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61/257,854 4 November 2009 (04.11.2009) US(71) Applicant (for all designated States except US): **TRI-UNE IP LLC** [US/US]; 681 North Plano Road, Suite 121, Richardson, TX 75081 (US).

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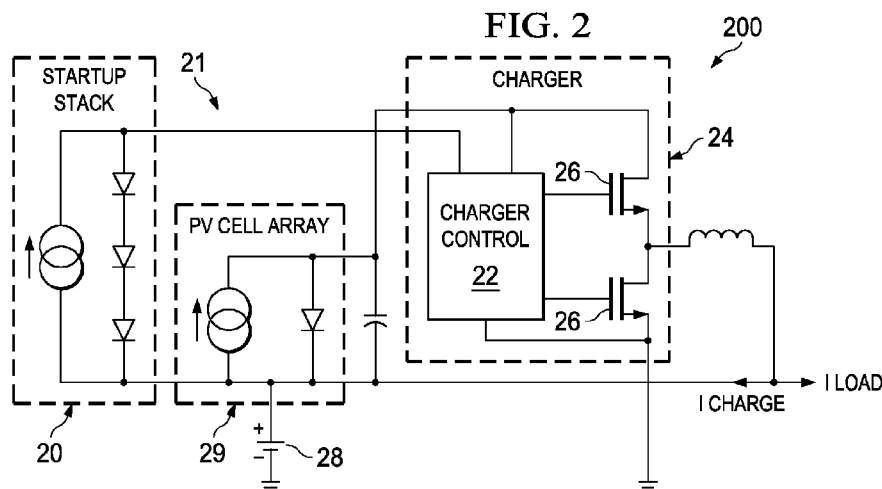
Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

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(54) Title: BOOTSTRAPPED CHARGER



(57) Abstract: The invention provides methods and systems (100, 200, 300, 400) for energy harvesting in which an energy storage device (12, 28, 39) is connected to a charger (14, 24, 30, 48) having a charge controller (17, 22, 46). In turn, a bootstrap circuit (11, 21, 33, 41) connected to the charge controller (17, 22, 46) provides power sufficient to cause the charge controller (17, 22, 46) to supply current to the energy storage device (12, 28, 39). Subsequently, the charger (14, 24, 30, 48) is used to regulate the output of a plurality of energy harvesting devices (10, 29, 33, 34, 44) operably coupled to the charger (14, 24, 30, 48) and to the energy storage device (12, 28, 39).

BOOTSTRAPPED CHARGER

PRIORITY ENTITLEMENT

[001] This application is entitled to priority based on Provisional Patent Application Serial Number 61/257,854, filed on November 4, 2009, which is incorporated herein for all purposes by this reference. This application and the Provisional Patent Application have at least one common inventor.

TECHNICAL FIELD

[002] The invention relates to electronic systems for energy harvesting and for the more efficient utilization of energy resources. More particularly, the invention relates to power control methods, systems, and circuitry designed to facilitate the harvesting of useable power from variable power energy sources and to battery charging with low, very low, or variable voltage or current inputs such as photovoltaic energy harvesting systems.

BACKGROUND OF THE INVENTION

[003] Systems for harvesting energy from renewable resources have long been desired in the arts. One of the problems associated with engineering energy harvesting systems is the challenge of making maximum use of energy sources which may be intermittent in availability and/or intensity. Unlike traditional power plants, alternative energy sources tend to have variable outputs. Solar power, for example, typically relies on solar cells, or photovoltaic (PV) cells to charge storage elements such as batteries or capacitors, which then may be used to supply power to a load. The sun does not always shine on the solar cells with equal intensity however, and such systems are required to operate at power levels that may vary depending on weather conditions, time of day, shadows from obstructions, and even momentary shadows, causing solar cell power output to fluctuate. Similar problems with output variability are experienced with other variable-output

power sources such as wind, piezoelectric, regenerative braking, hydro power, wave power, and so forth. It is known for energy harvesting systems to be designed to operate under the theoretical assumption that the energy source is capable of delivering at its maximum output level more-or-less all of the time. This theoretical assumption is rarely matched in practice. The current and voltage output of the solar cell, for example, varies depending on environmental conditions such as temperature and available light. At times, the output of the solar cell is very low. A system powered by the solar cell may not have sufficient headroom to operate properly at very low power levels, or may frequently operate outside of its ideal operating range due to headroom constraints.

[004] Due to these and other problems and potential problems with the current state of the art, improved methods, apparatus, and charger systems for energy harvesting would be useful and advantageous.

SUMMARY OF THE INVENTION

[005] The problem of harvesting energy from an intermittent and sometimes low-intensity source has been studied and approached with novel technological developments. Often, the current and voltage output of an energy harvesting device or apparatus varies depending upon environmental conditions, such as temperature and light for example, in the case of a solar cell or array. In many cases, the output of a solar cell may be useful, but is very low. A system powered by the solar cell in such cases may not have sufficient headroom to operate properly, or may operate outside of its ideal operating range due to headroom constraints. In a battery charging system for example, if the battery voltage is greater than the solar cell voltage, which is frequently the case, a boost regulator is required to supply the battery charging current. In carrying out the principles of the present invention, in accordance with preferred embodiments, the invention provides advances in the arts with novel methods and apparatus directed to providing charging

systems and methods for harvesting energy from intermittent and/or variable energy sources.

[006] According to one aspect of the invention, in an example of a preferred embodiment, an energy storage device charging system includes an energy storage device connected to a charger. The charger includes a charge controller to supply current to the energy storage device and a bootstrap circuit configured to provide power sufficient to operate the charger at low power levels.

[007] According to another aspect of the invention, in an exemplary preferred embodiment, an energy storage device charging system has an energy storage device operably connected to a charger having a charge controller. A bootstrap circuit is configured to provide power sufficient to cause the charge controller to supply current to the energy storage device. Energy harvesting devices are operably coupled to the charger. The energy harvesting devices are connected in relation to one another in a configuration switchable between a parallel arrangement and a series arrangement.

[008] According to still another aspect of the invention, preferred embodiments include photovoltaic cells coupled to provide energy in the energy storage device charging system further described.

[009] According to yet another aspect of the invention, an energy harvesting method includes the steps of providing an energy storage device operably connected to a charger having a charge controller and providing a bootstrap circuit operably connected to the charge controller. In a further step, power from the bootstrap circuit is used to cause the charge controller to supply current to the energy storage device. Thereafter, the charger regulates the output of energy harvesting devices operably coupled to the charger.

[010] The invention has advantages including but not limited to one or more of the following; energy harvesting at a range of operating levels and/or providing a configurable array of energy harvesting devices adaptable to real-time conditions. These and other advantageous features and benefits of the present invention can be understood by one of ordinary skill in the arts upon careful consideration of the detailed description of representative embodiments of the invention in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[011] The present invention will be more clearly understood from consideration of the following detailed description and drawings in which:

[012] Figure 1 is a simplified schematic drawing of an example of a preferred embodiment of an energy harvesting circuit according to the invention;

[013] Figure 2 is a simplified schematic drawing of an example of an alternative preferred embodiment of an energy harvesting circuit according to the invention;

[014] Figures 3A through 3C are simplified schematic drawings of an example of a preferred embodiment of a configurable array in an energy harvesting circuit according to the invention; and

[015] Figure 4 is a simplified schematic drawing of an example of a preferred embodiment of an energy harvesting circuit according to the invention having a bootstrap stack in series with a parallel array.

[016] References in the detailed description correspond to like references in the various

drawings unless otherwise noted. Descriptive and directional terms used in the written description such as right, left, back, top, bottom, upper, side, et cetera, refer to the drawings themselves as laid out on the paper and not to physical limitations of the invention unless specifically noted. The drawings are not to scale, and some features of embodiments shown and discussed are simplified or amplified for illustrating principles and features, as well as anticipated and unanticipated advantages of the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

[017] While the making and using of various exemplary embodiments of the invention are discussed herein, it should be appreciated that the present invention provides inventive concepts which can be embodied in a wide variety of specific contexts. It should be understood that the invention may be practiced with various alternative components without altering the principles of the invention. For purposes of clarity, detailed descriptions of functions, components, and systems familiar to those skilled in the applicable arts are not included. In general, the invention provides energy harvesting control capabilities useful in a variety of applications and systems.

[018] The charger circuit 100 configuration and method illustrated in Figure 1 places energy harvesting apparatus, such as one or more solar cell(s) 10 in series or in parallel with an energy storage device such as a battery 12, or array of batteries. A charger 14 provides a regulated connection between the energy harvesting device(s) 10 and energy storage device(s) 12 as further described. The charger 14 includes a charge controller 17 and is connected with a bootstrap circuit 11 which is configured to ensure appropriate startup power in instances when the output of the energy harvesting apparatus 10 is low and/or when the energy storage device 12 is in a depleted state. At startup, the charger 14 is preferably supplied power in the form of the summation of the battery voltage added together with the solar cell voltage. This configuration provides the additive voltage for

the operation of the charger circuit 100. In addition, charging current can be supplied to the battery 12 from the solar cell 10 using a boost regulator, for example represented by charger 14, even if the battery voltage is greater than the solar cell voltage. The same principle applies when using an array of solar cells, which may be represented by the single solar cell 10 of Figure 1. Likewise, additional batteries may be used. The individual solar cell elements in an array may be placed in parallel to the extent required to achieve the desired current level, allowing for an array architecture adaptable for efficient energy harvesting and charging operation. One of the potential challenges to using this architecture having all of the solar cells in parallel, is guaranteeing sufficient voltage for startup. Using the charger to supply the summation of the battery voltage and solar cell voltage provides sufficient headroom for the charger to operate. In addition, a charging current can be supplied for any battery voltage from the solar cell using a boost charger, even if the battery voltage is greater than the solar cell voltage. All the solar cell elements can be placed in parallel, allowing for a simpler array architecture and more efficient array operation. In the case where the battery 12 is completely discharged, for example, the parallel solar cell 10 may not produce sufficient voltage to begin charging the battery.

[019] As shown in Figure 2, in an alternative charging circuit 200 and method, a string of solar cells placed in series may be used as a startup stack 20 in a bootstrap circuit 21. In this configuration, the output of the startup stack 20 is preferably sufficient to independently provide the startup current necessary to run the control portion 22 of the charger IC 24. In this state, the charger 24 operates at 100% duty cycle. In this example, the output FETs 26 of the charger 24 do not switch in this state and require only a DC voltage applied to turn on the appropriate gate(s). Therefore, only a minimal power output from the bootstrap circuit 21 is required. When the battery 28 is sufficiently charged to require switching of the charger 24, the system 200 can draw power from the

solar cell array, e.g., parallel stack 29, preferably substantially maximizing energy harvesting.

[020] Another solution to the startup problem is to make the solar cell array reconfigurable between a bootstrap state and a fully operational charging state. Using such an arrangement, during startup, the array is configured in a series configuration that provides sufficient voltage to begin the charging operation. After the energy storage device reaches a sufficient level, the array is then reconfigured to a parallel architecture. An additional alternative embodiment of the charging circuit and method within the scope of the invention is shown in Figures 3A-3C, in which the charger circuit 300 is provided with a reconfigurable solar cell array 33. The reconfigurable solar cell array 33 includes individual solar cells 34 coupled by switches 36, 38, in an arrangement by which the cells 34 may be coupled in series, 36 in Figure 3B, or in parallel, 38 in Figure 3C. Preferably, during startup, the array 33 is configured in a series configuration for operation in the bootstrap mode; E.g., The series-connecting switches 36 are switched “on” and the parallel-connecting switches 38 are switched “off”. Such a series configuration provides voltage from the solar cell array 33 that is the sum of the voltage produced by the individual solar cells 34, preferably providing a sufficient voltage level to begin the charging of the battery 39. After the battery 39 has reached a sufficient charge level, the array 33 is then preferably reconfigured to a parallel architecture, by switching the series-connecting switches 36 to “off” and switching the parallel-connecting switches 38 to “on”. The resulting parallel configuration provides current from the solar cell array 33 that is the sum of the current produced by the individual solar cells 34, providing a relatively high current level suitable for utilizing the energy produced by the solar cells 34 for storing charge on the battery 39. Operating in this charging state, the circuit 300 preferably substantially optimizes the energy harvested from the solar cells and stored or otherwise supplied to a load. It should be appreciated by

those skilled in the arts that in addition to the all-series and all-parallel operation, portions of the reconfigurable solar array 33 may be operated in series while other portions are operated in parallel in order to produce a selected voltage/current output level.

[021] Now referring primarily to Figure 4, an embodiment of a charger circuit 400 and related method includes a bootstrap circuit 41 with a relatively small startup energy harvesting cell or array 42 supplemental to a relatively larger parallel energy harvesting array 44. The startup energy harvesting array 42 is preferably used to power the control circuitry 46 of the charger 48, and subsequent to startup of the charger, the larger parallel energy harvesting array 44 is used to power the higher-power output stage of the charger 48. The circuit shown in Figure 4 illustrates an example of a preferred embodiment in a fixed configuration. It should also be understood that this approach may also be used in combination with the reconfigurable array circuit 33 shown in the implementation described with respect to Figure 3.

[022] The methods and apparatus of the invention provide one or more advantages including but not limited to improved energy harvesting systems, and/or startup methods, and/or improved low-power efficiency in energy harvesting systems. While the invention has been described with reference to certain illustrative embodiments, those described herein are not intended to be construed in a limiting sense. For example, variations or combinations of steps or materials in the embodiments shown and described may be used in particular cases without departure from the invention. Modifications and combinations of the illustrative embodiments as well as other advantages and embodiments of the invention will be apparent to persons skilled in the arts upon reference to the drawings, description, and claims.

WE CLAIM:

1. An energy harvesting system comprising:
 - an energy harvesting device operably coupled with an energy storage device;
 - a charger operably coupled with the energy harvesting device and the energy storage device, the charger having a charge controller; and
 - a bootstrap circuit, wherein the bootstrap circuit is configured to provide power sufficient to cause the charge controller to supply current to operate the charger, whereby the charger is configured to regulate the transfer of energy from the energy harvesting device to the energy storage device.
2. The system according to claim 1 wherein the charger further comprises a buck charger.
3. The system according to claim 1 wherein the bootstrap circuit further comprises an energy harvesting device operably coupled to provide power to the charge controller.
4. The system according to claim 1 wherein the bootstrap circuit further comprises a battery.
5. The system according to claim 1 wherein the energy harvesting device further comprises a photovoltaic cell.
6. The system according to claim 1 wherein the energy harvesting device further comprises a piezoelectric generator.
7. The system according to claim 1 wherein the energy harvesting device further comprises a mechanical power generator.

8. The system according to claim 1 wherein the energy harvesting device further comprises a radio frequency power generator.

9. The system according to claim 1 wherein the energy harvesting device further comprises an array of individual energy harvesting devices configured to provide power to the charger, the individual energy harvesting devices being operably connected in relation to one another in a configuration switchable between a parallel arrangement and a series arrangement.

10. An energy storage device charging system comprising:

an energy storage device operably connected to;

a charger having a charge controller;

a bootstrap circuit, wherein the bootstrap circuit is configured to provide power sufficient to cause the charge controller to start operation of the charger to supply current from the energy harvesting device to the energy storage device; and

a plurality of energy harvesting devices operably coupled to the charger and to a load, the energy harvesting devices being operably connected in relation to one another in a configuration switchable between a parallel combination and a series combination.

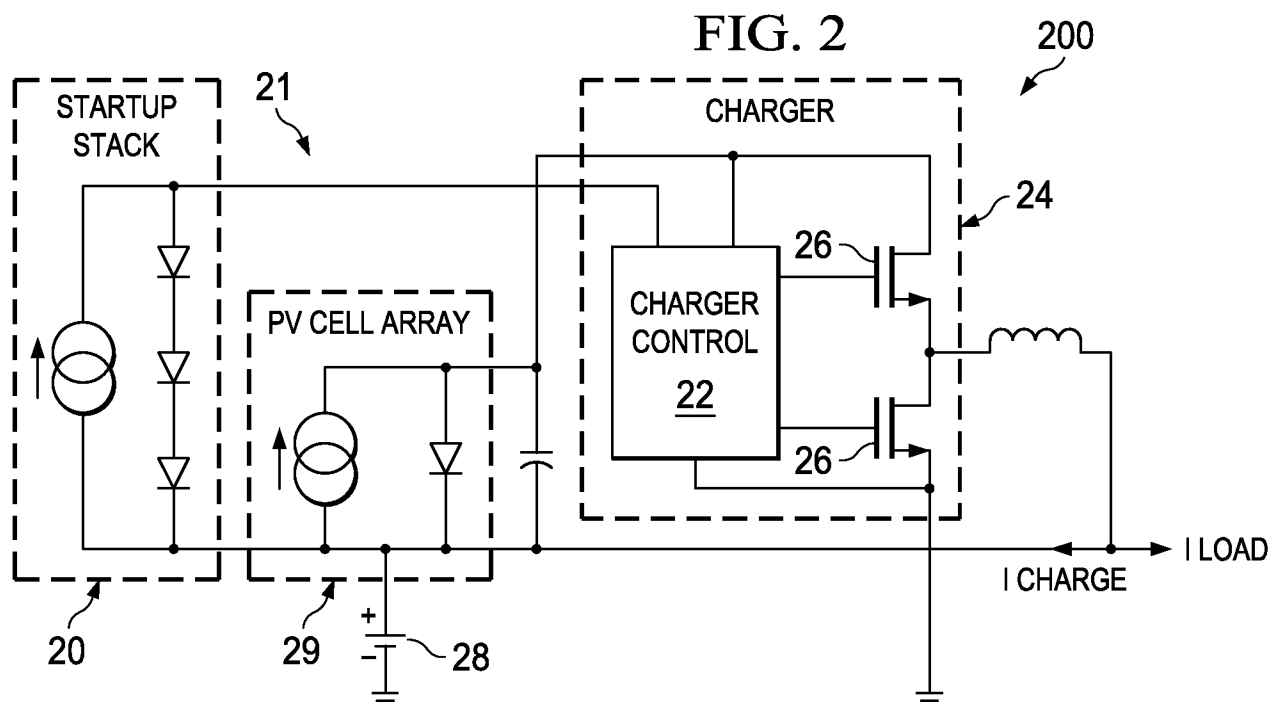
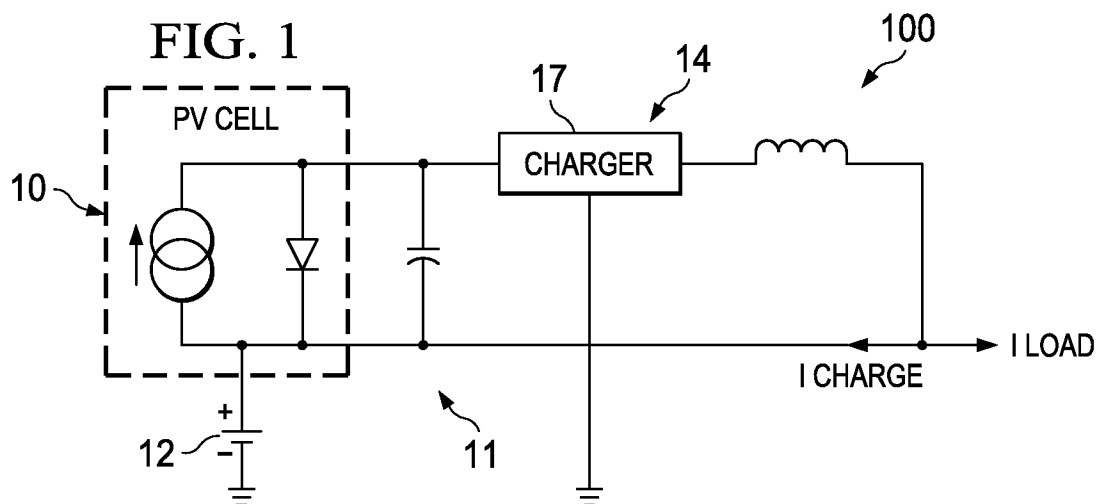
11. The system according to claim 10 wherein the charger further comprises a buck charger.

12. The system according to claim 10 wherein the bootstrap circuit further comprises a plurality of energy harvesting devices configured to provide power to the charge controller, the energy harvesting devices being operably connected in relation to one another in a configuration switchable between a parallel combination and a series combination.

13. The system according to claim 10 wherein the bootstrap circuit further comprises an energy harvesting device configured to provide power to the charge controller.
14. The system according to claim 10 wherein the bootstrap circuit further comprises a photovoltaic cell.
15. The system according to claim 10 wherein the bootstrap circuit further comprises a battery.
16. The system according to claim 10 wherein the bootstrap circuit further comprises a piezoelectric generator.
17. The system according to claim 10 wherein the bootstrap circuit further comprises a mechanical power generator.
18. The system according to claim 10 wherein the bootstrap circuit further comprises a radio frequency power generator.
19. The energy storage device charging system according to claim 10 wherein the energy storage device is operably coupled with portable electronic apparatus.
20. The energy storage device charging system according to claim 10 wherein the energy storage device is operably coupled with portable communications apparatus.
21. The energy storage device charging system according to claim 10 wherein the energy storage device is operably coupled with portable imaging apparatus.

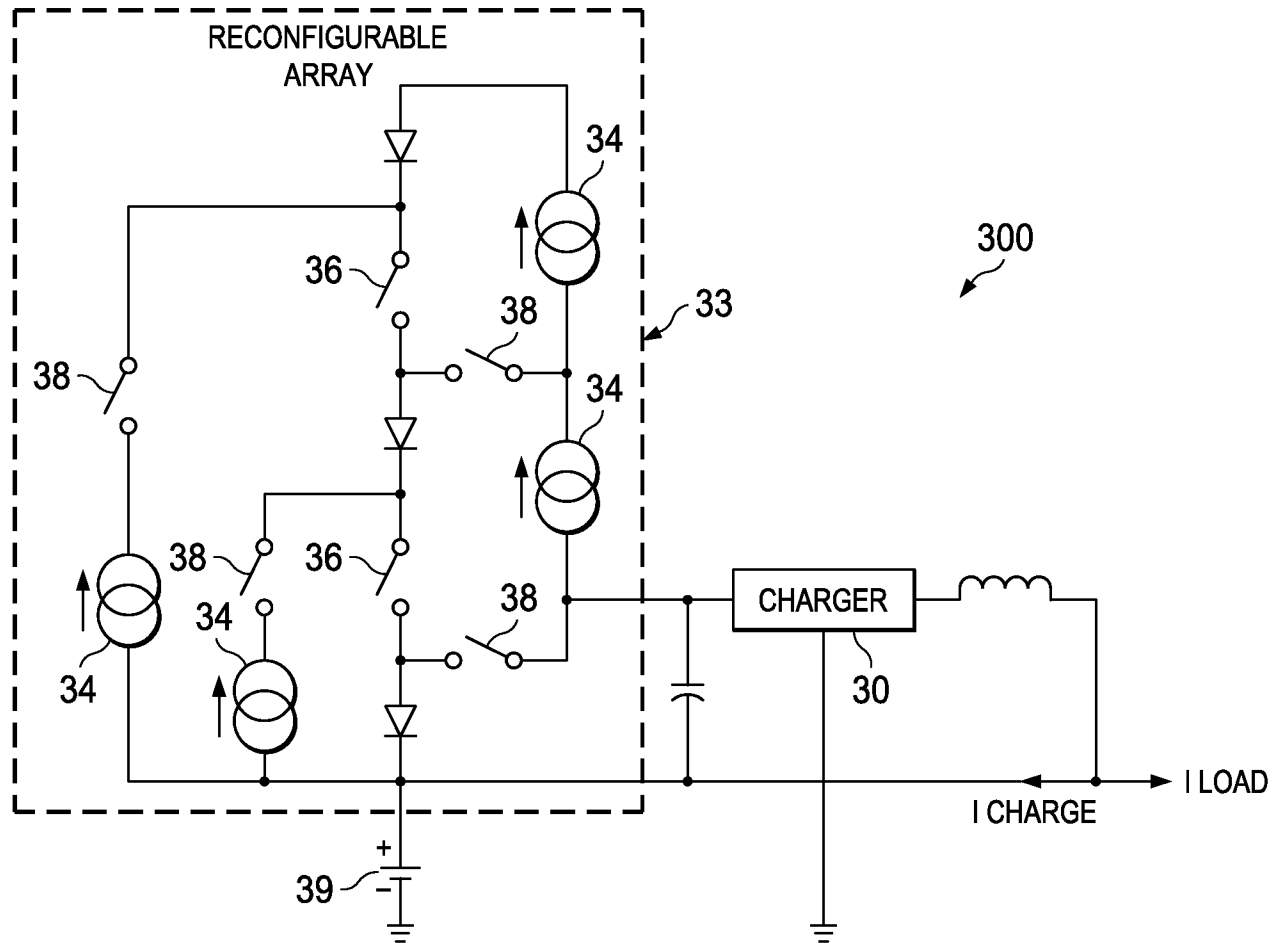
22. The energy storage device charging system according to claim 10 wherein the energy storage device is operably coupled with portable display apparatus.
23. The energy storage device charging system according to claim 10 wherein the energy storage device is operably coupled with portable audio apparatus.
24. The energy storage device charging system according to claim 10 wherein the energy storage device is operably coupled with portable computing apparatus.
25. An energy harvesting method comprising the steps of:
- providing an energy storage device operably connected to a charger having a charge controller;
 - providing a bootstrap circuit operably connected to the charge controller;
 - using power from the bootstrap circuit to cause the charge controller to supply current to the energy storage device; and thereafter
 - using the charger to regulate the output of a plurality of energy harvesting devices operably coupled to the charger and to the energy storage device.

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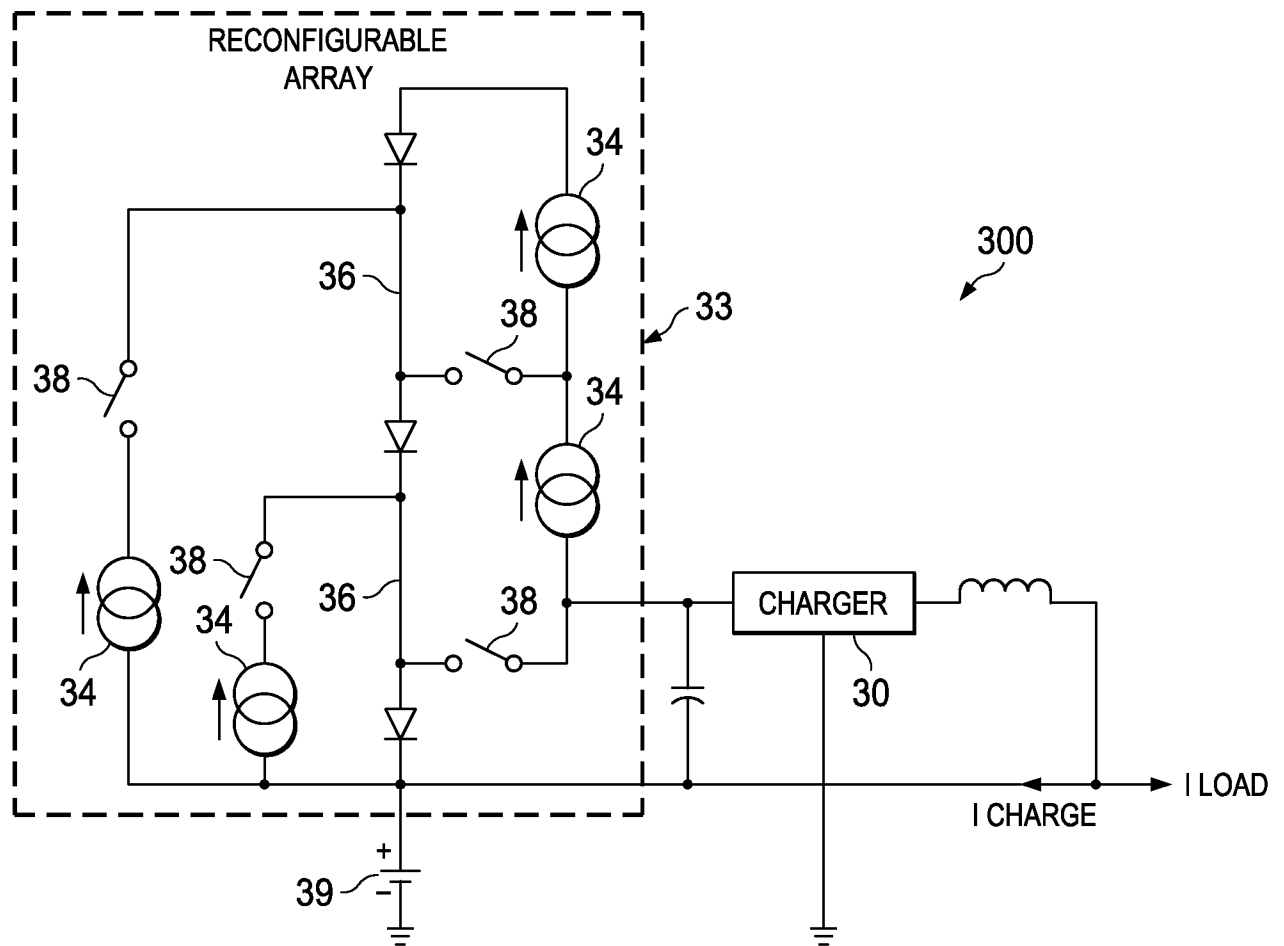
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FIG. 3A



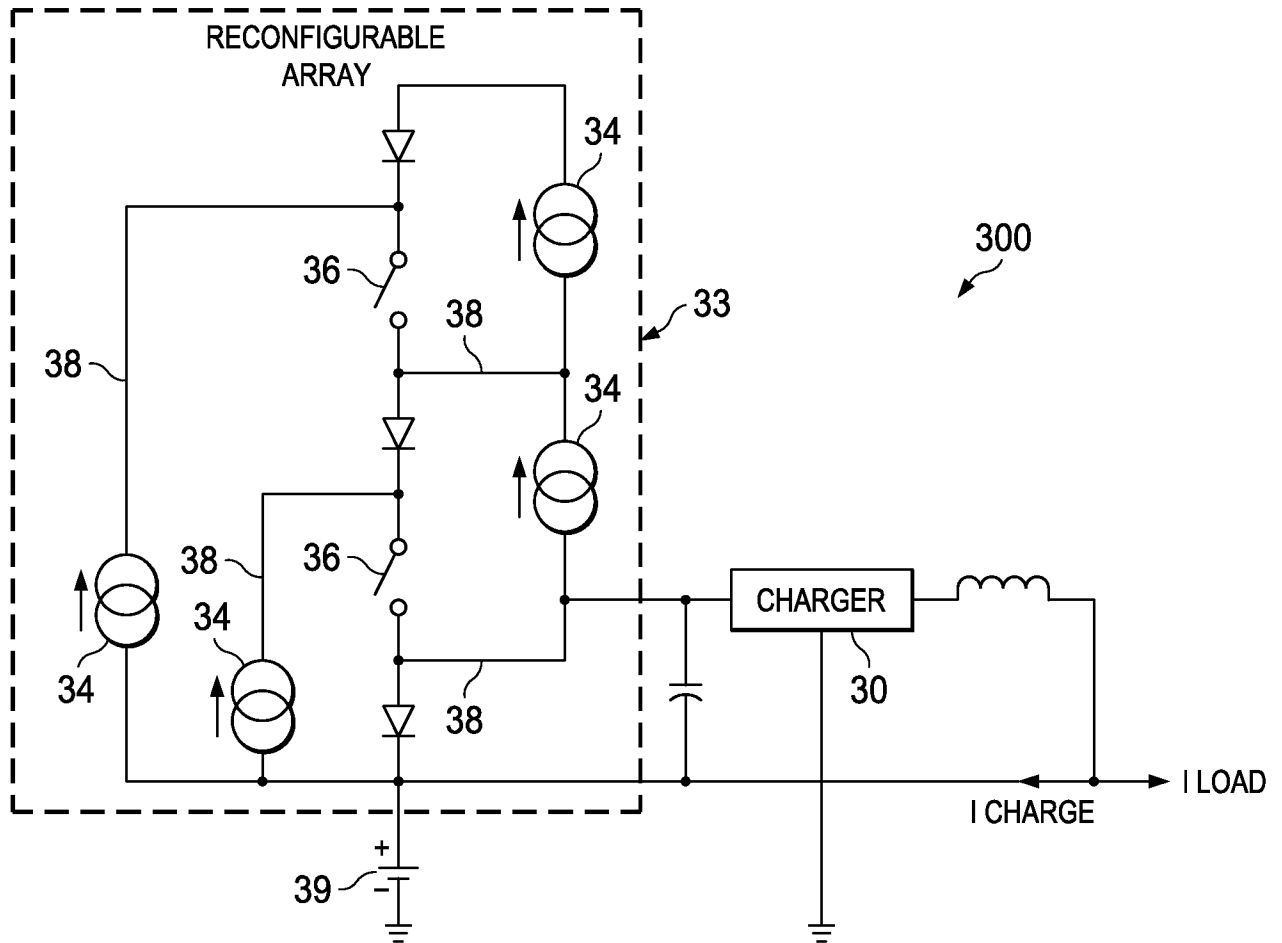
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FIG. 3B

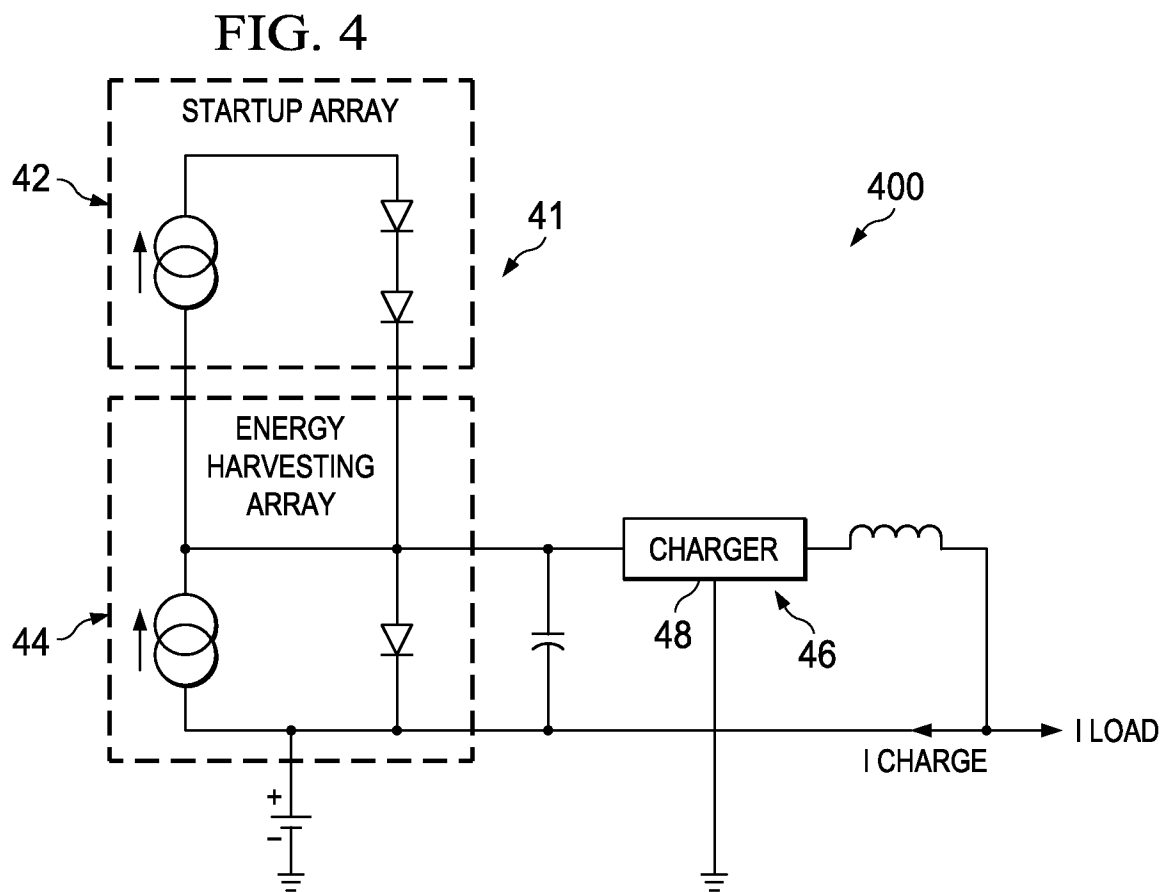


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FIG. 3C



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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2010/055338

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - H02J 7/00 (2010.01)

USPC - 320/137

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - H02J 1/00; H02J 7/00 (2010.01)

USPC - 307/71; 320/101, 137

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

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

MicroPatent, Google Patents

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X — Y	US 2006/0281435 A1 (SHEARER et al) 14 December 2006 (14.12.2006) entire document	1, 3-8, 25 ----- 2, 9-24
Y	US 2007/0228835 A1 (VARZHABEDIAN) 04 October 2007 (04.10.2007) entire document	2, 11
Y	US 6,060,790 A (CRAIG, JR) 09 May 2000 (09.05.2000) entire document	9-24
A	US 2007/0182362 A1 (TRAINOR et al) 09 August 2007 (09.08.2007) entire document	1-25
A	US 2009/0200985 A1 (ZANE et al) 13 August 2009 (13.08.2009) entire document	1-25

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

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Date of the actual completion of the international search

17 December 2010

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