored in the reference value field **98** of the memory structure shown in Figure **3**.

Block **204** then directs the main processor circuit **70** to determine whether or not there has been a change in current direction in the power system **10** and if so, to cause block **206** to direct the main processor circuit to issue bypass control signals to set all bypass circuits **31**, **33**, **35** and **37** inactive. The current direction is determined by reading the contents of the current direction field **106** in the control parameter array **94**, shown in figure **3**.

If there is no change in current direction since the last time the bypass routine **200** was run or after all bypass control signals have been set inactive, block **208** directs the main processor circuit **70** to set the bypass circuits active on all sensors associated with batteries having a voltage greater than the reference voltage. Over time, this has the effect of equalizing the voltage across each battery to approximately the same value. The bypass routine **200** is then ended.

The bypass routine has the effect of producing a bypass activation signal for activating a bypass circuit on any battery having a voltage greater than the reference value, when there is no change in the direction of current flow through the battery system. In addition, it causes a bypass circuit de-activation signal to be produced to de-activate a bypass circuit on any battery having an activated bypass circuit when there is a change in the direction of current flow in the system unless such battery has a voltage greater than the reference value of all battery voltages in the battery system, in which case the bypass circuit is not de-activated.

Effectively, using the system and methods described above, the voltage of any given battery relative to the voltage of other batteries in the battery system determines whether or not that battery is selected for more careful analysis based on an operating parameter of that battery. This operating parameter may be used to determine a reference voltage that is to be used in conjunction with the voltage of the selected battery to produce a control signal such as a current change signal and/or a voltage change signal that can be supplied to a controller of the load/charger device **18**. Thus, the relative voltage performance of a battery and more particularly the extreme battery voltages of all batteries in the battery system are used to invoke the use of the operating conditions of the battery exhibiting the extreme voltage to determine how best to adjust the charge or discharge current of the entire battery system to optimize power transfer to or from the battery system as a whole.

While specific embodiments of the invention have been described and illustrated, such embodiments should be considered illustrative of the invention only and not as limiting the invention as construed in accordance with the accompanying claims.

What is claimed is:

1. A method of controlling energy transfer between an energy bus and a system of batteries, the method comprising:

producing a control signal for use in changing the amount of energy transfer between the energy bus and the system of batteries in response to:

a representation of a reference voltage determined from an operating parameter of a battery exhibiting a voltage extremity in the system of batteries; and

a representation of said voltage extremity.

2. The method of claim 1 further comprising receiving said representation of said voltage extremity and receiving a representation of said operating parameter.

3. The method of claim 2 further comprising producing said representation of said voltage extremity.

4. The method of claim 3 wherein producing said representation of said voltage extremity comprises receiving representations of voltages of said batteries in the system of batteries.

5. The method of claim 4 further comprising determining which of said representations represents an extreme voltage among said representations of voltages.

6. The method of claim 5 wherein determining comprises sorting said representations of voltages.

7. The method of claim 3 further comprising producing said representation of said reference voltage.

8. The method of claim 7 wherein producing said representation of said reference voltage comprises receiving a representation of a temperature of said battery exhibiting said voltage extremity.

9. The method of claim 8 further comprising employing said temperature representation as an index to a look-up table relating reference voltages to temperature.

10. The method of claim 9 further comprising selecting said look-up table as a function of a state-of-charge of said battery having said voltage extremity.

11. The method of claim 10 further comprising receiving a representation of said state-of-charge.

12. The method of claim 11 further comprising producing said representation of said state of charge of said battery having said voltage extremity.

13. The method of claim 8 further comprising employing said temperature representation as an index to a lookup table relating optimal charging voltages to temperature.

14. The method of claim 8 further comprising employing said temperature representation as an index to a lookup table relating lowest permissible battery voltages to temperature.

15. The method of claim 8 further comprising producing said representation of temperature.

16. The method of claim 15 further comprising receiving a representation of voltage and a representation of temperature for each battery in the system.

17. The method of claim 16 further comprising associating respective said voltage and temperature representations with corresponding batteries.

18. The method of claim 17 further comprising selecting as said temperature representation for use in producing said representation of said reference voltage, a temperature representation associated with a battery with which said extreme voltage is associated.

19. The method of claim 1 further comprising producing said control signal as a function of a difference between said reference voltage and said voltage extremity.

20. The method of claim 1 wherein producing said control signal comprises producing a current change control signal indicative of a change in current available from the system of batteries.

21. The method of claim 20 further comprising producing said current change value as a function of a difference between said reference voltage and said voltage extremity.

22. The method of claim 1 wherein producing said control signal comprises producing a voltage change value indicative of a desired change in voltage to be applied to the system of batteries.

23. The method of claim **22** wherein producing said control signal comprises producing a target bus voltage control signal as a function of a previous target bus voltage value and said voltage change value.

24. The method of claim **1** further comprising determining whether or not energy transfer is to the energy bus or to the battery system and producing a current change signal when energy is flowing to the bus and producing a voltage change signal when energy is flowing to the battery system.

25. The method of claim **24** further comprising producing a bypass activation signal for activating a bypass circuit on any battery having a voltage greater than a reference value, when there is no change in the direction of current flow through the battery system.

26. The method of claim **1** further comprising producing a bypass circuit de-activation signal for de-activating a bypass circuit on any battery having an activated bypass circuit when there is a change in the direction of current flow in the batteries of the system unless said any battery has a voltage greater than the reference value.

27. An apparatus for controlling energy transfer between an energy bus and a system of batteries, the apparatus comprising:

an accessor for accessing an extreme voltage representation representing a voltage of a battery exhibiting an extreme voltage among voltages of all batteries in the system and a reference voltage representation derived from an operating parameter associated with said battery exhibiting said extreme voltage; and

a control signal generator in communication with said accessor and operable to produce a control signal for use in changing the

amount of energy transfer between the energy bus and the system in response to said representation of a reference voltage and said extreme voltage representation.

28. The apparatus of claim **28** further comprising a voltage extremity processor operable to produce said representation of said voltage extremity.

29. The apparatus of claim **28** further comprising memory accessible by said voltage extremity processor for receiving and storing representations of voltages of the batteries in the system.

30. The apparatus of claim **29** wherein said voltage extremity processor is configured to determine which of said representations of voltages of the batteries in the system represents said extreme voltage.

31. The apparatus of claim **30** wherein said voltage extremity processor comprises a sorter operable to sort said representations of voltages of the batteries in the system.

32. The apparatus of claim **28** further comprising a reference voltage processor operable to produce said representation of said reference voltage.

33. The apparatus of claim **32** wherein said reference voltage processor is operable to receive a representation of a temperature of said battery exhibiting said extreme voltage.

34. The apparatus of claim **33** further comprising a look-up table interface operable to employ said temperature representation as an index to a look-up table relating reference voltage representations to temperature representations.

35. The apparatus of claim 34 wherein said lookup table interface is operable to select said lookup table as a function of a state-of-charge of the battery having said extreme voltage.

36. The apparatus of claim 35 wherein said lookup table interface includes an input operable to receive a representation of said state-of-charge.

37. The apparatus of claim 36 further comprising a state-of-charge processor operable to produce said representation of said state-of-charge.

38. The apparatus of claim 33 further comprising a lookup table interface operable to employ said temperature representation as an index to a lookup table relating optimal charging voltages to temperature.

39. The apparatus of claim 33 further comprising a lookup table interface operable to employ said temperature representation as an index to a lookup table relating lowest permissible battery voltages to temperature.

40. The apparatus of claim 33 further comprising a memory for receiving and storing a representation of voltage and a representation of temperature for each battery in the system.

41. The apparatus of claim 40 further comprising means for producing said representation of voltage and said representation of temperature for each battery in the system.

42. The apparatus of claim 41 wherein said means for producing comprises a battery data acquisition system.

43. The apparatus of claim **40** further comprising an associator operable to associate respective said voltage and temperature representations with corresponding batteries.

44. The apparatus of claim **43** further comprising a selector operable to select as said temperature representation for use by said reference voltage processor a temperature representation associated with a battery with which said extreme voltage is associated.

45. The apparatus of claim **27** wherein said control signal generator comprises a difference processor operable to find a mathematical difference between said reference voltage and said extreme voltage.

46. The apparatus of claim **27** wherein said control signal generator is operable to produce a current change control signal indicative of a change in current available from the system of batteries.

47. The apparatus of claim **27** wherein said control signal generator is operable to produce a voltage change value indicative of a desired change in voltage to be applied to the system of batteries.

48. The apparatus of claim **47** wherein said control signal generator is operable to produce a target bus voltage control signal as a function of a previous target bus voltage value and said voltage change value.

49. The apparatus of claim **27** further comprising an energy flow determiner operable to determine whether or not energy transfer is to the energy bus or to the battery system, said energy flow determiner cooperating with said control signal generator to cause said control signal generator to produce a current change signal when energy is flowing to the bus and to produce a voltage change signal when energy is flowing to the battery system.

50. The apparatus of claim **27** further comprising a bypass controller operable to produce a bypass activation signal for activating a bypass circuit on any battery having a voltage greater than a reference value, when there is no change in the direction of current flow through the battery system.

51. The apparatus of claim **50** wherein said bypass controller is operable to produce a bypass circuit de-activation signal for de-activating a bypass circuit on any battery having an activated bypass circuit when there is a change in the direction of current flow in the batteries of the system unless said any battery has a voltage greater than said reference value.

52. A computer readable medium encoded with codes for directing a processor circuit to control energy transfer between an energy bus and a system of batteries, by:

producing a control signal for use in changing the amount of energy transfer between the energy bus and the system of batteries in response to a representation of a reference voltage determined from an operating parameter of a battery exhibiting a voltage extremity and a representation of said voltage extremity.

53. A signal for transmitting codes for directing a processor circuit to control energy transfer between an energy bus and a system of batteries, the signal being encoded with codes for directing the processor circuit to produce a control signal for use in changing the amount of energy transfer between the energy bus and the system of batteries in response to a representation of a reference voltage determined from an operating parameter of a battery exhibiting a voltage extremity and a representation of said voltage extremity.

54. An apparatus for controlling energy transfer between an energy bus and a system of batteries, the apparatus comprising a processor circuit operable to produce a control signal for use in changing the amount of energy transfer between the energy bus and the system of batteries, in response to a representation of a reference voltage determined from an operating parameter of a battery exhibiting a voltage extremity and a representation of said voltage extremity.

55. An apparatus for controlling energy transfer between an energy bus and a system of batteries, the apparatus comprising:

means for accessing an extreme voltage representation representing a voltage of a battery exhibiting an extreme voltage among voltages of all batteries in the system;

means for accessing a representation of a reference voltage derived from an operating parameter associated with said battery exhibiting said extreme voltage; and

means in communication with said means for accessing an extreme voltage representation and said means for accessing a representation of a reference voltage, for producing a control signal for use in changing the amount of energy transfer between the energy bus and the system in response to said representation of a reference voltage and said extreme voltage representation.