

ELECTRIC VEHICLE CHARGING APPARATUS, SYSTEM AND METHODS

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to U.S. Provisional Application Serial No. 62/892,800, filed on August 28, 2019 entitled “3-PHASE INTERLEAVED 20kW DC-DC EV CHARGER”, the entire disclosure of which is hereby incorporated herein by reference.

TECHNICAL FIELD

[0002] One or more aspects broadly relate electric vehicle charging and more specifically to a DC-DC electric vehicle charging apparatus, system, and related methods.

BACKGROUND

[0003] Rechargeable batteries have been used for electrical energy storage in a wide range of applications including their use in vehicles, power tools, lap-top computers, mobile phones, two-way radios, lights, and uninterruptible power supplies. Vehicles that use rechargeable batteries can include automobiles, battery electric vehicles, hybrid electric vehicles, boats, golf carts, and aircraft. Electric chargers and methods of charging have been developed and used for charging these rechargeable batteries. Stationary chargers use power from the electric power grid have also been widely used to charge the rechargeable batteries. For instance, electric chargers have been developed that use alternating current, and transform the alternating current from one voltage to another using one or more wire-wound transformers, which can lead to some chargers being bulky or heavy.

[0004] A need exists to reduce the size and mass of chargers to enable a charging apparatus to be easily transportable with the electric vehicle. Further, electric vehicle chargers need to be reliable, safe, easy to use, and efficient.

SUMMARY

[0005] An electric vehicle charging system includes an interleaved DC-DC control system configured to facilitate providing electric charge to an electric vehicle battery from an energy storage device. The interleaved DC-DC control system includes an inrush current limiting circuit and three parallel boost converters, where each boost converter of the three parallel boost converters is configured to operate in a discrete phase, and where the three parallel boost converters are communicatively coupled to the inrush current limiting circuit. Further, the interleaved DC-DC control system includes unidirectional current circuitry communicatively coupled to the three parallel boost converters. The electric vehicle charging system also includes a controller communicatively coupled to the interleaved DC-DC control system. The controller includes electronic control circuitry configured to control the interleaved DC-DC control system as well as vehicle communication circuitry configured to establish charging protocols between the interleaved DC-DC control system and the electric vehicle battery, where the vehicle communication circuitry is communicatively coupled to the electric control circuitry.

[0006] Further, a method of manufacturing an electric vehicle charging system is provided. The method includes using electroplating to form an interleaved DC-DC control system that includes magnetic core inductors, a heatsink, and multistrand wire, where the electroplating produces a single printed circuit board that includes three parallel boost converters. Further, the method includes stacking the interleaved DC-DC control system on an energy storage device, where the stacking aligns the interleaved DC-DC control system such that the single printed circuit board is a same length and width as the energy storage device.

[0007] Further, a method of charging an electric vehicle battery is provided. The method includes receiving, by an interleaved DC-DC control system, an electrical power input from an energy storage device, the electrical power input being received at an inrush current limiting circuit of the interleaved DC-DC control system, where the inrush current limiting circuit includes multiple switching components. A controller communicatively coupled to the interleaved DC-DC control system switches the multiple

switching components on and off during an inrush current phase so that an electrical current flows continuously to three parallel boost converters of the interleaved DC-DC control system. The three parallel boost converters boost an input voltage of the electrical power input to a higher voltage of the electric vehicle battery. An electromagnetic interference filter of the interleaved DC-DC control system filters out noise from the electrical power input. Unidirectional current circuitry transmits the electrical power input to the electric vehicle battery.

[0008] Additional features and advantages are realized through the concepts described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] Aspects described herein are particularly pointed out and distinctly claimed as examples in the claims at the conclusion of the specification. The foregoing and other objects, features, and advantages of the disclosure are apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

[0010] FIG. 1 is a block diagram illustrating an example diagram of a controller and a converter for an EV charging system, in accordance with aspects described herein;

[0011] FIG. 2 is a block diagram illustrating example components of the converter and the controller of the EV charging system of FIG. 1, in accordance with aspects described herein;

[0012] FIG. 3 depicts an example process for manufacturing an electric vehicle charging system, in accordance with aspects described herein; and

[0013] FIG. 4 depicts an example process for charging an electric vehicle battery, in accordance with aspects described herein.

DETAILED DESCRIPTION

[0014] Described herein is an electric vehicle (EV) charging system for charging an EV battery. The EV charging system may provide unidirectional flow of an electric

charge using direct current to direct current (DC-DC) conversion, where the electric input is received from an energy storage device and transmitted, via the EV charging system, to the EV battery. According to various embodiments, the EV charging system may provide an output of a constant current (CC) or constant voltage (CV) across a wide DC voltage output range to an EV battery. The direct current (DC) voltage output range can be boosted, for example, via an interleaved DC-DC control system to as much as six times the input voltage in order to transfer the lower battery voltage from the energy storage device to the higher vehicle battery voltage. Advantageously, according to aspects described herein, efficiency of the EV charging system may include a high peak efficiency of over 99%.

[0015] FIG. 1 is a block diagram illustrating an example diagram of a controller 104 and a converter 102 for an EV charging system 100. Converter 102 includes an interleaved DC-DC control system that may be configured to facilitate providing an electric charge to a Power Output, such as an EV battery 160, from a Power Input, such as an energy storage device 150, as described below. Converter 102 may be communicatively coupled to Controller 104, where controller 104 may include components to control the interleaved DC-DC control system of converter 102.

[0016] FIG. 2 is a block diagram illustrating example components of converter 102 and controller 104 of EV charging system 100 of FIG. 1. For instance, converter 102 includes an inrush current limiting circuit 106. Inrush current limiting circuit 106 may include isolated current sensors 108 and high impedance voltage sensors 110, which may ensure that electronic control circuitry 130 of controller 104 is electrically isolated in case of a fault. According to one embodiment, inrush current limiting circuit 106 may ensure that EV charging system 100 charges at a controlled rate when an EV battery is electrically connected to EV charging system 100. Advantageously, inrush current limiting circuit 106 may provide longer life expectancy and safer operation for all power components of EV charging system 100.

[0017] According to one embodiment, selectively switchable components of inrush current limiting circuit 106 are configured to receive an electrical power input from an energy storage device. The selectively switchable components may include isolated

current sensors 108, which may facilitate high power transfer, and high impedance voltage sensors 110, where both isolated current sensors 108 and high impedance voltage sensors 110 may be controlled by controller 104. Controller 104 may be configured to selectively switch on and switch off various switches of the selectively switchable components when operation of EV charging system 100 is initiated. For instance, switches may be switched off when the current going through the switch has reached a predetermined upper threshold. According to one embodiment, the switching frequency of the switchable components may be fixed. Additionally, high impedance voltage sensors 110 may include a higher impedance path than other switching component(s) of inrush current limiting circuit 106, where the higher impedance path facilitates controlling the charge up time. Isolated current sensors 108 may facilitate quickly isolating the input from the output circuitry in the event of the fault. Additionally, the selectively switchable components that are included in inrush current limiting circuit 106 may reduce the need for there to be an output switching element.

[0018] After the electrical power input passes through inrush current limiting circuit 106, the voltage of the electrical power input may be boosted by interleaved boost converters 112 that are communicatively coupled to inrush current limiting circuit 106. In particular, interleaved boost converters 112 may boost an input voltage of the electrical power input to a higher voltage that corresponds to the voltage of the EV battery. According to one embodiment, interleaved boost converters 112 include three parallel boost converters 114, 116, 118 that are each 20kW in addition to isolated current sensors 120. Each of boost converters 114, 116, 118 are configured to operate in a discrete phase to minimize ripple current in magnetic inductors of interleaved boost converters 112. For instance, electronic control circuitry 130 of controller 104 may set a duty ratio for each boost converter 114, 116, 118 that is offset at 120 degrees.

[0019] According to one embodiment, interleaved boost converters 112 may include more than three parallel boost converters 114, 116, 118. For example, interleaved boost converters 112 may include three additional parallel boost converters (not shown) in addition to boost converters 114, 116, 118 such that there is a total of six boost converters. Each of these six boost converters may be configured to operate 60 degrees

out of phase of each other. Other embodiments may have more than six boost converters. For instance, the interleaved boost converters 112 may include a total of nine boost converters (not shown) that are configured to operate 40 degrees out of phase of each other.

[0020] After the electrical power input passes through interleaved boost converters 112 an electromagnetic interference (EMI) filter 122 may inhibit transfer of noise to the EV battery. After being filtered, the electrical power input passes through unidirectional current circuitry 124 that prevents the EV battery from providing power back (i.e. discharging) into EV charging system 100. Advantageously, unidirectional current circuitry 124 ensures that power is only being provided to the EV battery and does not remove power from the EV battery. Unidirectional current circuitry 124 may also include isolated current sensors 126 and high impedance voltage sensors 128.

[0021] Controller 104, which includes electronic control circuitry 130 discussed above, controls the interleaved DC-DC control system of converter 102. Additionally, controller 104 includes vehicle communication circuitry 132 that is configured to establish charging protocols between the interleaved DC-DC control system and the EV battery.

[0022] According to one embodiment, EV charging system 100 may include a safety circuit configured to quickly discharge EV charging system 100 due to power failure. The safety circuit may include a resistor and multiple capacitors that are in parallel with the resistor. Additionally, the safety circuit may include an energy storage component that is configured to automatically engage if EV charging system 100 loses power such as, for example, in an emergency shutdown mode. In particular, the safety circuit facilitates running EV charging system 100 without an external load. According to one embodiment, the safety circuit may be turned on and off on command to facilitate with faster shutdowns during normal operations.

[0023] According to one embodiment, EV charging system 100 is transportable and includes a multilayered printed circuit board that is stacked on an energy storage device that provides the electric charge. According to one embodiment, the energy storage

device includes DC battery modules and the multilayered printed circuit board includes converter 102, which includes the interleaved DC-DC control system, and controller 104.

[0024] FIG. 3 depicts an example process 300 for manufacturing an electric vehicle charging system. At block 302, electroplating is used to form an interleaved DC-DC control system that includes magnetic core inductors, heatsink(s), and multistrand wire such as, e.g., Litz wire. The heatsink may include, any passive heat exchanger configured to transfer heat generated by an electronic and/or mechanical device to a fluid medium such as, for example, air or a liquid coolant. According to one embodiment, the heatsink(s) may be cut via an extrusion cut used that is used to obtain a desired size. The electroplating may produce a single printed circuit board that includes three parallel boost converters that are all located on the same circuit board. Advantageously, the combination of the magnetic core inductors and heatsink(s) may provide high power transfer in a small form factor. The interleaved DC-DC control system that is formed by the electroplating may include an inrush limiting circuit as well as an electromagnetic interference filter configured to inhibit transfer of noise to an electric vehicle battery. The interleaved DC-DC control system that is formed may also include unidirectional current circuitry configured to prevent discharge from the electric vehicle battery.

[0025] The process 300 also includes, at block 304, stacking the interleaved DC-DC control system on an energy storage device such as, e.g., battery modules. The stacking includes aligning the interleaved DC-DC control system such that the single printed circuit board that includes the three parallel boost converters is a same length and width as the energy storage device. According to one embodiment, the single printed circuit board may be a multilayered printed circuit board upon which the high-power components and the fine pitch components are located. Advantageously, the multiple layers may facilitate current sharing of high current phases. Additionally, the manufacturing process 300 avoids having to place smaller control components on separate boards from the high-power components.

[0026] According to various embodiments, the manufacturing process 300 may also include forming a controller that includes electronic control circuitry configured to control the interleaved DC-DC control system and also includes vehicle communication

circuitry configured to establish charging protocols between the interleaved DC-DC control system and the electric vehicle battery. The manufacturing process 300 may also include forming a safety circuit configured to discharge the electric vehicle charging system due to power failure. The safety circuit may include a resistor and multiple capacitors, where the multiple capacitors are in parallel with the resistor.

[0027] FIG. 4 depicts an example process 400 for charging an electric vehicle battery (e.g. EV battery 160). At block 402 an interleaved DC-DC control system receives an electrical power input from an energy storage device. The electrical power input may be received at an inrush current limiting circuit of the interleaved DC-DC control system, where the inrush current limiting circuit includes multiple switching components. At block 404 a controller communicatively coupled to the interleaved DC-DC control system may switch the multiple switching components on and off during an inrush current phase so that an electrical current flows continuously to three parallel boost converters of the interleaved DC-DC control system. According to one embodiment, one switching component of the multiple switching component includes a higher impedance path than another switching component. At block 406, the three parallel boost converters may boost an input voltage of the electrical power input to a higher voltage of the electric vehicle battery. According to one embodiment, each of the three parallel boost converters may be 20kW DC-DC converters that operate in discrete phase offsets, where each phase is offset by 120 degrees. The controller may also include converter control circuitry that reads sensor values from current sensors of the three parallel boost converters and based thereon sets a duty ratio for the three parallel boost converters. According to one embodiment, the interleaved DC-DC control system may include more than three parallel boost converters such as, for example, six boost converters, which are offset by 60 degrees, or nine boost converters, which are offset by 40 degrees. At block 408 an electromagnetic interference filter of the interleaved DC-DC control system may filter out noise from the electrical power input. At block 410, the electrical power input may be transmitted, via unidirectional current circuitry, to the electric vehicle battery. For instance, the electric vehicle battery may receive a 50kW standard charging speed. According to one embodiment, the example process 400 may also include activating,

based on detecting a power failure, a safety circuit configured to discharge the electrical power input, wherein the safety circuit includes a resistor in parallel with capacitors.

[0028] Although various examples are provided, variations are possible without departing from a spirit of the claimed aspects. For example, systems and methods are described above relating to charging an EV battery. The systems and methods may be used to charge other portable and stationary batteries, such as grid batteries, portable device batteries, and non-vehicle mobile energy storage device applications.

[0029] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises” and/or “comprising”, when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components and/or groups thereof.

[0030] The corresponding structures, materials, acts, and equivalents of all means or step plus function elements in the claims below, if any, are intended to include any structure, material, or act for performing the function in combination with other claimed elements as specifically claimed. The description of one or more embodiments has been presented for purposes of illustration and description, but is not intended to be exhaustive or limited to in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. The embodiment was chosen and described in order to best explain various aspects and the practical application, and to enable others of ordinary skill in the art to understand various embodiments with various modifications as are suited to the particular use contemplated.