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HYDROGEN FUEL CELL ELECTRIC VEHICLE ENERGY MANAGEMENT

Abstract

A fuel cell electric vehicle (FCEV) includes an electric traction motor configured to drive the FCEV and generate power through regenerative braking, a high voltage (HV) battery system including a HV bus and a HV battery configured to power the electric traction motor, and a fuel cell stack (FCS) configured to generate electricity to recharge the HV battery and/or power the electric traction motor. A powertrain control system for preventing over-voltage of the HV bus and HV battery includes a controller having one or more processors configured to control (i) a fuel cell power limit of the FCS, and (ii) a regenerative braking power limit of the electric traction motor. The controller is programmed to measure a voltage of the HV battery system, and selectively limit the fuel cell power limit and/or the regenerative braking power limit when the measure voltage exceeds a predetermined threshold.

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Background/Summary

FIELD

[0001] The present application relates generally to hydrogen fuel cell electric vehicle control systems and, more particularly, to hydrogen fuel cell electric vehicle energy management control system to prevent over-voltage.

BACKGROUND

[0002] A hydrogen fuel cell electric vehicle typically includes a battery pack that can be charged via regenerative braking or a hydrogen fuel cell stack. However, either charging method can potentially result in over-charging of the battery pack, which may result in faults that cause the battery pack to open contactors to disconnect from the vehicle or powertrain to protect itself. Once the contactors are open, the vehicle will lose traction power. Additionally, over-voltage may also occur in the high voltage bus, causing the fuel cell DC/DC converter to shut down to protect itself. Under low state of charge driving conditions, this may potentially result in loss of traction power or degraded driving performance once the fuel cell DC/DC shuts down. Accordingly, while such conventional systems do work well for their intended purpose, there is a desire for improvement in the relevant art.

SUMMARY

[0003] In accordance with one example aspect of the invention, a fuel cell electric vehicle (FCEV) is provided. In one example implementation, the FCEV includes an electric traction motor configured to drive the FCEV and generate power through regenerative braking, a high voltage (HV) battery system including a HV bus and a HV battery configured to power the electric traction motor, and a fuel cell stack (FCS) configured to generate electricity to recharge the HV battery and/or power the electric traction motor. A powertrain control system for preventing over-voltage of the HV bus and HV battery includes a controller having one or more processors configured to control (i) a fuel cell power limit of the FCS, and (ii) a regenerative braking power limit of the electric traction motor. The controller is programmed to measure a voltage of the HV battery system, and selectively limit the fuel cell power limit and/or the regenerative braking power limit when the measure voltage exceeds a predetermined threshold.

[0004] In addition to the foregoing, the described HEV may include one or more of the following features: wherein the controller is further programmed to measure (i) a voltage of individual battery cells of the HV battery and (ii) a voltage of the HV bus; wherein the controller is further programmed to continuously arbitrate the measured voltage of the individual battery cells and the measured voltage of the HV bus; and wherein the controller is further programmed to determine an arbitrated measured voltage, which is a maximum of the measured voltage of the individual battery cells and the measured voltage of the HV bus, where the HV bus voltage has the same scale of the battery cell voltage by using the HV bus voltage divided by the number of individual battery cells.

[0005] In addition to the foregoing, the described HEV may include one or more of the following features: wherein the controller includes a fuel cell power limit controller to control the fuel cell power limit of the FCS, and a regenerative brake power limit controller to control the regenerative braking power limit of the electric traction motor; wherein the fuel cell power limit controller and the regenerative brake power limit controller are propositional derivative (PD) controllers; and wherein the fuel cell power limit controller is programmed to reduce the fuel cell power limit when the arbitrated measured voltage exceeds a first threshold.

[0006] In addition to the foregoing, the described HEV may include one or more of the following features: wherein the regenerative brake power limit controller is programmed to reduce the regenerative braking power limit when the arbitrated measured voltage exceeds a second threshold, which is greater than the first threshold; wherein the fuel cell power limit is reduced to a minimum value before the regenerative braking power limit is reduced; and a motor control processor in signal communication with the electric traction motor and the controller, a battery pack control module in signal communication with the HV battery and the controller, and a fuel cell processor in signal communication with the FCS and the controller.

[0007] In accordance with another example aspect of the invention, a method of operating a powertrain control system to prevent over-voltage of a fuel cell electric vehicle (FCEV) is provided. The FCEV includes an electric traction motor, a high voltage (HV) battery system including a HV bus and a HV battery, a fuel cell stack (FCS), and a controller having one or more processors configured to control (i) a fuel cell power limit of the FCS and (ii) a regenerative braking power limit of the electric traction motor. In one example implementation, the method includes measuring, by the controller, a voltage of the HV battery system, and selectively limiting, by the controller, the fuel cell power limit and/or the regenerative braking power limit when the measured voltage exceeds a predetermined threshold.

[0008] In addition to the foregoing, the described method may include one or more of the following features: wherein measuring the voltage of the HV battery system includes measuring, by the controller, a voltage of individual battery cells of the HV battery, and measuring, by the controller, a voltage of the HV bus; by the controller, continuously arbitrating the measured voltage of the individual battery cells and the measured voltage of the HV bus; and determining, by the controller, an arbitrated measured voltage, which is a maximum of the measured voltage of the individual battery cells and the measured voltage of the HV bus, where the HV bus voltage has the same scale of the battery cell voltage by using the HV bus voltage divided by the number of individual battery cells.

[0009] In addition to the foregoing, the described method may include one or more of the following features: wherein the controller includes a fuel cell power limit controller to control the fuel cell power limit of the FCS, and a regenerative brake power limit controller to control the regenerative braking power limit of the electric traction motor; reducing, by the fuel cell power limit controller, the fuel cell power limit when the arbitrated measured voltage exceeds a first threshold; reducing, by the regenerative brake power limit controller, the regenerative braking power limit when the arbitrated measured voltage exceeds a second threshold, which is greater than the first threshold; wherein the fuel cell power limit is reduced to a minimum value before the regenerative braking power limit is reduced; and wherein the FCEV further includes a motor control processor in signal communication with the electric traction motor and the controller, a battery pack control module in signal communication with the HV battery and the controller, and a fuel cell processor in signal communication with the FCS and the controller.

[0010] Further areas of applicability of the teachings of the present disclosure will become apparent from the detailed description, claims and the drawings provided hereinafter, wherein like reference numerals refer to like features throughout the several views of the drawings. It should be understood that the detailed description, including disclosed embodiments and drawings references therein, are merely exemplary in nature intended for purposes of illustration only and are not intended to limit the scope of the present disclosure, its application or uses. Thus, variations that do not depart from the gist of the present disclosure are intended to be within the scope of the present disclosure.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1** is a schematic illustration of an example fuel cell electric vehicle (FCEV) architecture in accordance with the principles of the present application;

[0012] FIGS. **2**A-**2**B are a schematic illustration of an example control architecture of the FCEV shown in FIG. **1**, in accordance with the principles of the present application;

[0013] FIG. **3** is an example graph illustrating an example control sequence of the FCEV shown in FIG. **1**, in accordance with the principles of the present application; and

[0014] FIG. **4** illustrates an example control logic flow for operating a powertrain control system of the FCEV shown in FIG. **1**, in accordance with the principles of the present application.

DETAILED DESCRIPTION

[0015] As discussed above, a hydrogen fuel cell electric vehicle (FCEV) powertrain includes an electrified propulsion system with a high voltage (HV) battery system, which can be recharged via regenerative braking or the fuel cell stack (FCS). Such recharging methods may result in an over-charging or over-voltage scenario in the battery pack or the HV bus. Accordingly, described herein are systems and methods to prevent the HV battery pack and HV bus crossing an over-voltage threshold by managing the power limits of the FCS power and the regenerative braking power.

[0016] With initial reference to FIG. **1**, a schematic diagram of a fuel cell electric vehicle (FCEV) **10** is illustrated having an electrified powertrain **12** and a powertrain control system **14** according to example implementations of the disclosure. In the illustrated example, the powertrain **12** generally includes one or more electric traction motors **20** configured to selectively provide drive torque to a front axle **22** and/or a rear axle (not shown). The electric motor **20** is electrically coupled to a power inverter module (PIM) **26**.

[0017] To provide electric power to the electric traction motor **20**, the FCEV **10** includes a high voltage (HV) battery system **30** and a hydrogen fuel cell system **60**. The HV battery system **30** includes a HV traction battery **32** (e.g., 48V) to power high voltage loads such as the electric motor **20**. A contactor **34** is included as an electromechanical switching device utilized to selectively connect the HV battery **32** to a HV bus **36** of the high voltage battery system **30**. In some examples, the contactor **34** is integrated with the HV battery **32**. A HV interface connection **38** is electrically connected to the HV battery **32** and is configured to combine the HV power sources (HV battery **32** and fuel cell system **60**) together to support the load of the HV bus **36**. During charging, the HV interface connection **38** combines the power of the electric motor **20** and fuel cell system **60** to charge the HV battery **32**.

[0018] In the example embodiment, the HV battery system **30** also generally includes an onboard charger system **40** and a power distribution center (PDC) **42**. The onboard charger system **40** includes an integrated dual charge module (IDCM) **44** with an onboard charger **46** and a DC/DC converter **48**. The onboard charger system **40** is configured to support charging of the HV battery **32** from a wall charger **50**. The onboard charger system **40** is electrically coupled to the PDC **42**, which is electrically coupled to the HV interface connection **38**, as well as a Heat1 **52**, Heat2 **54**, and electric air compressor (EAC) **56**.

[0019] The PDC **42** includes various components such as fuses, relays, electronic control units, etc. to regulate and protect the electrical system. The PDC **42** is configured to ensure that electrical power is distributed efficiently to the various systems and components of the vehicle **10**, such as the propulsion systems, accessories lighting, heating, cooling, etc. Heat1 **52** and Heat2 **54** are heaters, which are utilized to control the operating temperature of components as well as ambient temperature.

[0020] With continued reference to FIG. **1**, the hydrogen fuel cell system **60** generally includes a hydrogen fuel cell stack (FCS) **62**, which is fluidly coupled to a hydrogen fuel source and an oxygen fuel source (not shown). In one example, the FCS **62** is a proton exchange membrane (PEM) fuel cell stack formed by stacking a plurality of fuel cells, which are configured to generate electricity by electrochemical reactions of a fuel gas (e.g., hydrogen) and an oxygen containing gas (e.g., ambient air). As is well known in the art, each fuel cell includes an electrolyte membrane disposed between an anode and a cathode. It will be appreciated, however, that the hydrogen fuel cell system **60** described herein may be utilized with various other types of fuel cells.

[0021] In the example embodiment, a contactor **64** is included as an electromechanical switching device utilized to selectively connect the FCS **62** to the HV bus **36**. In some examples, the contactor **64** is integrated with the FCS **62**. The FCS **62** is electrically connected to the HV interface connection **38** via a DC/DC converter **66**. In this way, the FCS **62** is configured to generate electricity by electrochemical reaction to provide power to the HV battery **32** for recharging, and/or to the electric motor **20** for operation thereof.

[0022] With continued reference to FIG. **1**, the powertrain control system **14** includes a controller **70**, such as an electric vehicle control unit (EVCU), for preventing over-voltage by managing the power limits of the hydrogen fuel cell stack power and the regenerative braking power, as described herein in more detail. In the example embodiment, the hybrid powertrain **12** is controlled by the powertrain control system **14**, which generally includes the controller **70** in signal communication with a motor control processor (MCP) **72**, a battery pack control module (BPCM) **74**, and a fuel cell processor (FCP) **76**.

[0023] The controller **70** is a central supervisory control configured to communicate with various components/modules of the hybrid powertrain **12** via a CAN bus **78**. The electric motor **20** is directly controlled by the MCP **72**, which is a controller configured for bi-directional communication with the controller **70** via the CAN bus **78**. The controller **70** is configured to control the electric motor **20** by forwarding signals, such as operation state, torque command, and voltage setpoints to the MCP **72**, and the MCP **72** provides feedback signals to the controller **70** related to the electric motor **20** such as operation status, output current, and voltage. Additionally, the MCP **72** receives commands from controller **70** to control the PIM **26** in a motor mode or a generator mode, as well as to control the power of discharge or charge. The MCP **72** may monitor the motor **20** and PIM **26** status, current, voltage, and temperature for feedback to the controller **70**.

[0024] In the example embodiment, the BPCM **74** is a control module of the HV battery system **30** and is configured to monitor the HV battery pack voltage, current, and temperature, as well as estimate the battery pack SOC, state of health (SOH), and power limits. The BPCM **74** monitors the HV battery system **30** and sends one or more data signals to the controller **70** related to such monitoring. Additionally, if the battery pack cell voltage or DC/DC converter output voltage is too high, the BPCM **74** is configured to command the contactor **34** to open to protect the system.

[0025] In the example implementation, the FCP **76** is a control module of the fuel cell system **60** and is configured to communicate with controller **70** to control the FCS **62** to reach a desired target output power. The FCP **76** is also configured to monitor the fuel cell status (e.g., voltage, current, and temperature) and provide signals indicative thereof to the controller **70**.

[0026] With reference now to FIG. **2**, an example control architecture **100** of the powertrain control system **14** for preventing battery cell or HV bus over-voltage is described in more detail. The supervisory controller **70** includes a fuel cell power limit controller **80** and a regenerative brake power limit controller **82** to respectively manage the output power limits (e.g., how much power provided to HV battery **32**) of the FCS **62** and the electric motor **20**.

[0027] When the vehicle **10** is operational, there are two power sources, the regenerative brake and the FCS **62**. However, if the battery cell voltage or HV bus voltage is above a threshold voltage, the contactors **34** are opened to protect the HV battery **32** or the DC/DC converter **66** stops working. To prevent over-voltage, the controller **70** is configured to control fuel cell power output and regenerative braking power output. As such, two separate closed loop controls are provided for the regenerative brake and the FCS. In the example embodiment, the fuel cell power limit controller **80** and regenerative brake power limit controller **82** are proportional derivative (PD) controllers.

[0028] As shown, the controller **70** receives signals from CAN bus **78** indicating a measured battery cell voltage **110**, a battery cell voltage maximum voltage threshold **120**, a measured HV bus voltage **130**, and a HV bus maximum voltage threshold **140**. In the example embodiment, the battery cell voltage maximum threshold voltage **120** and HV bus maximum voltage threshold **140** may be internally calculated or may be a static value based on battery pack and DC/DC component specifications. In one example, the controller **70** is in signal communication with one or more sensors (not shown) configured to monitor and provide voltage readings at each battery cell of the HV battery **32** and the HV bus **36**.

[0029] The controller **70** then combines the measured battery cell and HV bus voltages **110**, **130** and sends as one signal input (Arbitrated Measured Volt) to the fuel cell power limit controller **80** and regenerative brake power limit controller **82**. In the example embodiment, to combine the readings into a similar scale, the measured HV bus voltage is divided by the number of battery cells in the HV battery **32**. For example, the Arbitrated Measured Volt=max(Battery Cell Voltage, HV Bus Voltage), where the HV Bus Voltage has the same scale of Battery Cell Voltage by using the actual HV Bus Voltage divided by the number of battery cells or modules.

[0030] Similarly, the controller **70** combines the battery cell and HV bus voltage maximum thresholds **120**, **140** and sends as one signal input (Arbitrated Critical Threshold) fuel cell power limit controller **80** and regenerative brake power limit controller **82**. For example, the Arbitrated Critical Threshold=min(Max Battery Cell Voltage Threshold, Max HV Bus Voltage Threshold), where the Max HV Bus Voltage Threshold also has the same scale of Max Battery Cell Voltage Threshold by using the actual value divided by the number of battery cells or modules. Additionally, the fuel cell power limit controller **80** and regenerative brake power limit controller **82** each receive a signal indicating a reference voltage **150**, which is a calibrated value or safe buffer value based on the system requirement, to prevent reaching the over-voltage threshold.

[0031] Based on the previously measured/determined values, the controller **70** provides a fuel cell max power limit **160** (Threshold1) to the hydrogen fuel cell system **60**, and a regen brake max power limit **170** (Threshold2) to the electric motor **20**. These are the max power limits to prevent over-voltage. As such, the hydrogen fuel cell system **60** and electric motor **20** provide power at or below the max power limits **160**, **170** to the HV battery system **30**. The hydrogen fuel cell system **60** and the HV battery system **30** subsequently send signals **180** to the HV bus **36** indicating measured battery cell voltage **110** and HV bus voltage **130**, and maximum battery cell voltage threshold **120** and maximum HV bus voltage threshold **140**. The cycle then repeats.

[0032] With reference now to FIGS. **2-4**, an example operation of the powertrain control system **14** to prevent battery cell and HV bus over-voltage by managing the power max power limits of the hydrogen fuel cell stack power and regen braking power is described in more detail. In general, the powertrain control system **14** performs two functions. The first function includes voltage sensor readings and threshold arbitration. Because the individual battery cells of HV battery **32** and the HV bus **36** have separate sensor measurements and failure thresholds, the first function is configured to arbitrate the sensor readings and thresholds between the battery cells of HV battery **32** and the HV bus **36** to determine the previously designated Arbitrated Measured Volt and Arbitrated Critical Threshold.

[0033] The second function includes power limit controls for the hydrogen fuel cell system **60** and the electric motor **20** utilizing the fuel cell power limit controller **80** and regenerative brake power limit controller **82**. The input to the fuel cell power limit controller **80** is the error between the Arbitrated Measured Volt and the Reference Volt, and the output is the fuel cell max power limit **160**. The input to the regenerative brake power limit controller **82** is the error between the Arbitrated Measured Volt and the Reference Volt, and the output is the regen brake max power limit **170**.

[0034] Further, the control law optimizes the recovered energy by first prioritizing reduction of the fuel cell max power limit **160** before reducing the regen brake max power limit **170**. This prioritization conserves hydrogen fuel and take advantage of the no cost brake regen energy.

During operation, the fuel cell power limit controller **80** is activated at 'Threshold1', which equals the Arbitrated Critical Threshold subtracted by an Offset 1. Similarly, the regen brake power limit controller **82** is activated at 'Threshold2', which equals the Arbitrated Critical Threshold subtracted by an Offset 2. In the example embodiment, Offsets 1 and 2 are internally defined calibratable numbers to offset from the Arbitrated Critical Threshold (e.g., a buffer) to allow power limit controllers **80**, **82** to reduce voltage proactively before reaching the Arbitrated Critical Threshold.

[0035] FIG. **3** illustrates an example graph **200** of control sequences and the corresponding activated thresholds such as Threshold1, Threshold2, and Arbitrated Critical Threshold. During operation, the controller **70** is configured to continuously monitor voltage readings at each HV battery cell/module and the HV bus **36**, and subsequently arbitrate the measured voltages and thresholds to determine an Arbitrated Measured Voltage **210**, 'Threshold1' **220**, 'Threshold2' **230**, and Arbitrated Critical Threshold **240**. Reference Voltage **250** is a calibratable number based on hardware and/or software specifications or safety levels, which may be set by the manufacturer as the intended operation level for that component.

[0036] Based on the arbitrated voltages and thresholds (e.g., FIG. **2**), the fuel cell power limit controller **80** selectively controls a fuel cell maximum power limit **260** to the HV battery **32**, which is between a normal or original fuel cell max power limit **262** and a minimum fuel cell max power limit **264**. Similarly, based on the arbitrated voltages and thresholds, the regen brake power limit controller **82** selectively controls a regen brake maximum power limit **270** to the HV battery **32**, which is at or below a normal or original regen brake max power limit **272**.

[0037] With reference now to FIG. **4**, and with continued reference to FIG. **3**, an example control logic flow **300** for operating the powertrain control system **14** to prevent battery cell or HV bus over-voltage is provided. At step **302**, control (e.g., controller **70**) continuously monitors voltage readings at each battery cell/module of the HV battery **32** and the HV bus **36**. At step **304**, control subsequently arbitrates the measured voltages and thresholds, as previously described herein. At step **306**, control determines if the Arbitrated Measured Voltage **210** is greater than Threshold2 **230**. If no, control proceeds to step **308**. If yes, control proceeds to step **316**.

[0038] At step **308**, control determines if the Arbitrated Measured Voltage **210** is greater than Threshold1 **220**. If no, control proceeds to step **310**. If yes, control proceeds to step **314**.

[0039] At step **310**, control commands a normal operation (without power limitation) with the fuel cell power limit controller **80** enabling the normal cell max power limit **262**, and the regen brake power limit controller **82** enabling the normal regen brake max power limit **272**. At step **312**, control determines if the vehicle is shut down. If yes, control ends. If no, control returns to step **302**.

[0040] At step **314**, when the Arbitrated Measured Voltage **210** is greater than 'Threshold1' **220** (e.g., at time 't**1**' in FIG. **3**), controller **70** enables/commands the fuel cell power limit controller **80** to reduce the fuel cell power output. This is shown, for example, between time 't**1**' and time 't**2**' on FIG. **3**. Control then returns to step **302**.

[0041] As previously discussed, control proceeds to step **316** when the Arbitrated Measured Voltage **210** is greater than 'Threshold2' **230**. At step **316**, controller **70** enables/commands the fuel cell power limit controller **80** to reduce the fuel cell maximum power limit **260** to the minimum value **264** with the fastest allowable rate. At step **318**, control subsequently determines if the present Arbitrated Measured Voltage **210** is greater than 'Threshold2' **230** and a predetermined delay timer has expired (e.g., after reducing the fuel cell max power limit). If no, control returns to step **302**. If yes, control proceeds to step **320**. In this way, control can take further action if the delay timer is expired and the Arbitrated Measured Voltage is still above 'Threshold2', due to the reaction delay of the fuel cell system.

[0042] At step **320**, control maintains the fuel cell maximum power limit at the minimum value **264**, and enables/commands the regen brake power limit controller **82** to reduce the regen brake maximum power limit **270** (e.g., PIM **26** output), for example, as shown between time 't**2**' and time 't**3**'. In this way, control maintains the hydrogen fuel cell power limit to the minimum value, while the controller **70** enables the regen brake power limit controller **82** to manage the PIM **26** power output. Control then returns to step **302**.

[0043] Described herein are systems and methods for preventing battery cell or HV bus over-voltage that could lead to loss of propulsion in a fuel cell electric vehicle. A powertrain control system monitors battery cell and HV bus voltage, and subsequently arbitrates the sensor readings and thresholds between the battery cells and the HV bus. The system first reduces only the fuel cell power output when the arbitrated measured voltage exceeds a first threshold. If the arbitrated measured voltage exceeds a higher, second threshold, the system further reduces the regen braking power output.

[0044] It will be appreciated that the term "controller" or "module" as used herein refers to any suitable control device or set of multiple control devices that is/are configured to perform at least a portion of the techniques of the present disclosure. Non-limiting examples include an application-specific integrated circuit (ASIC), one or more processors and a non-transitory memory having instructions stored thereon that, when executed by the one or more processors, cause the controller to perform a set of operations corresponding to at least a portion of the techniques of the present disclosure. The one or more processors could be either a single processor or two or more processors operating in a parallel or distributed architecture.

[0045] It will be understood that the mixing and matching of features, elements, methodologies, systems and/or functions between various examples may be expressly contemplated herein so that one skilled in the art will appreciate from the present teachings that features, elements, systems and/or functions of one example may be incorporated into another example as appropriate, unless described otherwise above. It will also be understood that the description, including disclosed examples and drawings, is merely exemplary in nature intended for purposes of illustration only and is not intended to limit the scope of the present application, its application or uses. Thus, variations that do not depart from the gist of the present application are intended to be within the scope of the present application.

Claims

1. A fuel cell electric vehicle (FCEV), comprising: an electric traction motor configured to drive the FCEV and generate power through regenerative braking; a high voltage (HV) battery system including a HV bus and a HV battery configured to power the electric traction motor; a fuel cell stack (FCS) configured to generate electricity to recharge the HV battery and/or power the electric traction motor; and a powertrain control system for preventing over-voltage of the HV bus and HV battery, including a controller having one or more processors configured to control (i) a fuel cell power limit of the FCS, and (ii) a regenerative braking power limit of the electric traction motor, wherein the controller is programmed to: measure a voltage of the HV battery system; and selectively limit the fuel cell power limit and/or the regenerative braking power limit when the measured voltage exceeds a predetermined threshold.

2. The FCEV of claim 1, wherein the controller is further programmed to measure (i) a voltage of individual battery cells of the HV battery and (ii) a voltage of the HV bus.

3. The FCEV of claim 2, wherein the controller is further programmed to continuously arbitrate the measured voltage of the individual battery cells and the measured voltage of the HV bus.

4. The FCEV of claim 3, wherein the controller is further programmed to determine an arbitrated measured voltage, which is a maximum of the measured voltage of the individual battery cells and the measured voltage of the HV bus, where the HV bus voltage has the same scale of the battery cell voltage by using the HV bus voltage divided by the number of individual battery cells.

5. The FCEV of claim 4, wherein the controller includes: a fuel cell power limit controller to control the fuel cell power limit of the FCS; and a regenerative brake power limit controller to control the regenerative braking power limit of the electric traction motor.

6. The FCEV of claim 5, wherein the fuel cell power limit controller and the regenerative brake power limit controller are propositional derivative (PD) controllers.

7. The FCEV of claim 5, wherein the fuel cell power limit controller is programmed to reduce the fuel cell power limit when the arbitrated measured voltage exceeds a first threshold.

8. The FCEV of claim 7, wherein the regenerative brake power limit controller is programmed to reduce the regenerative braking power limit when the arbitrated measured voltage exceeds a second threshold, which is greater than the first threshold.

9. The FCEV of claim 8, wherein the fuel cell power limit is reduced to a minimum value before the regenerative braking power limit is reduced.

10. The FCEV of claim 1, further comprising: a motor control processor in signal communication with the electric traction motor and the controller; a battery pack control module in signal communication with the HV battery and the controller; and a fuel cell processor in signal communication with the FCS and the controller.

11. A method of operating a powertrain control system to prevent over-voltage of a fuel cell electric vehicle (FCEV) having an electric traction motor, a high voltage (HV) battery system including a HV bus and a HV battery, a fuel cell stack (FCS), and a controller having one or more processors configured to control (i) a fuel cell power limit of the FCS and (ii) a regenerative braking power limit of the electric traction motor, the method comprising: measuring, by the controller, a voltage of the HV battery system; and selectively limiting, by the controller, the fuel cell power limit and/or the regenerative braking power limit when the measured voltage exceeds a predetermined threshold.

12. The method of claim 11, wherein measuring the voltage of the HV battery system comprises: measuring, by the controller, a voltage of individual battery cells of the HV battery; and measuring, by the controller, a voltage of the HV bus.

13. The method of claim 12, further comprising, by the controller, continuously arbitrating the measured voltage of the individual battery cells and the measured voltage of the HV bus.

14. The method of claim 13, further comprising determining, by the controller, an arbitrated measured voltage, which is a maximum of the measured voltage of the individual battery cells and the measured voltage of the HV bus, where the HV bus voltage has the same scale of the battery cell voltage by using the HV bus voltage divided by the number of individual battery cells.

15. The method of claim 14, wherein the controller includes: a fuel cell power limit controller to control the fuel cell power limit of the FCS; and a regenerative brake power limit controller to control the regenerative braking power limit of the electric traction motor.

16. The method of claim 15, further comprising: reducing, by the fuel cell power limit controller, the fuel cell power limit when the arbitrated measured voltage exceeds a first threshold.

17. The method of claim 16, further comprising: reducing, by the regenerative brake power limit controller, the regenerative braking power limit when the arbitrated measured voltage exceeds a second threshold, which is greater than the first threshold.

18. The method of claim 17, wherein the fuel cell power limit is reduced to a minimum value before the regenerative braking power limit is reduced.

19. The method of claim 11, wherein the FCEV further includes: a motor control processor in signal communication with the electric traction motor and the controller; a battery pack control module in signal communication with the HV battery and the controller; and a fuel cell processor in signal communication with the FCS and the controller.
