(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
28 July 2022 (28.07.2022)

WIPO | PCT

(10) International Publication Number
WO 2022/159578 A1

(51) International Patent Classification:
H01M 8/12 (2016.01) *H01M 8/04225* (2016.01) *H01M 8/24* (2016.01) *H01M 8/04701* (2016.01) *H01M 8/0267* (2016.01)

(21) International Application Number: PCT/US2022/013124

(22) International Filing Date: 20 January 2022 (20.01.2022)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
63/140,067 21 January 2021 (21.01.2021) US

(71) Applicant: **CUMMINS ENTERPRISE LLC** [US/US]; 301 East Market Street, Indianapolis, Indiana 46204 (US).

(72) Inventors: **SHAPIRO, Andrew Philip**; 1086 Morningside Ave., Schenectady, New York 12309 (US). **BROWN, Keith G.**; 1 Vineyard Circle, Clifton Park, New York 12065 (US). **HUSSAINI, Irfan Saif**; 75 Valleywood Drive, Glenville, New York 12302 (US). **DEVRIES, Loren G.**; 1494 Sherman Lake Rd., Lino Lakes, Minnesota 55038 (US). **ZHANG, Yuetao**; 13 Addison Way, Rexford, New York 12148 (US).

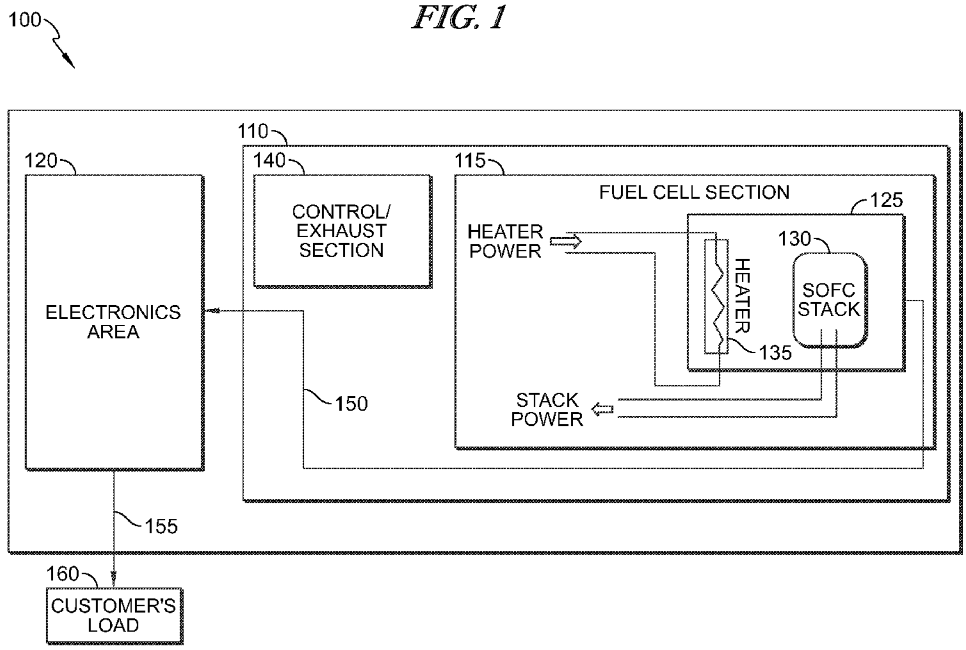
(74) Agent: **FREEMAN, Angela B.**; BARNES & THORNBURG LLP, 11 South Meridian Street, Indianapolis, Indiana 46204 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, IT, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,

(54) **Title:** POWER GENERATION SYSTEMS AND METHODS FOR CONTROLLING AND RETAINING FUNCTIONALITY OF HIGH TEMPERATURE FUEL CELLS IN STANDBY

FIG. 1



(57) **Abstract:** The present disclosure generally relates to heating a high temperature fuel cell system with an electrical heater powered by a fuel cell.

WO 2022/159578 A1

[Continued on next page]

MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

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))*
— *of inventorship (Rule 4.17(iv))*

Published:
— *with international search report (Art. 21(3))*

POWER GENERATION SYSTEMS AND METHODS FOR CONTROLLING AND RETAINING FUNCTIONALITY OF HIGH TEMPERATURE FUEL CELLS IN STANDBY

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This nonprovisional application claims the benefit and priority, under 35 U.S.C. § 119(e) and any other applicable laws or statutes, to U.S. Provisional Application Serial No. 63/140,067 filed on January 21, 2021, the entire disclosure of which is hereby expressly incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure generally relates to power generation systems and methods for controlling and retaining functionality of high temperature fuel cell in standby mode.

BACKGROUND

[0003] High temperature fuel cell systems are known for their efficient use of fuel to develop direct current (DC) and or alternating current (AC) electric power. Under normal operation, a typical high temperature fuel cell system, like a solid oxide fuel cell (SOFC) system, maintains a system operating temperature of approximately 500°C or greater, such as about 700°C. For a high temperature fuel cell system to become operational, the system typically requires significant startup time, ranging anywhere between 1 to 12 hours from near ambient environmental conditions.

[0004] When the system is not required to provide power to a load, the typical system may be kept in a hibernation mode, whereby the normal fuel and air processes are reduced, stopped, or the system is allowed to cool. However, quickly switching from such a hibernation mode to an operation mode, often in response to user demand, results in damage incurred by the parts and substantial loss of efficiency of the system. Accordingly, it is desirable to maintain the internal system temperatures of a power generation system at or as close to the approximate normal system operation temperatures in a standby mode to avoid the negative consequence of entering or exiting a hibernation mode. This will allow the fuel cell system to become fully functional in a short period of time as is required by many fuel cell system users.

[0005] Maintaining internal operation temperatures of high temperature fuel cell systems during a hibernation mode allows for rapid recovery to a power producing operation mode. One known method for maintaining approximate operational level internal temperatures of a high temperature fuel cell system requires heating the high temperature fuel cell system with the system's base fuel stock through a combustor/recuperator system. Another known method for maintaining the internal temperature of the high temperature fuel cell system is to provide temperature to the fuel cell system with a separate burner.

[0006] Both methods require a significant amount of fuel and air supply flows to maintain heat. Both methods also require controls that consume both significant amounts of fuel and parasitic power that waste a portion of the efficiencies achieved by the high temperature fuel cell system when in operation. Moreover, these methods create significant noise, vibration and exhaust emissions. These methods could also cause damage to the fuel cell without anode fuel flow.

[0007] A third method for maintaining operational temperatures when in hibernation mode involves using an electrical heater connected to an external and alternative power source. The electrical heater is configured to be coupled to the high temperature fuel cell. The heater intermittently heats the high temperature fuel cell system.

[0008] When the fuel cell system is in a hibernation mode, the electrical heater draws power from the alternate power source and provides resistive heat to the fuel cell. When the fuel cell system is in an operation mode, the electrical heater is turned off. However, the use of such an electrical heater device does not negate the potential damages that would be incurred by the fuel cell system when quickly transitioning between hibernation and operations modes due to the fuel cell systems' decreasing access to fuel and air when the fuel cell is in the hibernation model.

[0009] Use of an electrical heater that draws power from as external source does not prevent the fuel cell system from entering a hibernation mode where access to fuel and air is decreased. Furthermore, it is known in the art that external heaters waste fuel (e.g., natural gas or grid load) to heat up the fuel cell. In some instances, an external load bank can be used to get the fuel cell up to power before switching to the customer's load. A fuel cell cannot change instantly to a customer load, thus a fuel cell needs an external source (e.g., a battery or an electrical grid) to provide or sink power during fast transitions. However, it is also known that external loads waste power from the fuel cell without providing any added benefit to it.

[0010] For these and other reasons, the present specification provides an improved method and system for operational level internal temperatures of a high temperature fuel cell system to remain in a standby mode without the need to enter a hibernation mode when there is a decrease in fuel and air access to the fuel cell.

SUMMARY

[0011] Embodiments of the present invention are included to meet these and other needs. One embodiment is a high temperature fuel cell system comprises a fuel cell, an electrical heater, and an inverter. The electrical heater is powered by the fuel cell. The electrical heater provides load and heat to the fuel cell, and the fuel cell is retained at an operating temperature of 500°C or greater in a standby mode, a startup mode, and/or an operating mode.

[0012] In some embodiments of the fuel cell system, the load from the electrical heater is connected before the inverter. In some embodiments of the fuel cell system, the load from the electrical heater is connected after the inverter.

[0013] In some embodiments, the fuel cell system further comprises a one directional DC/DC boost connected to the fuel cell. In some embodiments, the fuel cell system further comprises a battery and a bi-directional DC/DC boost connected in parallel to the fuel cell.

[0014] In some embodiments, where the fuel cell system comprises a fuel cell, an electrical heater, an inverter, and a one directional DC/DC boost connected to the fuel cell, the load from the electrical heater is connected before the one directional DC/DC boost. In some embodiments, where the fuel cell system comprises a fuel cell, an electrical heater, an inverter, and a one directional DC/DC boost connected to the fuel cell, the load from the electrical heater is connected after the one directional DC/DC boost and before the inverter. In some embodiments, where the fuel cell system comprises a one directional DC/DC boost connected to the fuel cell, the load from the electrical heater is connected after the inverter.

[0015] In some embodiments, where the fuel cell system comprises a fuel cell, an electrical heater, an inverter, and a one directional DC/DC boost connected to the fuel cell, it further comprises a battery and a bi-directional DC/DC boost connected in parallel to the fuel cell. In some embodiments, where the fuel cell system comprises a fuel cell, an electrical heater, an inverter, a one directional DC/DC boost connected to the fuel cell, a battery and a bi-directional DC/DC boost connected in parallel to the fuel cell, the load from the electrical heater is connected after the one directional DC/DC boost and before the inverter. In some embodiments, where the fuel cell system comprises a fuel cell, an electrical heater, an inverter, a one directional DC/DC boost connected to the fuel cell, a battery and a bi-directional DC/DC boost connected in parallel to the fuel cell, the load from the electrical heater is connected before the one directional DC/DC boost. In some embodiments, where the fuel cell system comprises a fuel cell, an electrical heater, an inverter, a one directional DC/DC boost connected to the fuel cell, a battery and a bi-directional DC/DC boost connected in parallel to the fuel cell, the load from the electrical heater is connected after the inverter.

[0016] In some embodiments, where the fuel cell system comprises a fuel cell, an electrical heater, an inverter, a battery and a bi-directional DC/DC boost connected in parallel to the fuel cell, the load from the electrical heater is connected after the inverter. In some embodiments, where the fuel cell system comprises a fuel cell, an electrical heater, an inverter, a battery and a bi-directional DC/DC boost connected in parallel to the fuel cell, the load from the electrical heater is connected before the inverter.

[0017] In some embodiments, where the fuel cell system comprises a fuel cell, an electrical heater, an inverter, the system switches from an operating mode to a standby mode when no power is being drawn from an alternate load. The system directs its power towards the electrical heater in the standby mode

[0018] In some embodiments, where the fuel cell system comprises a fuel cell, an electrical heater, and an inverter, the electrical heater is a calrod. In some embodiments, where the fuel cell system comprises a fuel cell, an electrical heater, and an inverter, the electrical heater is a resistive panel. In some embodiments, where the fuel cell system comprises a fuel cell, an electrical heater, and an inverter, the electrical heater is a resistive coil embedded in an insulation container or a hotbox.

[0019] In some embodiments, the fuel cell system further comprises a parasitic load. In some embodiments, the parasitic load of the fuel cell system is selected from the group consisting of one or more blowers, controllers, valves, heaters, coolers, filters, turbines, and humidifiers.

[0020] In some embodiments, a method of operating a high temperature fuel cell system comprises putting at least one fuel cell in an operating mode. The system comprises a plurality of fuel cells, each of which is in close contact with an electrical heater. Each of the electrical heaters is powered by the fuel cell it is in close contact with. Each of the electrical heaters simultaneously provides load and heat to the fuel cell it is in close contact with, and wherein each of the fuel cells may be in a standby mode, in a startup mode, and/or in an operating mode. In some embodiments, the method further comprises retaining the fuel cell at an operating temperature of 500°C or greater in standby mode.

[0021] In some embodiments, a method of operating a high temperature fuel cell system comprises operating a parasitic load. In some embodiments, the parasitic load of the present method is selected from the group consisting of one or more blowers, controllers, valves, heaters, coolers, filters, turbines, and humidifiers.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings, in which like characters represent like parts throughout the drawings, wherein:

[0023] FIG. 1 is a block diagram of one embodiment of a system for heating a high temperature fuel cell system as described in the present application.

[0024] FIG. 2 is a block diagram of one embodiment of a system for heating a high temperature fuel cell system illustrating the electrical heater in close contact with the fuel cell, a DC/DC boost, an inverter, and a battery, where the resistive load is connected through the DC/DC boost, before the inverter.

[0025] FIG. 3 is a block diagram of one embodiment of a system for heating a high temperature fuel cell system illustrating the electrical heater in close contact with the fuel cell, a DC/DC boost, and an inverter, where the resistive load is connected through the DC/DC boost, before the inverter.

[0026] FIG. 4 is a block diagram of one embodiment of a system for heating a high temperature fuel cell system illustrating the electrical heater in close contact with the fuel cell, a DC/DC boost, an inverter, and a battery, where the resistive load is connected before the DC/DC boost.

[0027] FIG. 5 is a block diagram of one embodiment of a system for heating a high temperature fuel cell system illustrating the electrical heater in close contact with the fuel cell, a DC/DC boost, and an inverter, where the resistive load is connected before the DC/DC boost.

[0028] FIG. 6 is a block diagram of one embodiment of a system for heating a high temperature fuel cell system illustrating the electrical heater in close contact with the fuel cell, a DC/DC boost, an inverter, and a battery, where the resistive load is connected after the inverter.

[0029] FIG. 7 is a block diagram of one embodiment of a system for heating a high temperature fuel cell system illustrating the electrical heater in close contact with the fuel cell, a DC/DC boost, and an inverter, where the resistive load is connected after the inverter.

DETAILED DESCRIPTION

[0030] In the following detailed description, reference is made to the accompanying drawings that form a part hereof and in which is shown by way of illustration specific illustrative embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice what is claimed and it is to be understood that other embodiments may be utilized and that logical, mechanical, and electrical changes may be made without departing from the spirit and scope of the claims. The following detailed description is, therefore, not to be taken in a limiting sense.

[0031] Embodiments presented herein involve systems and methods for maintaining near operating mode internal temperatures of high temperature fuel cell systems, such as solid oxide fuel cell (SOFC) systems, during a standby mode, a startup mode, an operating mode, or a shutdown mode. Advantageously, these embodiments provide a fuel-efficient method of maintaining the internal system temperature of a high temperature fuel cell system. An exemplary high temperature fuel cell system is a solid oxide fuel cell (SOFC) system.

[0032] In some embodiments, the present systems and methods for maintaining near operating mode internal temperatures may comprise lower temperature fuel cell systems (e.g., operating temperatures below 500°C), such as proton exchange membrane fuel cell (PEMFC) systems or other types of fuel cells systems (e.g., phosphoric acid fuel cells (PAFCs) 104 and molten carbonate fuel cells (MCFCs). In other embodiments, the present systems and methods do not comprise or include proton exchange membrane fuel cell (PEMFC) systems or other types of fuel cells systems (e.g., phosphoric acid fuel cells (PAFCs)) 104 and molten carbonate fuel cells (MCFCs).

[0033] FIG. 1 is a block diagram of a power generation system for heating a high temperature fuel cell system 100 (e.g., integrated power generation and heater system) according to an embodiment of the present invention. The integrated power generation and heater system 100 includes a fuel cell area 110 and an electronics area 120. The fuel cell area 110 comprises a fuel cell section 115 and a controls/exhaust section 140. A fuel cell 130 and an internal electrical heater 135 closely coupled to the fuel cell 130 are housed within a hotbox 125 with a thermal casing. In some embodiments, the hotbox 125 is an insulation container or is comprised and/or embedded in an insulation container. In some embodiments, the contactors connecting the heater 135 to the connection point may be in the electronics area 120.

[0034] The controls/exhaust section 140 comprises controls (not shown) that regulate the amount of fuel sent to the fuel cell 130 from an external fuel source (not shown). In some embodiments, the controls/exhaust section 140 also comprises a blower and an exhaust system (not shown) that allows air to travel into the thermal casing of the hotbox 125 to the fuel cell 130 and allows unused fuel, water, and gases to leave the system 100. The thermal casing of the hotbox 125 of the fuel cell section 115 provides separation between the fuel cell 130 and the remaining system 100 to protect the other components of system 100 and to retain heat around the fuel cell 130.

[0035] The electrical heater 135 is designed to provide load to the fuel cell 130 and heat to the fuel cell 130 at the same time. This helps to smooth out state transitions. In some embodiments, the high temperature fuel cell 130 is a solid oxide fuel cell (SOFC). In other embodiments, the fuel cell may be other high temperature fuel cells of the art (e.g., proton exchange membrane, molten carbonate, etc.). The electrical heater 135 inside the hotbox 125 is connected to the fuel cell output using a contactor.

[0036] In some embodiments, the electrical heater 135 is a calrod. In some embodiments, the electrical heater 135 is a resistive panel. In some embodiments, the electrical heater 135 is a resistive parasitic load 260 on the fuel cell 130. In some embodiments, the electrical heater 135 is a resistive coil embedded in the hotbox 125.

[0037] In one embodiment, as illustrated in FIG. 2, the resistive load 230 is connected through a DC/DC boost 210 to enable the fuel cell 130 to maintain some load and provide heat to the hotbox 125. In some embodiments, the DC/DC boost 210 is one directional. In other embodiments, the DC/DC boost 210 is bidirectional. In further embodiments, the DC/DC boost 210 is not bidirectional.

[0038] In some embodiments, the fuel cell 130 has a voltage output 270 in the range from about 190 VDC to about 360 VDC (Volts DC). In some embodiments, the voltage 270 is input into the inverter 220 after the DC/DC boost 210 and is in the range from about 400 VDC to about 800 VDC. In some embodiments, the fuel cell 130 has a voltage output 270 ranging from about 390 VDC to about 880 VDC. In some embodiments, the voltage 270 is input into the inverter 220 after the DC/DC boost 210 and ranges from about 900 VDC to about 1500 VDC.

[0039] In some embodiments, the present power generation and fuel cell system may comprise an optional parasitic load 260. An illustrative parasitic load 260 of the present power generation and fuel cell system comprises one or more blowers, controllers, valves, heaters, coolers, filters, turbines, humidifiers, and/or any other component that requires power to operate and is connected (e.g., directly or indirectly) to the fuel cell system. In some embodiments, the parasitic load 260 may be positioned after the DC/DC boost 210 converter so as to drive DC parasitic loads 260. In other embodiments, the parasitic load 260 may be positioned elsewhere so as to drive DC parasitic loads 260.

[0040] The voltage output 270 of the present power generation system may be in any VAC (Volts AC) standard. For example the voltage output may be a 1-phase or 3-phase VAC standard. The VAC standard of the voltage output 270 may also be in any configuration, including Delta and Y configurations. In some embodiments, the voltage output 270 is about 208 VAC 3-phase Delta. In other embodiments, the voltage output 270 is different and may be any VAC. An illustrative voltage output 270 may be about 480 VAC, about 240 VAC, and/or about 600 VAC, etc.

[0041] In such embodiments, the fuel cell 130 and the one directional DC/DC boost 210 are in a parallel configuration with a battery 240 in series with a bi-directional DC/DC boost 250. In some embodiments, the DC/DC boost 210, the inverter 220, the battery 240, and the bidirectional DC/DC boost 250 is in the electronics area 120. In other embodiments, contactors connecting the heater 135 to the connection point are in the electronics area 120.

[0042] To put the fuel cell 130 in a “hot” standby mode the output of the fuel cell 130 is brought down to the value of the resistive load. The load is then switched to the electrical heater 135. The output power from the system is zero. The fuel cell 130, at zero load and in partial load scenarios does not produce enough heat to keep itself hot (i.e., at operating temperature) for near instantaneous higher power option. Though an internal burner can provide some heat, the heat provided by such a burner is not enough to enable the system to be functional or operational, particularly when the load is very low or when the load is zero.

[0043] Additionally, during startup, it is not efficient for the fuel cell 130 to go from zero load to full load. Instead, the fuel cell needs time to heat up from the zero load steady state temperature to full load operating temperature. By putting the electrical heater 135 after the DC/DC boost 210 the electrical heater 135 can be programmed to provide a load lower than its nominal rating in order to slowly bring up the temperature and the current in the fuel cell 130 before needing to supply load to a device, instrument, equipment or industrial facility operated by a customer.

[0044] The temperature of the fuel cell 130 may be increased by some combination of agents selected from a group consisting of the internal resistive heating from the load of the fuel cell and an internal natural gas burner, with the extra heat from the electrical heater 135 in the hotbox providing the load. Once the fuel cell 130 is at operating temperature, the load may be delivered to the customer by the battery 240 connected to a bi-directional DC/DC boost 250 for a short period while the load on the fuel cell 130 is switched from the electrical heater 135 to the customer load.

[0045] This internal hotbox resistive load provides two functions of providing heat to the fuel cell 130 and load to the fuel cell 130. In one embodiment, as illustrated in FIG. 3, the resistive load 230 is connected through a DC/DC boost 210, but there is no battery 240 in a parallel configuration with the fuel cell 130. The fuel cell 130 has a voltage output in the range from about 190 VDC to about 360 VDC. The voltage being input into the inverter 220 after the DC/DC boost 210 is in the range from about 400 VDC to about 800 VDC.

[0046] In one embodiment, as illustrated in FIG. 4 the resistive load 230 is attached directly to the fuel cell 130. The fuel cell 130 and the one-directional DC/DC boost 210 is in a parallel configuration with a battery 240 in series with a bi-directional DC/DC boost 250. The DC/DC boost 210 is one directional. The fuel cell 130 has a voltage output in the range from about 190 VDC to about 360 VDC. The voltage being input into the inverter 220 after the DC/DC boost 210 is in the range from about 400 VDC to about 800 VDC, such as about 480 VAC, about 240 VAC, and/or about 600 VAC, or any specific value within that range.

[0047] In some embodiments, there may be a higher voltage case such as a VDC stack, which may eliminate the need for a DC/DC boost box 250. In some embodiments, the voltage stack may be a 400 VDC stack. In other embodiments, the voltage stack may be a 600 VDC stack. In further embodiments, the voltage stack maybe an 800 VDC stack.

In some embodiments, the voltage stack may be one that is greater than a 400 VDC stack but less than a 800 VDC stack.

[0048] In one embodiment, as illustrated in FIG. 5 the resistive load 230 is attached directly to the fuel cell 130, but there is no battery 240 in a parallel configuration with the fuel cell 130. The DC/DC boost 210 is one directional. The fuel cell 130 has a voltage output in the range from about 190 VDC to about 360 VDC. The voltage being input into the inverter 220 after the DC/DC boost 210 is in the range from about 400 VDC to about 800 VDC.

[0049] In some embodiments, as illustrated in FIG. 6, the resistive load is attached after the load inverter 220. The DC/DC boost 210 is one directional. The fuel cell 130 and the one-directional DC/DC boost 210 is in a parallel configuration with a battery 240 in series with a bi-directional DC/DC boost 250. The fuel cell 130 has a voltage output in the range from about 190 VDC to about 360 VDC. The voltage being input into the inverter 220 after the DC/DC boost 210 is in the range from about 400 VDC to about 800 VDC.

[0050] In some embodiments, as illustrated in FIG. 7, the resistive load is attached after the load inverter 220, but there is no battery 240 in a parallel configuration with the fuel cell 130. The DC/DC boost 210 is one directional. In some embodiments, the fuel cell 130 has a voltage output in the range from about 190 VDC to about 360 VDC. The voltage being input into the inverter 220 after the DC/DC boost 210 is in the range from about 400 VDC to about 800 VDC. The voltage being input into the inverter 220 after the DC/DC boost 210 is in the range from about 400 VDC to about 800 VDC.

[0051] Each architecture has a benefit for the fuel cell 130. When the electric heater 135 is directly attached to the fuel cell 130, it enables the fuel cell 130 to keep operating in the event of loss of the inverter 220 or the DC/DC boost 210. However, in such cases, the control of the load may be limited. When the load is attached to the DC/DC boost 210, the turning on and off of the heater for different heater load states will cause less disturbance to the fuel cell 130, and allow usage even if the inverter is disabled. However, the higher voltage from the DC/DC boost 210 can cause other usability issues such as the need for stronger dielectrics. When it is attached after the inverter 220, it allows the most controllability and least fuel cell 130 disturbance, but it makes load switching between the electrical heater 135 and external load more difficult.

[0052] In operation, the system 100 of FIG. 1 has four modes, a startup mode, an operating mode, a standby mode, and a shutdown mode. When the system 100 is not generating a sufficient amount of power to operate an external load, the system 100 is in a standby mode. When the system 100 is generating sufficient power to operate an external load, such as a customer's load, the system 100 is in an operating mode. The system 100 is in a startup mode when the system 100 transitions or is in the process of transitioning from a standby mode to an operating mode.

[0053] In one embodiment, the system 100 is in shutdown mode when it is not fully in any one of a startup mode, a standby mode, or an operating mode. In other embodiments, the system 100 is in shutdown mode when the system transitions or is in the process of transitioning from an operating mode to a standby mode. In further embodiments, the system 100 is in shutdown mode when the system is in the process of transitioning from providing sufficient power to operate an external load to not providing sufficient power to operate an external load for any reason.

[0054] When system 100 is in a standby mode, the system is programmed to run at a minimal capacity such that the fuel cell 130 can power the electrical heater 135 to generate heat. Thus, the electrical heater 135 is powered by the fuel cell 130 to heat the hotbox 125 to a near operating mode temperature. In an illustrative embodiment, the operating temperature is approximately 700°C, such as in the case of a SOFC.

[0055] The operating temperature for a high temperature fuel cell of the present disclosure, including SOFCs or other fuel cell types, is at or about 500°C or greater. Typical high temperature fuel cell operating temperatures are within a range of from about 500°C to about 1000°C, from about 600°C to about 1000°C, from about 700°C to about 1000°C, from about 800°C to about 1000°C, from about 900°C to about 1000°C, from about 700°C to about 950°C, from about 750°C to about 900°C, and from about 800°C to about 900°C. In some embodiments, the operating temperature for the fuel cells may be below 500°C, such as ranging from about 50°C to about 499°C, including any specific or range of temperature comprised therein. In other embodiments, the operating temperature for the fuel cells may not be below 500°C, such as ranging from about 50°C to about 499°C, including any specific or range of temperature comprised therein.

[0056] In some embodiments, about 10% power is required to keep hotbox 125 at the requisite operating temperature, thus preventing excessive fuel loss. In some embodiments, the system 100 can include a temperature monitoring component, device or circuit (not shown) that monitors the temperature of the fuel cell 130 and allows electrical heater 135 to receive power from the fuel cell 130.

[0057] When system 100 is in the operating mode, the controls/exhaust area 120 allow fuel and air to enter the hotbox 125, which allows the fuel cell 130 to generate power. Power generated by the fuel cell 130 can be sent via electrical connection 150 to the electronics area 110 and from there to an external load, such as the customer's load 160, via electrical connection 155. If the fuel cell 130 is not required to generate power for the load 160, the system 100 returns to the standby mode. When the system is in the standby mode, the system directs the power towards the electrical heater 135, which prevents complete system shut down. This is also useful during startup mode, as the system has been using power to keep the fuel cell 130 heated. The electrical heater 135 fully meets the load requirement for this process.

[0058] Importantly, a battery 240 of the present system may provide energy to the electrical heater 135 under no load or partial load conditions. To do so, the battery 240 would have to be sized to account for the customer's maximum time frame of allowance in that state. Thus, an additional benefit of the integrated power generation and heater system 100 as described herein is that the system does not depend on an external power source. Thus, the system 100 only requires a smaller sized battery 240 since the battery 240 will only be used for short transient conditions. This is because the no load or partial load conditions may be controlled with a combination of lower loading of the fuel cell 130, and partial or full loading on the internal heater 135.

[0059] In some embodiments, a plurality of systems 100 may be connected. Each of those systems 100 may be independently controlled such that they may be in a startup mode, an operating mode and/or a standby mode. In some embodiments, the system 100 may be used to power a stationary center such as data center. In some embodiments, the system 100 may be used to power a moving object, such as a vehicle (e.g., truck, car or train).

[0060] The following numbered embodiments are contemplated and non-limiting:

1. A high temperature fuel cell system comprising: a fuel cell; an electrical heater; and an inverter; wherein the electrical heater is powered by the fuel cell, wherein the electrical heater provides load and heat to the fuel cell, and wherein the fuel cell is retained at an operating temperature of 500°C or greater in a standby mode, in an operating mode, or in a startup mode.

2. A method of operating a high temperature fuel cell system comprising: putting at least one fuel cell in an operating mode; wherein the system comprises a plurality of fuel cells, each of which is in close contact with an electrical heater, wherein each of the electrical heaters is powered by the fuel cell it is in close contact with, wherein each of the electrical heaters simultaneously provides load and heat to the fuel cell it is in close contact with, and wherein each of the fuel cells may be in a standby mode, a startup mode, or in the operating mode.

3. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the fuel cell system is a solid oxide fuel cell system, an integrated power generation and heater system, a proton exchange membrane fuel cell system, a molten carbonate fuel cell system, a phosphoric acid fuel cell system and/or any other high and/or low temperature fuel cell system of the art.

4. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the system comprises a fuel cell area and/or an electronics area.

5. The system and/or the method of clause 4, any other suitable clauses, or any combination of suitable clauses, wherein the fuel cell area comprises a fuel cell section and/or a controls/exhaust section.

6. The system and/or the method of clause 5, any other suitable clauses, or any combination of suitable clauses, wherein the fuel cell section comprises a hotbox.

7. The system and/or the method of clause 6, any other suitable clauses, or any combination of suitable clauses, wherein the hotbox houses the fuel cell and the electrical heater.

8. The system and/or the method of clause 6, any other suitable clauses, or any combination of suitable clauses, wherein the hotbox has a thermal casing.

9. The system and/or the method of clause 8, any other suitable clauses, or any combination of suitable clauses, wherein the thermal casing provides separation between the fuel cell and the system.

10. The system and/or the method of clause 9, any other suitable clauses, or any combination of suitable clauses, wherein the separation protects other components of the system and/or retains heat around the fuel cell.

11. The system and/or the method of clause 6, any other suitable clauses, or any combination of suitable clauses, wherein the hotbox is an insulation container or is comprised and/or embedded in an insulation container.

12. The system and/or the method of clause 6, any other suitable clauses, or any combination of suitable clauses, wherein the hotbox is kept at the requisite operating temperature when the system is at about 10% power.

13. The system and/or the method of clause 5, any other suitable clauses, or any combination of suitable clauses, wherein the controls/exhaust system comprises controls, a blower, and/or an exhaust system.

14. The system and/or the method of clause 13, any other suitable clauses, or any combination of suitable clauses, wherein the controls regulate the amount of fuel sent to the fuel cell from an external fuel cell.

15. The system and/or the method of clause 13, any other suitable clauses, or any combination of suitable clauses, wherein the blower and/or the exhaust system allows air to travel into the thermal casing of the hotbox to the fuel cell, and/or allows unused fuel, water, and gases to leave the system.

16. The system and/or the method of clause 4, any other suitable clauses, or any combination of suitable clauses, wherein the electronics area houses contactors connecting the heater to a connection point.

17. The system and/or the method of clause 4, any other suitable clauses, or any combination of suitable clauses, wherein the electronics area houses a DC/DC boost, the inverter, a battery, and/or a bidirectional DC/DC boost.

18. The system and/or the method of clause 17, any other suitable clauses, or any combination of suitable clauses, wherein the DC/DC boost is one directional, bidirectional, and/or not bidirectional.

19. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the system has a voltage output.

20. The system and/or the method of clause 19, any other suitable clauses, or any combination of suitable clauses, wherein the voltage output is a 1-phase volts AC (VAC) standard, a 3-phase VAC standard, and/or any volts VAC standard.

21. The system and/or the method of clause 20, any other suitable clauses, or any combination of suitable clauses, wherein the VAC standard is in Delta configurations, Y configurations, and/or any other configuration.

22. The system and/or the method of clause 19, any other suitable clauses, or any combination of suitable clauses, wherein the voltage output is about 208 VAC 3-phase Delta, about 480 VAC, about 240 VAC, about 600 VAC, and/or any VAC.

23. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, further comprising a resistive load connected through the DC/DC boost.

24. The system and/or the method of clause 23, any other suitable clauses, or any combination of suitable clauses, wherein the load from the electrical heater and/or the resistive load connected through the DC/DC boost enables the fuel cell to maintain some load and provide heat to the hotbox.

25. The system and/or the method of clause 23, any other suitable clauses, or any combination of suitable clauses, wherein the load from the electrical heater and/or the resistive load is attached directly to the fuel cell.

26. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, further comprising the one directional DC/DC boost connected to the fuel cell.

27. The system and/or the method of clause 26, any other suitable clauses, or any combination of suitable clauses, wherein the load from the electrical heater and/or the resistive load is connected before the one directional DC/DC boost, is connected after the one directional DC/DC boost and before the inverter, and/or is connected after the inverter.

28. The system and/or the method of clause 26, any other suitable clauses, or any combination of suitable clauses, further comprising a battery and the bidirectional DC/DC boost connected in parallel to the fuel cell.

29. The system and/or the method of clause 28, any other suitable clauses, or any combination of suitable clauses, wherein the load from the electrical heater and/or the resistive load is connected after the one directional DC/DC boost and before the inverter, is connected before the one directional DC/DC boost, and/or is connected after the inverter.

30. The system and/or the method of clause 28, any other suitable clauses, or any combination of suitable clauses, wherein the load from the electrical heater and/or the resistive load is attached directly to the fuel cell.

31. The system and/or the method of clause 28, any other suitable clauses, or any combination of suitable clauses, wherein the battery provides energy to the electrical heater under no load or partial load conditions and/or is sized to account for the customer's maximum time frame of allowance in that state.

32. The system and/or the method of clause 31, any other suitable clauses, or any combination of suitable clauses, wherein the no load or partial load conditions are controlled with a combination of lower loading of the fuel cell and partial or full loading on the internal heater.

33. The system and/or the method of clause 28, any other suitable clauses, or any combination of suitable clauses, wherein the battery is a smaller sized battery and/or is used for short transient conditions.

34. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, further comprising the battery and the bidirectional DC/DC boost connected in parallel to the fuel cell.

35. The system and/or the method of clause 34, any other suitable clauses, or any combination of suitable clauses, wherein the load from the electrical heater and/or the resistive load is connected before and/or after the inverter.

36. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, further comprising retaining the fuel cell at an operating temperature of 500°C or greater in standby mode.

37. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, further comprising a parasitic load.

38. The system and/or the method of clause 37, any other suitable clauses, or any combination of suitable clauses, wherein the parasitic load is selected from the group consisting of one or more blowers, controllers, valves, heaters, coolers, filters, turbines, humidifiers and/or any other component that requires power to operate.

39. The system and/or the method of clause 37, any other suitable clauses, or any combination of suitable clauses, wherein the parasitic load is directly or indirectly connected to the fuel cell system.

40. The system and/or the method of clause 37, any other suitable clauses, or any combination of suitable clauses, wherein the parasitic load is positioned after the DC/DC boost or elsewhere to drive DC parasitic loads.

41. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, further comprising operating the parasitic load.

42. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, further comprising a VDC stack and/or a voltage stack.

43. The system and/or the method of clause 42, any other suitable clauses, or any combination of suitable clauses, wherein the voltage stack is a 400 VDC stack, a 600 VDC stack, a 800 VDC stack, and/or is greater than a 400 VDC stack but less than a 800 VDC stack.

44. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, further comprising a temperature monitoring component, device, or circuit.

45. The system and/or the method of clause 44, any other suitable clauses, or any combination of suitable clauses, wherein the temperature monitoring component, device, or circuit monitors the temperature of the fuel cell and/or allows the heater to receive power from the fuel cell.

46. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the system does not depend on an external power source.

47. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the system includes a plurality of systems.

48. The system and/or the method of clause 47, any other suitable clauses, or any combination of suitable clauses, wherein each of the systems are independently controlled such that they may be in the startup mode, the operating mode and/or the standby mode.

49. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the system is used to power a stationary center, a data center, a moving object, a vehicle, a truck, a car, and/or a train.

50. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the fuel cell is a solid oxide fuel cell, a proton exchange membrane fuel cell, a molten carbonate fuel cell, a phosphoric acid fuel cell and/or any other high and/or low temperature fuel cell system of the art.

51. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the fuel cell has a voltage output in the range from about 190 Volts DC (VDC) to about 360 VDC, and/or from about 390 VDC to about 880 VDC.

52. The system and/or the method of clause 51, any other suitable clauses, or any combination of suitable clauses, wherein the voltage is input into the inverter after the DC/DC boost and/or is in the range from about 400 VDC to about 800 VDC, about 480 VAC, about 240 VAC, about 600 VAC, from about 900 VDC to about 1500 VDC, and/or any specific value within that range.

53. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the temperature of the fuel cell is increased by some combination of agents selected from a group consisting of the internal resistive heating from the load of the fuel cell and an internal natural gas burner.

54. The system and/or the method of clause 53, any other suitable clauses, or any combination of suitable clauses, wherein the internal resistive heating from the load of the fuel cell is from the electrical heater in the hotbox providing the load.

55. The system and/or the method of clause 54, any other suitable clauses, or any combination of suitable clauses, wherein the internal hotbox resistive load provides heat to the fuel cell and load to the fuel cell.

56. The system and/or the method of clause 53, any other suitable clauses, or any combination of suitable clauses, wherein the load is delivered to the customer by the battery connected to the bidirectional DC/DC boost for a short period while the load on the fuel cell is switched from the electrical heater to the customer load once the fuel cell is at operating temperature.

57. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the electrical heater is a calrod, a resistive panel, an internal electrical heater, a resistive parasitic load on the fuel cell, and/or a resistive coil embedded in the insulation container or the hotbox.

58. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the electrical heater provides load and heat to the fuel cell at the same time.

59. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the electrical heater is connected to an output of the fuel cell using a contactor.

60. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the electrical heater is programmed to provide a load lower than its nominal rating to slowly bring up the temperature and the current in the fuel cell before needing to supply load to a device, instrument, equipment or industrial facility operated by a customer.

61. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the electrical heater fully meets the load requirement to keep the fuel cell heated.

62. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the load from the electrical heater and/or the resistive load is connected before and/or after the inverter.

63. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the operating temperature is at or about 700°C, at or about 500°C or greater, from about 500°C to about 1000°C, from about 600°C to about 1000°C, from about 700°C to about 1000°C, from about 800°C to about 1000°C, from about 900°C to about 1000°C, from about 700°C to about 950°C, from about 750°C to about 900°C, from about 800°C to about 900°C, at or about 500°C or lower, from about 50°C to about 499°C, and/or any specific or range of temperature comprised therein.

64. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the system switches from the operating mode to the standby mode when no power is being drawn from an alternate load, and wherein the system directs its power towards the electrical heater in the standby mode.

65. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the standby mode is a hot standby mode.

66. The system and/or the method of clause 65, any other suitable clauses, or any combination of suitable clauses, wherein the hot standby mode comprises bringing the output of the fuel cell down to the value of the resistive load.

67. The system and/or the method of clause 66, any other suitable clauses, or any combination of suitable clauses, further comprising switching the resistive load to the electrical heater.

68. The system and/or the method of clause 65, any other suitable clauses, or any combination of suitable clauses, wherein the hot standby mode comprises an output power from the system of zero.

69. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the standby mode occurs when the system is not generating a sufficient amount of power to operate an external load.

70. The system and/or the method of clause 69, any other suitable clauses, or any combination of suitable clauses, wherein the system in standby mode is programmed to run at a minimal capacity such that the fuel cell can power the electrical heater to generate heat.

71. The system and/or the method of clause 70, any other suitable clauses, or any combination of suitable clauses, wherein the electrical heater is powered by the fuel cell to heat the hotbox to a near operating mode temperature.

72. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the standby mode occurs when fuel cell is not required to generate power for the load.

73. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the standby mode includes the system directing the power towards the electrical heater.

74. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the operating mode occurs when the system is generating sufficient power to operate an external load and/or a customer's load.

75. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the operating mode includes the controls/exhaust area allowing fuel and air to enter the hotbox and/or allowing the fuel cell to generate power.

76. The system and/or the method of clause 75, any other suitable clauses, or any combination of suitable clauses, wherein the power generated by the fuel cell is sent via electrical connection to the electronics area and/or to the external load via electrical connection.

77. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, wherein the startup mode occurs when the system transitions or is in the process of transitioning from the standby mode to the operating mode.

78. The system and/or the method of clauses 1 and/or 2, any other suitable clauses, or any combination of suitable clauses, further comprising a shutdown mode.

79. The system and/or the method of clause 78, any other suitable clauses, or any combination of suitable clauses, wherein the shutdown mode occurs when the system is not fulling in any one of the startup mode, the standby mode, or the operating mode.

80. The system and/or the method of clause 78, any other suitable clauses, or any combination of suitable clauses, wherein the shutdown mode occurs when the system transitions or is in the process of transitioning from the operating mode to the standby mode.

81. The system and/or the method of clause 78, any other suitable clauses, or any combination of suitable clauses, wherein the shutdown mode occurs when the system is in the process of transitioning from providing sufficient power to operate an external load to not providing sufficient power to operate an external load.

[0061] Moreover, the features illustrated or described in connection with one exemplary embodiment may be combined with any other feature or element of any other embodiment described herein. Such modifications and variations are intended to be included within the scope of the present disclosure. Further, a person skilled in the art will recognize that terms commonly known to those skilled in the art may be used interchangeably herein.

[0062] As used herein, an element or step recited in the singular and proceeded with the word “a” or “an” should be understood as not excluding plural of said elements or steps, unless such exclusion is explicitly stated. Furthermore, references to “one embodiment” of the presently described subject matter are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features. Specified numerical ranges of units, measurements, and/or values comprise, consist essentially or, or consist of all the numerical values, units, measurements, and/or ranges including or within those ranges and/or endpoints, whether those numerical values, units, measurements, and/or ranges are explicitly specified in the present disclosure or not.

[0063] Unless defined otherwise, technical and scientific terms used herein have the same meaning as is commonly understood by one of ordinary skill in the art to which this disclosure belongs. The terms “first,” “second,” “third” and the like, as used herein do not denote any order or importance, but rather are used to distinguish one element from another. The term “or” is meant to be inclusive and mean either or all of the listed items. In addition, the terms “connected” and “coupled” are not restricted to physical or mechanical connections or couplings, and can include electrical connections or couplings, whether direct or indirect.

[0064] Moreover, unless explicitly stated to the contrary, embodiments “comprising,” “including,” or “having” an element or a plurality of elements having a particular property may include additional such elements not having that property. The term “comprising” or “comprises” refers to a composition, compound, formulation, or method that is inclusive and does not exclude additional elements, components, and/or method steps. The term “comprising” also refers to a composition, compound, formulation, or method embodiment of the present disclosure that is inclusive and does not exclude additional elements, components, or method steps.

[0065] The phrase “consisting of” or “consists of” refers to a compound, composition, formulation, or method that excludes the presence of any additional elements, components, or method steps. The term “consisting of” also refers to a compound, composition, formulation, or method of the present disclosure that excludes the presence of any additional elements, components, or method steps.

[0066] The phrase “consisting essentially of” or “consists essentially of” refers to a composition, compound, formulation, or method that is inclusive of additional elements, components, or method steps that do not materially affect the characteristic(s) of the composition, compound, formulation, or method. The phrase “consisting essentially of” also refers to a composition, compound, formulation, or method of the present disclosure that is inclusive of additional elements, components, or method steps that do not materially affect the characteristic(s) of the composition, compound, formulation, or method steps.

[0067] Approximating language, as used herein throughout the specification and claims, may be applied to modify any quantitative representation that could permissibly vary without resulting in a change in the basic function to which it is related. Accordingly, a value modified by a term or terms, such as “about”, and “substantially” is not to be limited to the precise value specified. In some instances, the approximating language may correspond to the precision of an instrument for measuring the value. Here and throughout the specification and claims, range limitations may be combined and/or interchanged. Such ranges are identified and include all the sub-ranges contained therein unless context or language indicates otherwise.

[0068] As used herein, the terms “may” and “may be” indicate a possibility of an occurrence within a set of circumstances; a possession of a specified property, characteristic or function; and/or qualify another verb by expressing one or more of an ability, capability, or possibility associated with the qualified verb. Accordingly, usage of “may” and “may be” indicates that a modified term is apparently appropriate, capable, or suitable for an indicated capacity, function, or usage, while taking into account that in some circumstances, the modified term may sometimes not be appropriate, capable, or suitable.

[0069] It is to be understood that the above description is intended to be illustrative, and not restrictive. For example, the above-described embodiments (and/or aspects thereof) may be used individually, together, or in combination with each other. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the subject matter set forth herein without departing from its scope. While the dimensions and types of materials described herein are intended to define the parameters of the disclosed subject matter, they are by no means limiting and are exemplary embodiments. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. The scope of the subject matter described herein should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

[0070] This written description uses examples to disclose several embodiments of the subject matter set forth herein, including the best mode, and also to enable a person of ordinary skill in the art to practice the embodiments of disclosed subject matter, including making and using the devices or systems and performing the methods. The patentable scope of the subject matter described herein is defined by the claims, and may include other examples that occur to those of ordinary skill in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

[0071] While only certain features of the invention have been illustrated and described herein, many modifications and changes will occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

WHAT IS CLAIMED IS:

1. A high temperature fuel cell system comprising:

a fuel cell;

an electrical heater; and

an inverter;

wherein the electrical heater is powered by the fuel cell,

wherein the electrical heater provides load and heat to the fuel cell, and wherein the fuel cell is retained at an operating temperature of 500°C or greater in a standby mode, in an operating mode, or in a startup mode.

2. The system of claim 1, further comprising a one directional DC/DC boost connected to the fuel cell.

3. The system of claim 1, further comprising a battery and a bi-directional DC/DC boost connected in parallel to the fuel cell.

4. The system of claim 2, wherein the load from the electrical heater is connected before the one directional DC/DC boost.

5. The system of claim 2, wherein the load from the electrical heater is connected after the one directional DC/DC boost and before the inverter.

6. The system of claim 2, wherein the load from the electrical heater is connected after the inverter.

7. The system of claim 1, wherein the load from the electrical heater is connected before the inverter.

8. The system of claim 1, wherein the load from the electrical heater is connected after the inverter.

9. The system of claim 2, further comprising a battery and a bi-directional DC/DC boost connected in parallel to the fuel cell.

10. The system of claim 9, wherein the load from the electrical heater is connected after the one directional DC/DC boost and before the inverter.

11. The system of claim 9, wherein the load from the electrical heater is connected before the one directional DC/DC boost.

12. The system of claim 9, wherein the load from the electrical heater is connected after the inverter.

13. The system of claim 3, wherein the load from the electrical heater is connected after the inverter.

14. The system of claim 3, wherein the load from the electrical heater is connected before the inverter.

15. The system of claim 1, wherein the system switches from the operating mode to the standby mode when no power is being drawn from an alternate load, and wherein the system directs its power towards the electrical heater in the standby mode.

16. The system of claim 1, wherein the electrical heater is a calrod.

17. The system of claim 1, wherein the electrical heater is a resistive panel.

18. The system of claim 1, wherein the electrical heater is a resistive coil embedded in a insulation container or a hotbox.

19. A method of operating a high temperature fuel cell system comprising:

placing at least one fuel cell in an operating mode;

wherein the system comprises a plurality of fuel cells, each of which is in close contact with an electrical heater, wherein each of the electrical heaters is powered by the fuel cell it is in close contact with, wherein each of the electrical heaters simultaneously provides load and heat to the fuel cell it is in close contact with, and wherein each of the fuel cells may be in a standby mode, a startup mode, or in the operating mode.

20. The method of claim 19, comprising retaining the fuel cell at an operating temperature of 500°C or greater in standby mode.

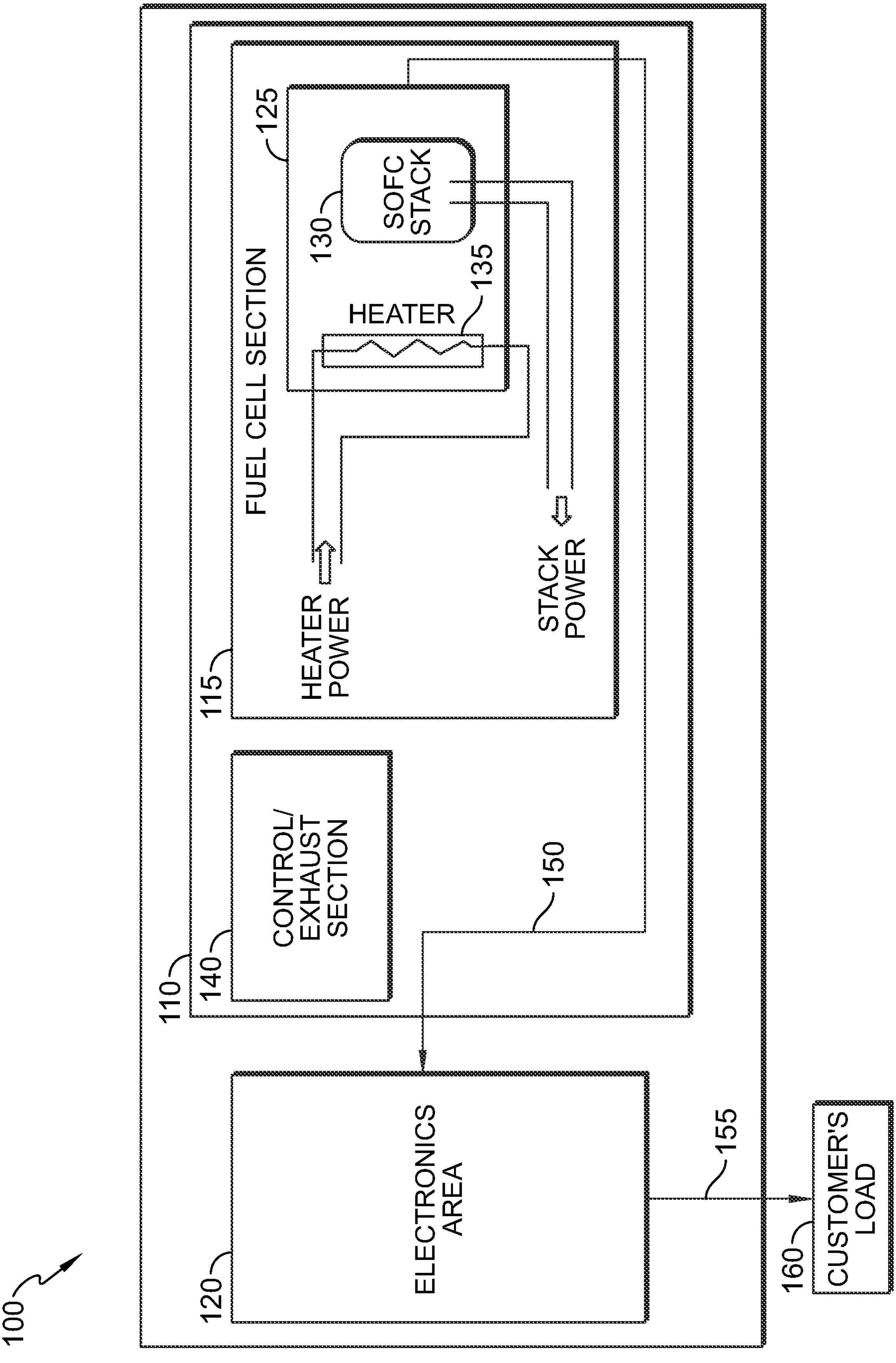

FUEL CELL SECTION
SOFC STACK
HEATER
HEATER POWER
STACK POWER
CONTROL/ EXHAUST SECTION
ELECTRONICS AREA
CUSTOMER'S LOAD
100
110
115
120
125
130
135
140
150
155
160

FIG. 1

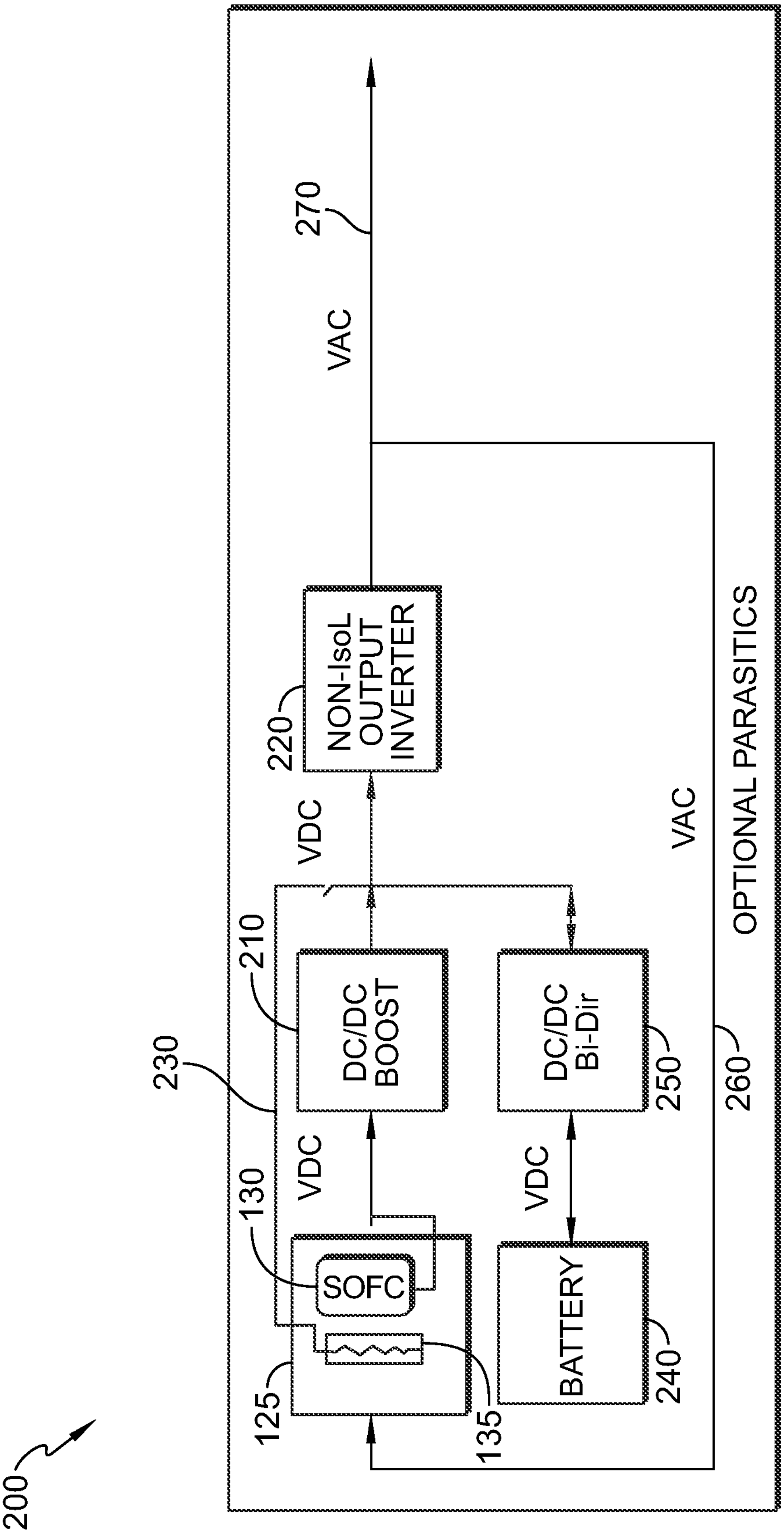

200
SOFC
130
125
135
VDC
230
210
DC/DC
BOOST
VDC
220
NON-IsoL
OUTPUT
INVERTER
VAC
270
BATTERY
240
VDC
DC/DC
Bi-Dir
250
260
VAC
OPTIONAL PARASITICS

FIG. 2

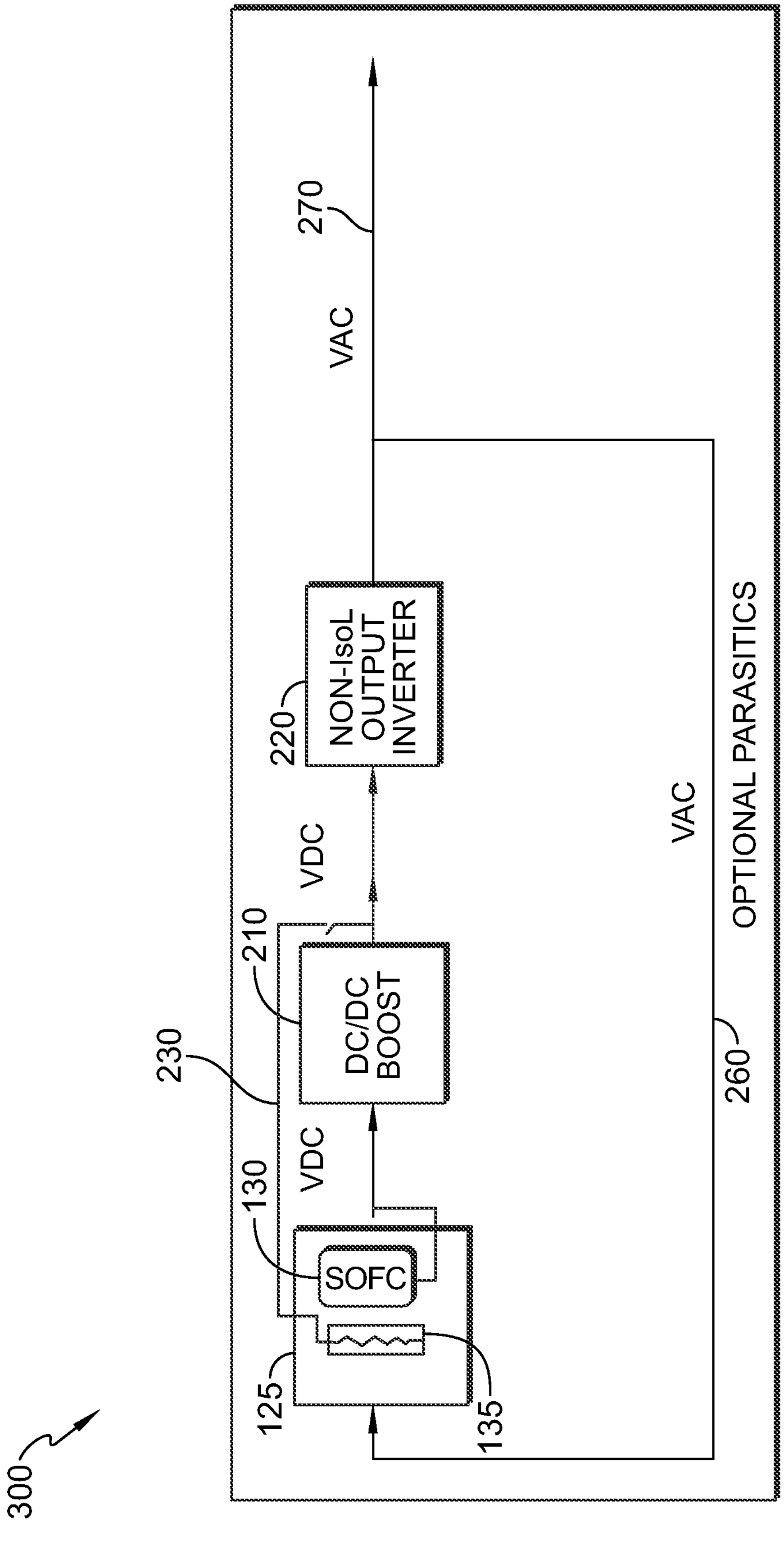

300
125
135
130
SOFC
VDC
230
210
DC/DC
BOOST
VDC
220
NON-IsoL
OUTPUT
INVERTER
VAC
270
VAC
260
OPTIONAL PARASITICS

FIG. 3

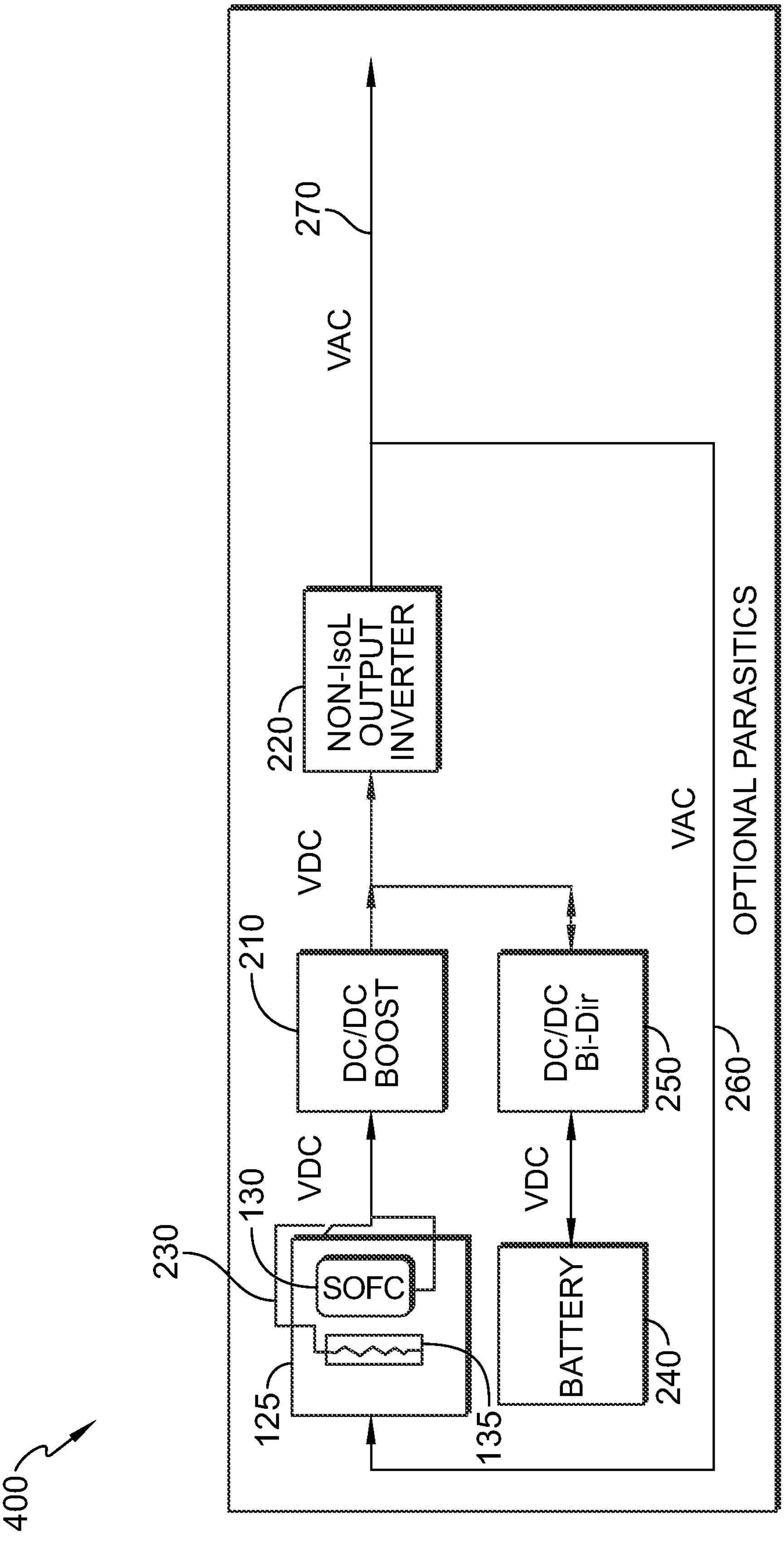

400
230
130
SOFC
125
135
VDC
DC/DC BOOST
210
VDC
NON-IsoL OUTPUT INVERTER
220
VAC
270
BATTERY
240
VDC
DC/DC Bi-Dir
250
260
VAC
OPTIONAL PARASITICS

FIG. 4

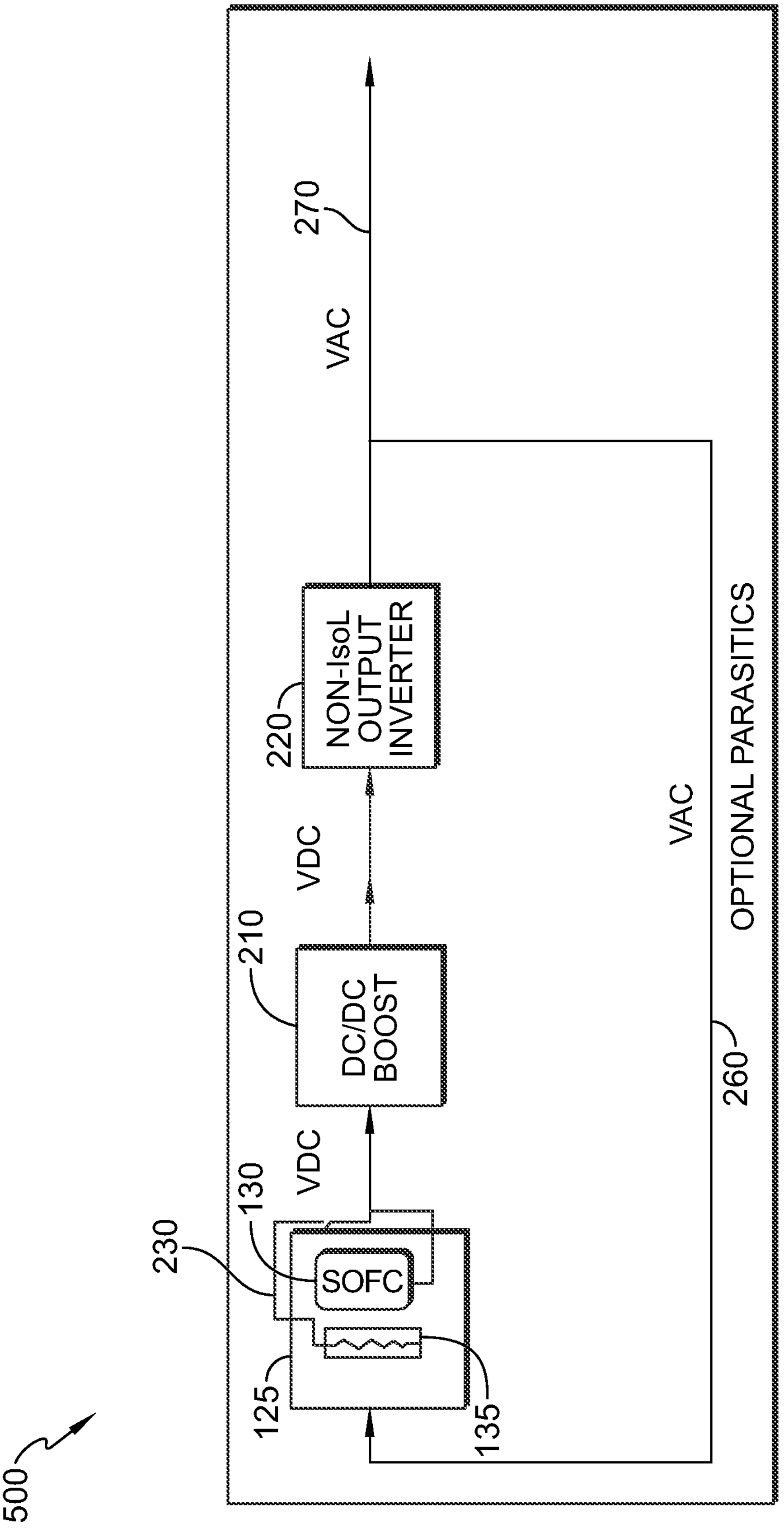
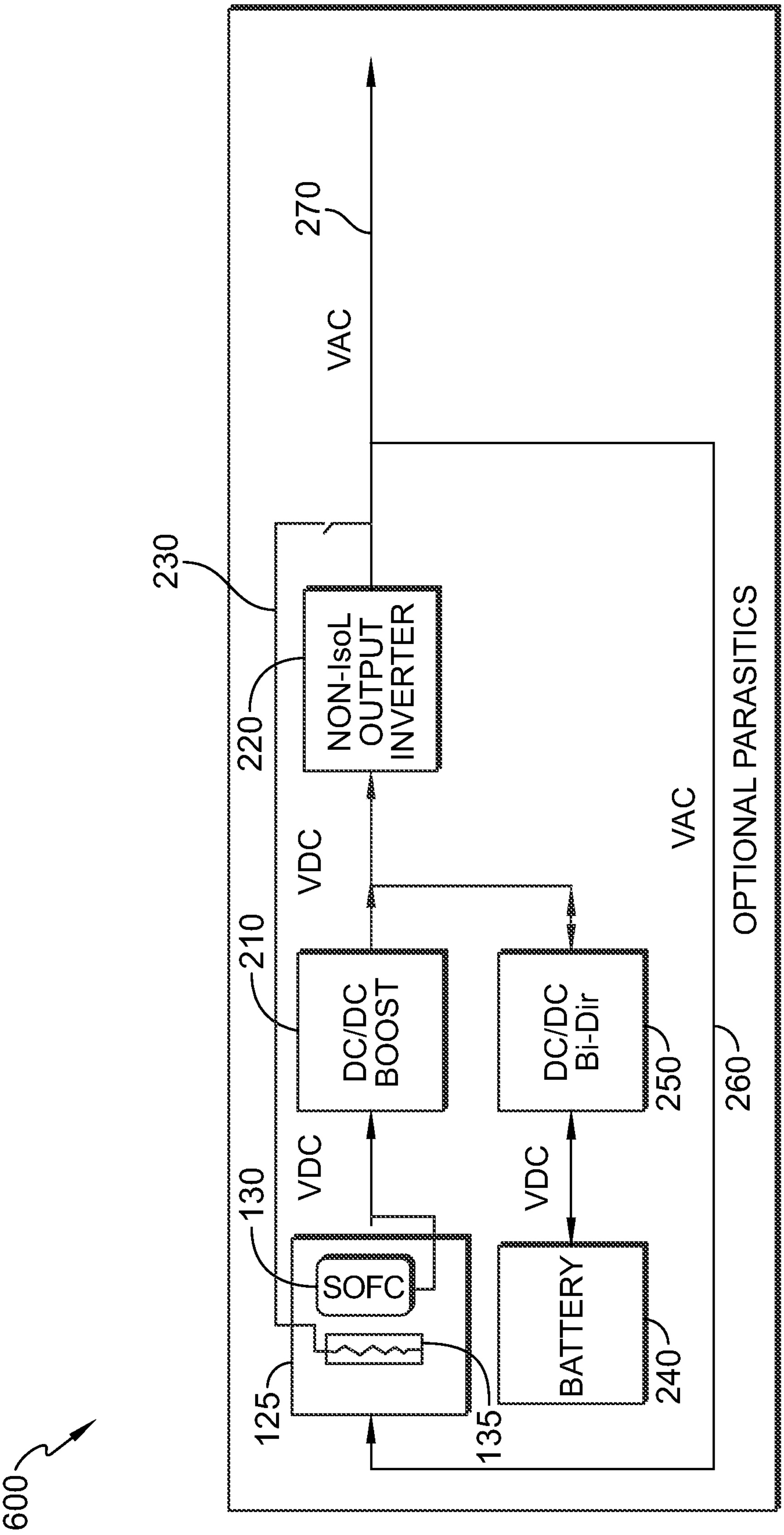

500
230
130
SOFC
125
135
VDC
DC/DC BOOST
210
VDC
NON-IsoL OUTPUT INVERTER
220
VAC
270
VAC
OPTIONAL PARASITICS
260

FIG. 5



600
125
130
SOFC
135
VDC
DC/DC
BOOST
210
BATTERY
240
VDC
DC/DC
Bi-Dir
250
VDC
NON-IsoL
OUTPUT
INVERTER
220
230
VAC
270
VAC
OPTIONAL PARASITICS
260

FIG. 6

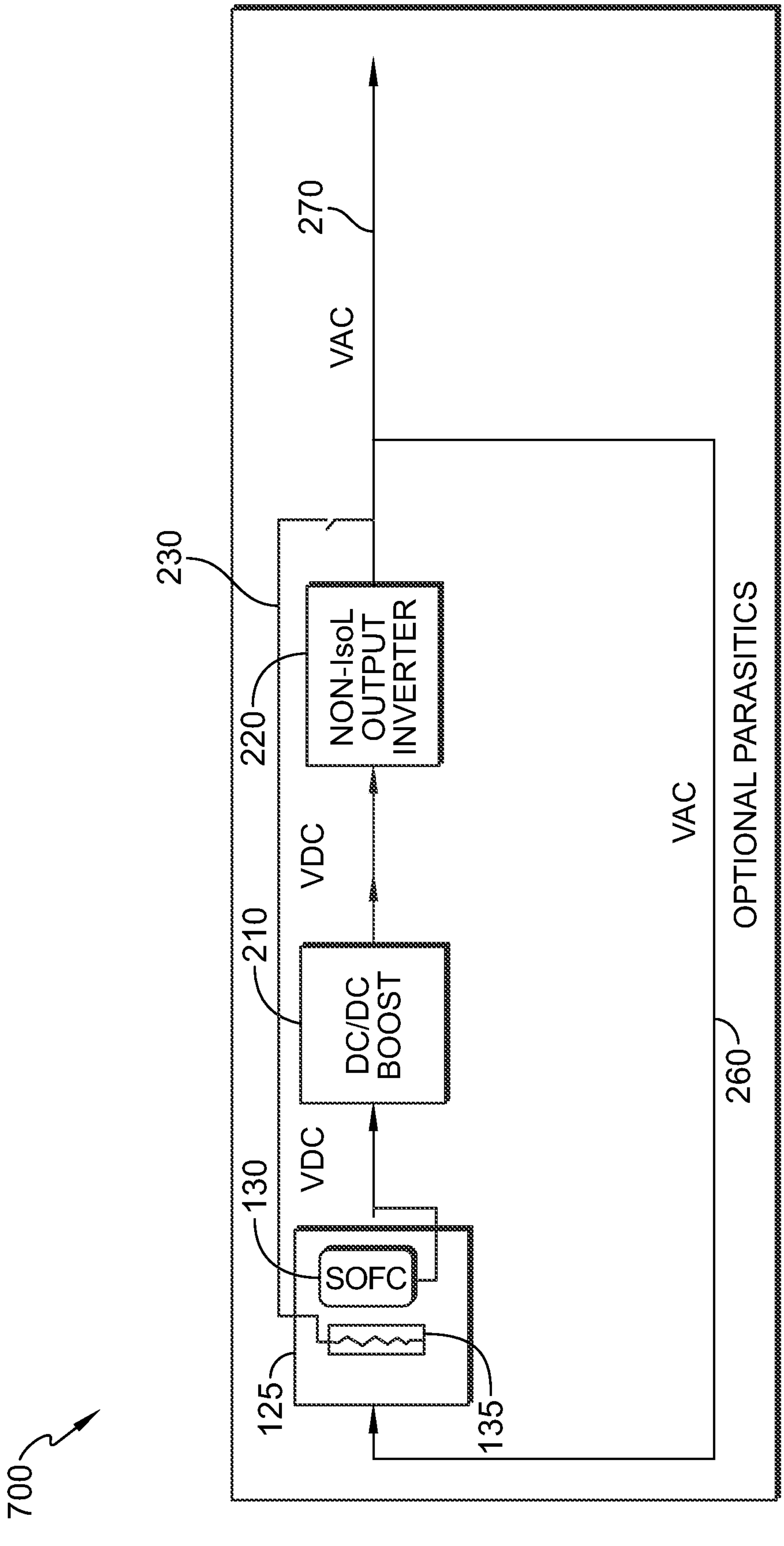

700
125
135
130
SOFC
VDC
DC/DC BOOST
210
VDC
NON-IsoL OUTPUT INVERTER
220
230
VAC
270
VAC
260
OPTIONAL PARASITICS

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 22/13124

A. CLASSIFICATION OF SUBJECT MATTER
IPC - H01M 8/12; H01M 8/24; H01M 8/0267; H01M 8/04225; H01M 8/04701 (2022.01)

CPC - H01M 8/12; H01M 8/24; H01M 8/0267; H01M 8/04225; H01M 8/04701; H01M 2008/1293

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)
See Search History document

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

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

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 2017/0149076 A1 (KYOCERA CORPORATION) 25 May 2017 (25.05.2017) entire document, especially para [0023, [0031], [0025], [0065]	1, 2, 5-8, 15 --- 3, 4, 9-14, 16-18
X	US 2004/0048128 A1 (JANKOWSKI ET AL.) 11 March 2004 (11.03.2004) entire document, especially para [0027], [0029], [0045], [0007]	19, 20
Y	US 2014/0056035 A1 (CONVION OY) 27 February 2014 (27.02.2014) entire document, especially para [0033], [0013]	3, 9, 10, 12-14
Y	US 2018/0366751 A1 (NISSAN MOTOR CO., LTD.) 20 December 2018 (20.12.2018) entire document, especially para [0042], [0053], [0005]	4, 11
Y	US 2007/0243444 A1 (ZHENG ET AL.) 18 October 2007 (18.10.2007) entire document, especially para [0012], [0009]	16
Y	US 2013/0071294 A1 (REDMOND) 21 March 2013 (21.03.2013) entire document, especially para [0101], [0018]	17
Y	US 3,723,187 A (TOYDOKA ET AL.) 27 March 1973 (27.03.1973) entire document, especially Col 2, ln 40-41; Col 2, ln 37-39	18

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"D" document cited by the applicant in the international application
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"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
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 March 2022	APR 26 2022

Name and mailing address of the ISA/US	Authorized officer
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Kari Rodriquez Telephone No. PCT Helpdesk: 571-272-4300