Adaptable and efficient energy storage by reconfiguring battery connections

FIELD OF THE INVENTION

This application is in the field of systems for managing or optimizing the charging of batteries from electrical energy sources. More specifically, this application is in the field of systems for monitoring a plurality of rechargeable batteries and an electrical energy input and optimizing the configuration of the batteries and the energy input so that storage rate of the electrical energy can be improved.

BACKGROUND TO THE INVENTION

The following discussion of the background to the invention is intended to facilitate an understanding of the present invention. However, it should be appreciated that the discussion is not an acknowledgement or admission that the material referred to was published, known or part of the common general knowledge in any jurisdiction as at the priority date of the application.

Various fitness equipment, such as treadmill, stationary bicycle, ladder climbing machine, spinning, and elliptical machines, are operated by users who by exerting force generate electricity that can be used to charge and power various mobile devices and other electrical equipments. When this equipment displays the amount of energy stored for charging and powering mobile devices, it will encourage users to do more exercise and provide overall more positive experience to the users.

However, due to incompatibility between the electricity generators that can be attached to fitness equipment and the charging systems of mobile devices, the efficiency of energy transfer and storage is poor. Thus it takes too long to charge mobile devices using fitness equipment for typical users to notice real benefits and rewards from their exercise time. This also limits practical uses of fitness equipment as alternative energy source for various household electrical equipments.

Therefore, there is an urgent need for an efficient and effective system to address the aforementioned disadvantages. The present invention seeks to provide such a system for monitoring energy generation sources and configuring charging processes to optimise energy storage and utilization to overcome at least in part some of the aforementioned disadvantages.

SUMMARY OF THE INVENTION

Throughout this document, unless otherwise indicated to the contrary, the terms “comprising”, “consisting of”, and the like, are to be construed as non-exhaustive, or in other words, as meaning “including, but not limited to”.

The present invention is an energy storage system for efficiently storing electrical energy from an unpredictable electrical energy source into multiple rechargeable batteries by adaptively configuring connections and states of charge of multiple rechargeable batteries to the electrical energy source.

In one embodiment, the electrical energy source is originated by any electricity stream from electrical generators, such as dynamos, attached to fitness equipment, such as treadmills, stationary bicycles, ladder climbing machines, spinning, and elliptical trainers. Preferably, an input voltage detector is electrically connected to the energy source. A charge controller controls at least two energy storage devices, wherein each energy storage device comprises one charging circuit with a battery voltage detector, and at least one rechargeable battery, and the charge controller communicably coupled to the the energy storage devices and the input voltage detector. The charging circuits are initially disabled preventing the flow of electrical energy from the energy source to the batteries.

Next, the system determines connection utility values of the energy storage devices based on one or more battery and energy source parameters using the charge controller and the input voltage detectors, wherein the connection utility values are based on the input power voltage, the states of charge of the energy storage devices, and the current minimum voltage requirements of the energy storage devices for charging the batteries attached to the energy storage devices.

Next, the system connects zero or more storage devices to the energy source based on the connection utility values of the selected energy storage devices by enabling the charging circuits of the selected energy storage devices, thereby allowing electrical energy to flow into the batteries.

Next, the system determines disconnection utility values of the energy storage devices based on one or more battery and energy source parameters using the charge controller and the input voltage detector, wherein the disconnection utility values are the input power voltage, the states of charge of the energy storage devices, and the minimum voltage requirements of the energy storage devices for charging the batteries attached to the energy storage devices.

Next, the system disconnects zero or more energy storage devices from the energy source based on the disconnection utility values by disabling the charging circuits of the selected energy storage devices, thereby stopping the flow of electrical energy into the batteries.

The system repeats the determining steps, the connection step, and the disconnection step until all batteries are substantially charged, a specified charge level is obtained, a specified charging time period has elapsed. or until the input power voltage drops below a predefined value.

In one embodiment, the steps of determining connection utility values and connecting zero or more energy storage devices are executed only when the input voltage is above a predefined value lvm + α, wherein lvm > 0 and α > 0.

In one embodiment, the steps of determining disconnection utility values and disconnecting zero or more energy storage devices are executed only when the input voltage is below a predefined value lvm.

In one embodiment, the system adjusts the charge currents of one or more of the connected energy storage devices until the charge currents of the energy storage devices reaches the maximum charge rates of the batteries attached to the storage devices or until the input power voltage drops below any of the minimum voltage requirements of the energy storage devices for charging the batteries attached to the energy storage devices.

In one embodiment, the system is a portable system that can be detached after charged, wherein the system continues to function as a charger or power source for electrical equipments.

In one embodiment, the system selects an energy storage device for discharging when an electrical equipment is connected, wherein an energy storage device with the highest state of charge is selected for discharging.

In one embodiment, the system measures the one or more parameters for the two or more energy storage devices, wherein the one or more parameters comprise at least one of a parallel resistance, a series resistance, a parallel capacitance, a phase angle, a battery temperature, a battery internal pressure, a battery internal resistance, a battery terminal voltage and a voltage derivative with time.

BRIEF DESCRIPTION OF DRAWINGS

The present invention will now be described, by way of illustrative example only, with reference to the accompanying drawings, of which:

FIG 1 is a diagram of the wiring, controls, and devices that compose the disclosed energy storage system.

FIG. 2 is a diagram of the wiring, controls, and devices that compose the charge controller, and chargers, and discharge controller.

FIG. 3 is a flow chart of the charge controller processor that controls the charging of the energy storage devices.

DETAILED DESCRIPTION

Particular embodiments of the present invention will now be described with reference to the accompanying drawings. The terminology used herein is for the purpose of describing particular embodiments only and is not intended to limit the scope of the present invention. Additionally, unless defined otherwise, all technical and scientific terms used herein have the same meanings as commonly understood by one of ordinary skill in the art to which this invention belongs.

The use of the singular forms “a”, “an”, and “the” include both singular and plural referents unless the context clearly indicates otherwise.

The use of “or”, “/” means “and/or” unless stated otherwise. Furthermore, the use of terms “including” and “having” as well as other forms of those terms, such as “includes”, “included”, “has”, and “have” are not limiting.

In general, the present invention is an energy storage system for efficiently storing electrical energy from an unpredictable electrical energy source into multiple rechargeable batteries by adaptively configuring connections of multiple rechargeable batteries to the changing voltages of the energy source and the states of charge of the rechargeable batteries. The system monitors the input voltage of the electrical energy source and the voltages of the rechargeable batteries. The system adaptively reconfigures the connections and charging states of the rechargeable batteries to the input voltage of the electrical energy source and states of charge (SOC) of the batteries to increase the energy storage rate of the system measured in watt for a predetermined duration of time.

FIG. 1 is a diagram of the wiring, controls, and devices that compose the disclosed energy storage system 100. As shown, the energy storage system is connected to an electrical energy source 101, such as a dynamo, that is connected to a fitness equipment 102. The energy storage system comprises a charge controller 103 that controls two or more energy storage devices 104 to store electrical energy from the energy source 101. Each of the energy storage devices 104 has a charger and at least one rechargeable battery. The energy storage devices are connected to a discharge controller 105 to supply power to an electrical equipment 106.

The system controls the energy storage devices 104 for a predetermined time duration where the rechargeable batteries of the energy storage devices may be at different states of charge and the power output of the electrical energy source 101 is unpredictable such that it has a wide range of voltage and current levels due to the unpredictable nature of force that users exert on fitness equipment during a period of exercise time. A typical exercise time would be between 15 minutes to 30 minutes. The charge controller algorithm schedules charging of the energy storage devices to maximise the energy storage rate measured in watt.

FIG.2 is a diagram of the wiring, controls, and devices that compose the charge controller 200, energy storage devices 201, and discharge controller 202. The charge controller 200 provides an input voltage detector 203 electrically connected to the energy source 204, a number of

energy storage devices 201 electrically connected to the energy source 204 and a charge controller electrically connected to a number of energy storage devices 201, wherein each energy storage device comprises a charging circuit 205 with a battery voltage detector 206, and one or more batteries 207. The charge controller processor 208 is communicably coupled to the energy storage devices 104, 201 and the input voltage detector 203. The charging circuits 205 are initially disabled preventing the flow of electrical energy from the energy source 204 to the batteries 207.

Next, the system determines connection utility values of the energy storage devices 104, 201 based on one or more battery and energy source parameters using the charge controller 103, 200 and the input voltage detector 203, wherein the connection utility values are based on the input voltage, the states of charge of the energy storage devices 104, 201, and the minimum input voltage requirements of the energy storage devices 104, 201 for charging the batteries 207 attached to the energy storage devices. In this step, the charge controller 103 senses that the energy source 101, 204 is generating more energy than that is being stored to the batteries and so it needs to connects more energy storage devices to store the extra energy. The charge controller selects energy storage devices to be connected that are just enough to store additional energy being generated. The charge controller prioritises the selection based on the amount of energy being generated and the states of charge of the batteries.

Next, the system connects zero or more storage devices based on the connection utility values to the energy source 204 by enabling the charging circuits 205 of the selected energy storage devices, thereby allowing electrical energy to flow into the batteries 207.

Next, the system determines disconnection utility functions of the energy storage devices 104, 201 based on one or more batteries 207 and energy source parameters using the charge controller 200 and the input voltage detector 203, wherein the disconnection utility values are based on the input power voltage, the states of charge of the energy storage devices 104, 201, and the minimum voltage requirements of the energy storage devices for charging the batteries 207. In this step, the charge controller 103 senses that the amount of energy being generated is reduced and so it needs to disconnect some energy storage devices so that other remaining energy storage devices connected can continue to store energy. The charge controller selects energy storage devices to be disconnected that are just enough to increase the input voltage back to normal. The charge controller prioritises the selection based on the amount of energy being generated and the states of charge of the batteries.

Next, the system disconnects zero or more energy storage devices 104, 201 from the energy source 204 based on the disconnection utility values by disabling the charging circuits of the selected energy storage devices, thereby stopping the flow of electrical energy into the batteries 207.

The system repeats the determining steps, the connection step, and the disconnection step until all batteries are substantially charged, a specified charge level is obtained, a specified charging

time period has elapsed. or until the input power voltage drops to below a predetermined value, thereby adapting the rate of energy storage to the changing amount of electric being generated by the energy source 101, 204. This ensures that the energy storage system will capture most of the energy generated by users improving energy storage rate by up to the number of energy storage devices 104, 201. For example, to store 100 watt of energy being generated, the energy storage system would have about 10 batteries, each of which having the charge rate of 10 watt.

In one embodiment, the steps of determining connection utility values and connecting zero or more energy storage devices are executed only when the input voltage 203 is above a predefined value lvm + α, wherein lvm > 0 is the minimum of the required charging voltages of the energy storage devices 104, 201 and α > 0 is a threshold value used to prevent rapid switching.

In one embodiment, the value α is the maximum amount of the input voltage 203 that will drop if an energy storage device 104, 201 is connected. Connecting an energy storage device to the power source by enabling the charging circuit 205 will cause the input voltage to drop and α is the estimated amount of voltage that will drop.

In one embodiment, charge controller selects and connects the energy storage devices that can store more energy by calculating the connection utility values C_j using the following equation for each of the *j*-th energy storage device:

$$C_j = 0, \text{ if } Vi \leq (lvm_j + \alpha_j)$$

$$C_j = 1/(Vi - (lvm_j + \alpha_j)), \text{ if } Vi > (lvm_j + \alpha_j)$$

where Vi is the current input voltage, lvm_j is the required charging voltage of the *j*-th energy storage device, and α_j is the estimated amount of the input voltage that will drop if the *j*-th energy storage device is connected. The energy storage devices having higher connection utility values are connected first and the connection utility values are recalculated before attempting to connect another energy storage device. Energy storage devices having connection utility value of 0 are not connected.

In one embodiment, charge controller selects and disconnects the energy storage devices such that it can minimise the loss of energy storage rate by calculating the disconnection utility values D_j using the following equation for each of the *j*-th energy storage device:

$$D_j = 1/\beta_j$$

where β_j is the estimated amount of the input voltage that will be increased if the *j*-th energy storage device is disconnected. The energy storage devices having higher disconnection utility values are disconnected first and the disconnection utility values are recalculated before attempting to disconnect another energy storage device.

In one embodiment, the steps of determining disconnection utility values and disconnecting zero or more energy storage devices are executed only when the input voltage is below the minimum input voltage Ivm required to charge energy storage devices.

The invention solves the problem of increasing the energy storage rate of an energy storage system comprising multiple rechargeable batteries where the electrical voltage and current of an energy source is unpredictable. A typical application is storing electrical energy from fitness machines equipped with generators, where people normally do some fixed amount of exercise at different levels of force. Scheduling charging of the batteries that are different in both capacity, battery voltage, and charging rate is essential to store all the energy generated during the exercise time.

For example, the maximum charging current of typical lithium-type batteries is 1C (one battery capacity). A single cell lithium-type battery (3.7v) with battery capacity C of 3000mAh can only be charged at 3000mA current (i.e., energy storage rate of 11.1 watt) to avoid damaging the battery. A typical capacity of a 3.7v mobile phone battery is 3000mAh, that is, it can normally be charged at 11.1Wh. Therefore, if the energy being generated is 100W, the rest of the energy (88.9W) will be lost.

Charging multiple batteries increases the energy storage rate, but batteries can be in different states (charge levels, temperature, and remaining life). For example, lithium ion batteries have two charging stages: fast-charge and top-up charge stages. During the fast-charge stage, battery cells can be charged faster without damaging the batteries until the internal battery temperature reaches a certain level resulting in increased battery cell voltages (e.g., 4.1v). During the top-up stage, the battery cells are charged at a much slower current rate of 0.2C (20% of the battery capacity) or less. The top-up stage is used to top-up charged cells or until the battery cell is cools down. The maximum charge current during the fast-charge stage is usually set at 1C or a bit higher. The maximum charge current during the top-up stage is set at 0.2C or lower. Given this, charging multiple batteries from unpredictable input power is a complex problem. Existing parallel chargers work with constant and reliable input power, but not with unstable and unpredictable input power. If some battery cells are underperforming, charging takes much longer with parallel chargers as the underperforming cells have to be balanced before they can be charged with higher current.

To solve this problem, we configure battery connections and the charging schedule of individual battery based on the input voltage of the electrical energy source 101, 204 and the states of charge (SOC) of the individual batteries 207.

FIG. 3 shows a flowchart of the charge controller processor that controls the charging of the energy storage devices. The input voltage 203 (output of the energy source 101, 204) and the battery voltages 206 of each individual battery 207 are measured during charging. If the input voltage 203 is higher than a predetermined minimum input voltage Ivm, the one battery having the highest connection utility value (e.g., the battery having the lowest battery voltage) is

selected to be connected and charged. The charger controller processor 208 then gradually increases the charging current until the maximum charge current level for the battery is reached or until the input voltage drops below Ivm + α, for a margin voltage value α ≥ 0. If the input voltage is still higher than Ivm + α, a second battery is connected to be charged. This process continues until all remaining batteries are connected or until the input voltage is lower than Ivm + α, thereby increasing the energy storage rate of the energy storage system 100. This allows the energy storage device 100 to adapt its energy storage rate to the changing amount of electrical energy generated from the energy source 101, 204. The total energy storage rate of the energy storage system 100 is the sum of the energy storage rates of the energy storage devices 104, 201 connected.

On the other hand if the input voltage drops below Ivm, a battery that is being charged and has the highest disconnection utility value (e.g., a battery with the lowest level of charging current) is selected to be disconnected. This is repeated until the input voltage becomes higher than Ivm, thereby increasing the input voltage and allowing any energy storage devices that are still connected continue to store energy. This allows the energy storage device 100 to adapt its energy storage rate to the changing amount of electrical energy generated from the energy source 101, 204. If the input voltage is lower than Ivm, all batteries are disconnected. The transitions are time filtered with latches to avoid rapid switching of battery connections.

In one embodiment, the system further comprises the step of adjusting the charge currents of one or more of connected energy storage devices 104, 201 by controlling the charging circuits 205 until the charging currents of the energy storage devices reaches the maximum charge rates of the batteries 207 attached to the storage devices 104, 201 or until the input power voltage drops below any of the minimum voltage requirements of the energy storage devices 104, 201 for charging the batteries 207 attached to the energy storage devices 104, 201.

In one embodiment, the energy storage system 100 is a portable system that can be detached from the energy source 101 and the fitness equipment 102, wherein the system continues to function as a power source for electrical equipments 106.

This convenient feature allows users to quickly store a large amount of energy in short time without having to wait for hours to store enough energy to charge a portable mobile devices, such as mobile phones.

In one embodiment, the energy storage system 100 further comprises the step of selecting an energy storage device 104, 201 for discharging, wherein the energy storage device with the highest state of charge is selected for discharging. During discharge, the discharge controller 209 selects energy storage devices with high battery voltages 206 for discharging using electrical switches 210 to convert more cells to the fast-charge stage. This method automatically balances the battery cells by charging the batteries that are at the lowest charge level first and discharging from the batteries that are at the highest charge level. It also automatically increases and reduces energy storage rates based on the input voltage.

In one embodiment, the electrical energy source 101 is connected to at least one fitness equipment 102 to generate electricity using a dynamo generator which converts physical energy of users' electrical energy.

In one embodiment, the energy storage system further comprises the step of measuring the one or more parameters for the two or more energy storage devices, wherein the one or more parameters comprise at least one of a parallel resistance, a series resistance, a parallel capacitance, a phase angle, a battery temperature, a battery internal pressure, a battery internal resistance, a battery terminal voltage and a voltage derivative with time. The charge controller communicable coupled to the energy storage devices obtain the states of charge of the batteries to estimate the estimated drop α or increase β amount of the input voltage when the energy storage devices are connected or disconnected, respectively, and the required charge voltages lvm of the batteries of the energy storage devices.

It is to be understood that the above embodiments have been provided only by way of exemplification of this invention, and that further modification and improvements thereto, as would be apparent to persons skilled in the relevant art, are deemed to fall within the broad scope and ambit of the present invention described herein. It is to be understood that features from one or more of the described embodiments may be combined to form further embodiments.

Claims

1. An energy storage system for efficiently storing electrical energy from an electrical energy source into two or more batteries, comprising the steps of:

   providing an input voltage detector electrically connected to the energy source, a number of energy storage devices electrically connected to the energy source and a charge controller electrically connected to the energy storage devices, wherein each energy storage device comprises a charging circuit with a voltage detector and one or more batteries, the charge controller communicably coupled to the energy storage devices and the input voltage detector, and the charging circuits are initially disabled preventing the flow of electrical energy from the energy source to the batteries;

   determining connection utility values of the energy storage devices based on one or more battery and energy source parameters using the charge controller and the input voltage detectors, wherein the connection utility values are based on the input power voltage, the states of charge of the batteries of the energy storage devices, and the minimum voltage requirements of the energy storage devices for charging the batteries attached to the energy storage devices;

   connecting zero or more storage devices based on the connection utility values of the selected energy storage devices to the energy source by enabling the charging circuits of the selected energy storage devices, thereby allowing electrical energy to flow into the batteries;

   determining disconnection utility functions of the energy storage devices based on one or more battery and energy source parameters using the charge controller and the input voltage detector, wherein the disconnection utility values are based on the input power voltage, the states of charge of the batteries of the energy storage devices, and the minimum voltage requirements of the energy storage devices for charging the batteries attached to the energy storage devices;

   disconnecting zero or more energy storage devices from the energy source based on the disconnection utility values by disabling the charging circuits of the selected energy storage devices, thereby stopping the flow of electrical energy into the batteries;

   repeating the determining steps, the connection step, and the disconnection step until all batteries are substantially charged, a specified charge level is obtained, a specified charging time period has elapsed. or until the input power voltage drops to a predefined value.

2. The energy storage system of statement 1, the steps of determining connection utility values and connecting zero or more energy storage devices are executed only when the input voltage is above a predefined value lvm + α wherein lvm is the minimum of the charging voltage requirements of the energy storage devices and α > 0 is a predefined value.

3. The energy storage system of statement 1 wherein the steps of determining disconnection utility values and disconnecting zero or more energy storage devices are executed only when the input voltage is below a predefined value lvm.

4. The energy storage system of statement 2, the value α is the maximum amount of the input voltage that will drop if an energy storage device is connected.

5. The energy storage system of statement 1 wherein the connection utility values C_j are calculated using the following equation for each of the *j*-th energy storage device:

$$C_j = 0, \text{ if } Vi \leq (lvm_j + \alpha_j)$$

$$C_j = 1/(Vi - (lvm_j + \alpha_j)), \text{ if } Vi > (lvm_j + \alpha_j)$$

where Vi is the current input voltage, lvm_j is the required charging voltage of the *j*-th energy storage device, and α_j is the estimated amount of the input voltage that will drop if the *j*-th energy storage device is connected;

6. The energy storage system of statement 1 wherein the disconnection utility values D_j are calculated using the following equation for each of the *j*-th energy storage device:

$$D_j = 1/\beta_j$$

where β_j is the estimated amount of the input voltage that will be increased if the *j*-th energy storage device is disconnected;

7. The energy storage system of statement 1, further comprising the step of adjusting the charge currents of one or more of the connected energy storage devices until the charge currents of the energy storage devices reach the maximum charge rates of the batteries attached to the storage devices or until the input power voltage drops below any of the minimum voltage requirements of the energy storage devices for charging the batteries attached to the energy storage devices.

8. The energy storage system of statement 1 wherein the energy storage system is a portable system that can be detached from the energy source and the fitness equipment, wherein the system continues to function as a power source for electrical equipments.

9. The energy storage system of statement 1, further comprising the step of selecting an energy storage device for discharging, wherein an energy storage device with the highest state of charge is selected for discharging.

10. The energy storage system of statement 1 wherein the electrical energy source is connected to at least one fitness equipment to generate electricity using a dynamo generator which converts physical energy of users to electrical energy.

11. The energy storage system of statement 1, further comprising the step of measuring the one or more parameters for the two or more energy storage devices, wherein the one or more parameters comprise at least one of a parallel resistance, a series resistance, a parallel capacitance, a phase angle, a battery temperature, a battery internal pressure, a battery internal resistance, a battery terminal voltage and a voltage derivative with time.