

Energy Storage System and Method of Boosting an Electrical Power for Outputting to a Load

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims benefit under 35 U.S.C. § 119(e) of U.S. Provisional Application having Serial No. 63/012,084 filed Apr. 20, 2020, which is hereby incorporated by reference herein in its entirety.

FIELD OF INVENTION

[0002] The present invention generally relates to energy storage systems; specifically, to energy storage systems used as a device to provide electrical energy to devices, equipment and/or loads, especially in situations where the existing electrical infrastructure is not suitable to power such devices, equipment and/or loads and/or where it may not be economically feasible or operationally practical to build suitable electrical infrastructure to power such devices, equipment and/or loads.

BACKGROUND OF INVENTION

[0003] Various industries use electrically operated equipment in their operations. An existing grid mains connection may not be available or the existing grid mains connection may not be suitable to power such equipment. Furthermore, it may be uneconomic or impractical to extend a grid mains connection of sufficient capacity to the location of such equipment. By contrast, a diesel or fossil-fuel generator may be used to provide sufficient power to such equipment and can be transported to most locations. As a result, various industries commonly use diesel or fossil-fuel generators to provide the electrical power required to operate such equipment.

[0004] Generators however, create significant amounts of carbon emissions and air quality pollutants. Generators also need to be switched off regularly for refueling, resulting in frequent interruptions to the operations of the equipment being powered by such generators.

SUMMARY OF INVENTION

[0005] In the light of the foregoing background, it is an object of the present invention to provide an improved energy storage system.

35 [0006] Accordingly, provided herein is an alternate system which is capable of providing power to equipment which, when compared to a generator or a sole electrical source, results in lower emissions of carbon and air quality pollutants, and which reduces the frequency of operational interruption to such equipment.

40 [0007] In some embodiments, the system boosts the electrical power from incoming power source (e.g. mains electricity) for outputting to high-demand electrically operated equipment.

[0008] Accordingly, one embodiment provides an energy storage system which includes an electrical input adapted to connect to an external power source; an electrical output adapted to connect to a load; a power bus connected between the electrical input and the electrical output; and a battery system comprised of one or more battery modules or one or more battery packs connected to the power bus. The energy storage system can switch between a first mode in which the battery module is recharged by electrical power received from the electrical input via the power bus, and a second mode in which the battery module discharges to boost the electrical power received from the electrical input via the power bus for outputting to the electrical output.

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[0009] In some embodiments, in the second mode the electrical power received from the electrical input is boosted for its power capacity.

[0010] In some embodiments, in the first mode the electrical power received from the electrical input is directly outputted to the electrical output.

55 [0011] According to a variation of the disclosed embodiments, the electrical input is an AC input, and the electrical output is an AC output. The power bus is a DC bus.

[0012] According to another variation of the disclosed embodiments, the energy storage system further contains a rectifier coupled between the electrical input and the power bus; and an inverter coupled between the power bus and the electrical output.

60 [0013] According to a further variation of the disclosed embodiments, the energy storage system is further adapted to be switched to a third mode in which the battery module discharges to provide battery power to the electrical output without the electrical power received from the electrical input.

[0014] In one implementation, the energy storage system has the form factor of a
65 shipping container.

[0015] According to another aspect of the invention, a method of boosting an electrical power for outputting to a load comprises the steps of receiving an electrical power from an electrical input, discharging a battery module to obtain a battery power, and boosting the electrical power using the battery power for outputting to an electrical output.

70 [0016] In some embodiments, the electrical power from the electrical input is AC power. The method further contains the step of rectifying the electrical power to DC power for combining with the battery power.

[0017] Additionally or alternatively, the electrical output is an AC output. The method further contains the step of transforming a boosted DC power to AC power for outputting.

75 [0018] Therefore, disclosed herein are energy storage systems for providing electrical power to electrically operated loads or equipment. Such a system may be especially useful in scenarios where an electrical source may not be suitable for powering such electrically operated loads or equipment. The energy storage system, in one embodiment, is comprised of a rectifier, an inverter and a battery module. With the battery power
80 stored in the battery module, the input electrical power can be boosted for example in terms of power capacity. In one example, an input electrical power of not more than 50 kilowatts which is connected to the power bus, can be boosted by the energy storage system to achieve an output electrical power which is more than 50 kilowatts of power.

[0019] On the other hand, some implementations of the energy storage system are in the dimension and specification of standard shipping containers, for example 8ft or 10ft containers. Therefore, it is extremely easy and convenient to transport the energy storage system to any worksite with container trucks. It should be noted that when compared to conventional diesel container generator, the size of the energy storage system disclosed herein could be made much more compact (e.g. by adopting an 8ft container form factor) where the diesel container generators are usually in the form factor of a 20ft container.

[0020] By adopting the battery module (e.g. Li-ion battery modules) which is a fossil fuel free energy source as compared to diesel engines, some embodiments of the invention provide further advantages to completely replace the dirty, noisy and hazardous diesel generators. In terms of environment impacts, the energy storage system could be up to thirty two times quieter than a diesel generator, which is ideal for urban environments where the engine noise and vibration of a generator can be a disturbance. The energy storage system also produces zero emissions, with none of the harmful CO, CO₂ NO_x, PM or SO₂ emissions of a diesel generator, allowing it for use in areas with poor ventilation. The energy storage system also eliminates diesel handling, spills and devastating diesel fires. The lack of moving parts makes the system orders of magnitude safer by design. Internet connectivity enables remote monitoring, device management, remote troubleshooting and data analytics. An automatic recharging means that nearly zero maintenance once installed. Lastly, with the form factor of a shipping container the energy storage system is plug-and-play, which could replace most large diesel generators between 200-600kVA, and can be installed and be ready for operation in under 2 hours.

[0021] In one embodiment it is provided a general method for determining the minimum capacity of the energy storage system to support the electrically operated load, the method allowing for sources with different characteristics and loads with different characteristics.

[0022] Another embodiment provides method of providing electricity to a machine or machines requiring power greater than 50 kilowatts using an energy storage system comprising continuously charging the battery from a lower power electricity input of not

more than 50 kilowatts; storing the electricity in the battery; and providing at the output the electricity to such machine or machines requiring power greater than 50 kilowatts; whereby the power difference between the input and output is provided by the battery.

[0023] These and additional features provided by the embodiments described herein will be more fully understood in view of the following detailed description, in conjunction with the drawings.

BRIEF DESCRIPTION OF FIGURES

[0024] The foregoing and further features of the present invention will be apparent from the following description of embodiments which are provided by way of example only in connection with the accompanying figures, of which:

[0025] FIG. 1 provides a high-level diagram of the connections of an energy storage system, which is recharged by a source while simultaneously being used to provide electrical power to a load;

[0026] FIG. 2 illustrates an exemplary embodiment of the architecture of an energy storage system of the present invention;

[0027] FIG. 3 illustrates a schematic diagram of an energy storage system according to an embodiment of the present invention;

[0028] FIG. 4 illustrates an energy storage system equipped with a shipping container according to an embodiment of the present invention.

[0029] In the drawings, like numerals indicate like parts throughout the several embodiments described herein.

DETAILED DESCRIPTION

[0030] In the claims which follow and in the preceding description, except where the context requires otherwise due to express language or necessary implication, the word “comprise” or variations such as “comprises” or “comprising” is used in an inclusive sense, i.e. to specify the presence of the stated features but not to preclude the presence or addition of further features in various embodiments of the invention.

[0031] As used herein and in the claims, “couple” or “connect” refers to electrical coupling or connection either directly or indirectly via one or more electrical means unless otherwise stated.

[0032] Embodiments of the present invention provide a new apparatus and method for providing electrical power to electrically operated equipment in situations where it may be uneconomic or impractical to use a grid mains connection to do so. The following description is presented to enable one of ordinary skill in the art to make and use the invention and is provided in the context of a patent application and its requirements. Various modifications to the disclosed embodiment and the generic principles and features described herein will be readily apparent to those skilled in the art. Thus, the present invention is not intended to be limited to the embodiments shown but is to be accorded the widest scope consistent with the principles and features described herein.

[0033] Battery or battery cells may refer to any of a variety of different rechargeable configurations and cell chemistries including, but not limited to, lithium-ion, lithium-ion polymer, nickel-metal hydride, nickel cadmium, nickel hydrogen, nickel zinc, silver zinc, zinc-air, lead-acid, vanadium redox, vanadium flow or other chargeable type or configuration. The terms “battery”, “battery module”, “battery system” and “battery subsystem” may be used interchangeably and as used herein refer to a device which has the capability to be charged and discharged such as a battery, battery pack, capacitor, supercapacitor or ultracapacitor.

[0034] FIG. 1 provides an exemplary implementation of an energy storage system **100** according to a first embodiment of the invention, which is used to provide electrical power to an electrically powered load **101**, and which is recharged by a source **102**.

[0035] In one implementation, source **102** is a small and reliably available-on-demand electrical supply, such as a small, temporary grid mains connection (which would ordinarily be insufficient to power load **101**). In another implementation, source **102** is an irregular and uncontrolled electrical supply, such as a solar panel and/or a wind turbine. In a further implementation, source **102** is a controllable electrical supply which is only available for short durations each period due to any one or any combination of noise, environmental or regulatory restrictions, such as a diesel generator which is switched on periodically for a duration no longer than is necessary to sufficient recharge energy storage system **100** to a level where energy storage system **100** is able to provide power to load **101** until the next period when the diesel generator can be switched on. In yet a further implementation, source **102** is any combination of a small and reliably available-on-demand electrical supply and/or an irregular and uncontrolled electrical supply and/or a controlled electrical supply which is only available for short durations each period. In all the embodiments described in this paragraph, the source **102** would ordinarily be unsuitable to directly provide power to the load **101**.

[0036] FIG. 2 shows, according to another embodiment of the invention, an energy storage system **200**, such as may be used to implement the present invention. The present invention is not limited to this particular implementation of the energy storage system. As shown in FIG. 2, the energy storage system **200** includes a battery subsystem **210**, a rectifier **211** and an inverter **212**. A power bus which is the DC bus **213** electrically couples the battery subsystem **210**, rectifier **211** and inverter **212**. An external power source connects to an electrical input **240** and in turn to the rectifier **211**. The external power source is an AC source similar to those mentioned above, and thus the electrical input **240** is an AC input. On the other hand, the load **201** is an AC load which is connected to an electrical output **250** and thus the electrical output **250** is an AC output.

The electrical output **250** is further connected to the inverter **212**. The battery subsystem **210** as shown in FIG. 2 contains multiple battery units **210a** connected in series.

[0037] The DC bus **213** is energised by the rectifier **211** or the battery subsystem **210** or both the rectifier **211** and the battery subsystem **210**, depending on the availability of the source **202** and the state-of-charge of the battery subsystem **210**. The energy storage system **200** is therefore adapted to work under different working modes and being switchable between these working modes, including a first mode in which the battery subsystem **210** is recharged by electrical power received from the electrical input **240** via the DC bus **213**, a second mode in which the battery subsystem **210** discharges to boost the electrical power received from the electrical input **210** via the DC bus **213** for outputting to the electrical output **250**, and a third mode in which the battery subsystem **210** discharges to provide battery power to the electrical output **250** when there is no electrical power received from the electrical input **240**.

[0038] In the first mode, the AC electrical power received from the electrical input **240** also powers the load **201** directly via the DC bus **213** besides recharging the battery subsystem **210**, although as mentioned above such a direct powering to the load **201** might not be sufficient for the normal operation of the load **201**. In the first mode, the DC bus **213** provides DC power to the inverter **212**, where the DC power is converted by the rectifier **211** from the inputted AC power. The inverter **212** then provides AC power to the load **201**. When the power drawn by the load **201** through the inverter **212** is less than the power available from the source **202** through the rectifier **211**, and when the battery subsystem **210** is not full, the battery subsystem **210** is recharged through the DC bus **213**.

[0039] When the power drawn by the load **201** through the inverter **212** is greater than the power available from the source **202** through the rectifier **211**, and when the battery subsystem **210** is not empty, the battery **210** is discharged through the DC bus **213** in the second mode. To fulfill the requirements of the second mode, the inverter **212** and the battery subsystem **210** is sized such that they are capable of meeting the maximum electrical requirements of the load **201**. For example, if the load **201** requires a three-phase electrical supply and has a peak power demand of 300 kilowatts, then i) the

inverter **212** shall be one which provides sufficient power to meet the load's peak power demand; and ii) the battery subsystem **210** shall be sized such that it is capable of providing sufficient power to the inverter **212**, in order for the inverter **212** to provide sufficient power to meet the load **201**'s peak power demand.

[0040] In the third mode, when there is no source **202** available to the energy storage system **200**, the battery subsystem **210** then becomes the only power source to supply the load **201**. All the power outputted to the load **201** then comes from the battery power from the battery subsystem **210** as converted by the inverter **212**.

[0041] Although not shown, the battery subsystem **210** may further contain further subsystems and components such as a battery management system, one or more DC-DC converters, one or more switches, relays, contactors, one or more disconnect or overcurrent protection devices or other electrical protection device or devices in order to provide safe, reliable and long-lasting operation.

[0042] Although not shown, the energy storage system **200** may further contain other auxiliary systems, subsystems or components, such as, but not limited to, heat pumps, heat exchangers, air-conditioners, cooling fans, thermal management systems, one or more energy management systems, a fire detection system, a fire suppression system, a flood sensing system, one or more human machine interfaces, internal communication systems and external communication systems, in order to provide safe, reliable and long-lasting operation and ease of management of energy storage system **200**.

[0043] A further consideration in determining the capacity of battery subsystem **210** is ensuring that its state-of-charge, at all times, remains above the threshold value whereby the energy storage system **200** is shut down, accounting for the net rate of charging or discharging of the battery subsystem **210** through the DC bus **213**.

[0044] Turning now to FIG. 3, an electrical schematic of another embodiment of the invention is shown. In this embodiment, the source **301** is a 20 kilowatt, three-phase utility mains connection and the load **302** is a 300 kilowatt, three-phase electrical distribution panel which is connected to a tower crane. It should be noted that in other

variations of the embodiments, the source may be an electrical supply required with a few kilowatts to under 50 kilowatts depending on various applications. The energy storage system is able to deliver at the output the necessary power for equipment (such as tower crane, site office, passenger or material hoist, etc.) to operate. In some further variations, the output power is significantly greater than the input power. In some cases, the output provides greater than 50 kilowatts.

[0045] In the embodiment of FIG. 3, energy storage system **300** is comprised of a battery subsystem **310**, a three-phase rectifier with a 63 kilowatt power rating **311**, a three-phase inverter with a 315 kilowatt power rating **312** and a DC bus **313**. In this embodiment, inverter **312** is connected to 300 kilowatt delta-wye transformer **314** in order to allow single-phase loads to be connected. The external power source **301** connects to the rectifier **311** via an electrical input **340**, and the load **302** connects to the transformer **314** via an electrical output **350**. There are also multiple circuit breakers **360** in the circuit of the energy storage system **300** for safety purposes.

[0046] In this embodiment, the battery subsystem **310** is comprised of a plurality of battery units with each individual battery unit **310a** further comprised of a 224 lithium-ion battery cells in a 14S16P configuration. In this embodiment, fifteen battery units **310a** are connected in series to form a single “battery string” **310b** and a total of seven battery strings **310b** are connected to the DC bus **313**, providing a total nominal energy storage capacity of 300 kilowatt-hours. The battery subsystem **310** in this embodiment is managed by a battery management system **310c**, in order to ensure safe, reliable and long-lasting operation. This embodiment further contains a plurality of safety switchgear and further management and control systems including a power conversion subsystem controller **315**, energy management system **316**, fire detection and suppression system **317**, a ‘DC section’ thermal management system **318**, an ‘AC section’ cooling system **319**, an uninterruptible power supply system **320** to provide a backup electrical supply to the critical management and control systems, a flood detection system **321**, a human-machine interface **322**, an emergency power off switch **323** and a cellular communication interface **324** in order to ensure safe, reliable and long-lasting operation. All components,

subsystems and systems that make up energy storage system **300** are, in this embodiment, enclosed in and protected by a durable and weatherproof shipping container **400**, as shown in FIG. 4. Artwork is painted to the exterior of shipping container **400** for aesthetic purposes and to communicate the branding of the energy storage system **300**.

[0047] For each of the energy storage systems in the embodiment of FIG. 2 or that of FIG. 3, necessary engineering designs have also been made to make the storage system usable, durable and marketable for construction site environments in any weather conditions and any site configurations. This includes making proper arrangements of the accessories or functional provisions on the surface of the energy storage system (in the form factor of a container) that have catered for actual site operations and specific requirements for outdoor usage. Such arrangements may be made to also other container-like energy storage system designs in the spirit of the systems described in the present disclosure.

[0048] In particular, take the shipping container **400** as an example, the container **400** contains a plug zone **460** on its side wall. Plugs (not shown) are configured in the plug zone **460** which implement the electrical input and electrical output of the energy storage system as mentioned above. Note that there may be more than one such plug zone **460** on the container **400**. The plug zone's locations and orientation are so designed to avoid flooding, to facilitate easy plugging for site electricians safe uses and to suit the types of electrical equipment that are commonly used on site.

[0049] In addition, the arrangement of the battery modules (not shown in FIG. 4) inside the container **400** is so designed to have the centre of gravity as close to the centre of the container as possible to avoid tipping or overturning of the container during lifting operation, that suit the safety standard in construction sites.

[0050] The outer surfaces of the container **400** are provided with safety notices (not shown) in different languages to suit the use in construction sites where there is no restriction on access around the energy storage unit on site unlike other similar equipment for use in other premises or situation where they are stored in a locked room.

[0051] The dimensions, weight and the output performance of the container **400** are inter-related to each other, and the specification of these combinations for the final products relies on the construction domain knowledge and market knowledge.

[0052] The exemplary embodiments of the present invention are thus fully described. Although the description referred to particular embodiments, it will be clear to one skilled in the art that the present invention may be practiced with variation of these specific details. Hence this invention should not be construed as limited to the embodiments set forth herein.

[0053] While the invention has been illustrated and described in detail in the drawings and foregoing description, the same is to be considered as illustrative and not restrictive in character, it being understood that only exemplary embodiments have been shown and described and do not limit the scope of the invention in any manner. It can be appreciated that any of the features described herein may be used with any embodiment. The illustrative embodiments are not exclusive of each other or of other embodiments not recited herein. Accordingly, the invention also provides embodiments that comprise combinations of one or more of the illustrative embodiments described above. Modifications and variations of the invention as herein set forth can be made without departing from the spirit and scope thereof, and, therefore, only such limitations should be imposed as are indicated by the appended claims.

[0054] It is to be understood that, if any prior art publication is referred to herein, such reference does not constitute an admission that the publication forms a part of the common general knowledge in the art, in any country.

[0055] Specific embodiments of this invention may have an energy storage system of any energy storage capacity and any power capacity. In some embodiments, the energy storage system has energy storage capacity greater than 50 kilowatt-hours and power capacity greater than 50 kilowatts.

[0056] In the description herein, numerous specific details are provided to provide a thorough understanding of the embodiments of the present invention. One skilled in the

relevant art will recognise, however, that an embodiment of the invention can be practiced without one or more of the specific details, or with other apparatus, systems, subsystems, assemblies, methods, components, materials, parts and/or the like. Well-known structures, materials or operations are not specifically shown or described in detail to avoid obscuring aspects of embodiments of the present invention.

[0057] A “source” for purposes of embodiments of the present invention may be any electrical source. The source can be, by way of example only but not by limitation, the mains grid, a solar PV system, a wind generator, a wind turbine, a fuel cell, a diesel generator or any combination of the previous.

[0058] A “load” for purposes of embodiments of the present invention may be any device which consumes power.

[0059] It will be appreciated that one or more of the elements depicted in the drawings/figures can also be implemented in a more separated or integrated manner, or even removed or rendered as inoperable in certain cases, as is useful in accordance with a particular application.

[0060] The battery subsystem in FIG. 2 is shown as a series-connected group of battery cells, and the battery subsystem in FIG. 3 is shown as a parallel-connected group of battery units, where each unit contains series-connected battery cells. However, those skilled in the art should realize that the configuration of the battery module may be a combination of series and/or parallel connected battery cells, battery modules or battery packs of many different configurations. For example, in one variation the battery subsystem is comprised of a plurality of parallel connected battery strings, which are further comprised of a plurality of series and parallel connected battery cells. In another variation, the battery subsystem is comprised of a plurality of parallel connected battery strings, which are further comprised of a plurality of series connected battery cells. In a further variation, the battery subsystem is comprised of a plurality of series connected battery cells.

What is claimed is:

1. An energy storage system, comprising
 - a) an electrical input adapted to connect to an external power source;
 - b) an electrical output adapted to connect to a load;
 - c) a power bus connected between the electrical input and the electrical output; and
 - d) a battery module connected to the power bus;wherein the energy storage system is adapted to be switched between a first mode in which the battery module is recharged by electrical power received from the electrical input via the power bus, and a second mode in which the battery module discharges to boost the electrical power received from the electrical input via the power bus for outputting to the electrical output.
2. The energy storage system of claim 1, wherein in the second mode the electrical power received from the electrical input is boosted for its power capacity.
3. The energy storage system of claim 2, wherein in the first mode the electrical power received from the electrical input is directly outputted to the electrical output.
4. The energy storage system of claim 2, wherein the electrical input is an AC input, and the electrical output is an AC output; the power bus being a DC bus.
5. The energy storage system of claim 4, further comprising:
 - e) a rectifier coupled between the electrical input and the power bus; and
 - f) an inverter coupled between the power bus and the electrical output.
6. The energy storage system of claim 5, wherein the energy storage system is further adapted to be switched to a third mode in which the battery module discharges to provide battery power to the electrical output without the electrical power received from the electrical input.
7. The energy storage system of any one of the preceding claims, wherein the energy storage system has the form factor of a shipping container.
8. A method of boosting an electrical power for outputting to a load, comprising the steps of:
 - a) receiving an electrical power from an electrical input;
 - b) discharging a battery module to obtain a battery power; and

- c) boosting the electrical power using the battery power for outputting to an electrical output.
9. The method of claim 8, wherein the electrical power from the electrical input is AC power; the method further comprising the step of rectifying the electrical power to DC power for combining with the battery power.
10. The method of claim 8, wherein the electrical output is an AC output; the method further comprising the step of transforming a boosted DC power to AC power for outputting.