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(54) BYPASSING PROPERLY OPERATING CELLS

(57) Systems and methods are provided for operating an electrolyzer. The systems and methods include operations comprising: determining that a first electrolytic cell in a first electrolyzer stack is associated with a first set of performance criteria that fails to satisfy one or more operating conditions; identifying a second electrolytic cell that is associated with a second set of performance criteria that satisfies the one or more operating conditions; and bypassing the first electrolytic cell and the second electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions and based on identifying the second electrolytic cell that is associated with the second set of performance criteria that satisfies the one or more operating conditions.

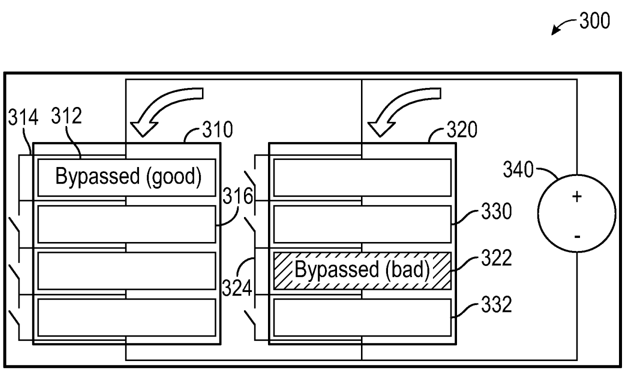

FIG. 3

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Description

FIELD OF THE DISCLOSURE

[0001] This document pertains generally, but not by way of limitation, to electrolysis cells.

BACKGROUND

[0002] Fuel cells are used to convert chemical energy (usually from hydrogen) to electrical energy. Since each fuel cell usually produces between 1 and 2 volts, oftentimes such fuel cells are stacked in series in order to produce a high power at a relatively low current. Hydrogen can also be generated with similar devices. Instead of hydrogen and oxygen as inputs and electrons as the desired output, the inputs are electricity and water and hydrogen is the desired output.

OVERVIEW

[0003] This disclosure describes, among other things, techniques for operating electrolysis cells.

[0004] In some examples, the techniques described herein relate to a system including: a first electrolyzer stack including a first plurality of electrolytic cells; and control circuitry coupled to the first electrolyzer stack and configured to perform operations including: determining that a first electrolytic cell in the first electrolyzer stack is associated with a first set of performance criteria that fails to satisfy one or more operating conditions; identifying a second electrolytic cell that is associated with a second set of performance criteria that satisfies the one or more operating conditions; and bypassing the first electrolytic cell and the second electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions and based on identifying the second electrolytic cell that is associated with the second set of performance criteria that satisfies the one or more operating conditions.

[0005] In some aspects, the techniques described herein relate to a system, wherein the second electrolytic cell is in the first electrolyzer stack and is adjacent to the first electrolytic cell on a first side of the first electrolytic cell.

[0006] In some aspects, the techniques described herein relate to a system, wherein the operations further include: identifying a third electrolytic cell in the first electrolyzer stack that is adjacent to the first electrolytic cell on a second side of the first electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions.

[0007] In some aspects, the techniques described herein relate to a system, wherein the operations further include: determining that the third electrolytic cell is associated with a third set of performance criteria that satisfies the one or more operating conditions; and bypassing the third electrolytic cell along with the first electrolytic cell and the second electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions and based on identifying the third electrolytic cell in the first electrolyzer stack that is adjacent to the first electrolytic cell on a second side of the first electrolytic cell.

[0008] In some aspects, the techniques described herein relate to a system, wherein the operations further include: bypassing multiple adjacent electrolytic cells along with the first electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions, the multiple adjacent electrolytic cells being on a same side relative to the first electrolytic cell and being associated with respective sets of performance criteria that satisfies the one or more operating conditions.

[0009] In some aspects, the techniques described herein relate to a system, wherein the operations for bypassing the first electrolytic cell and the second electrolytic cell include closing a single switch that is associated with the first electrolytic cell for routing current from a first bipolar plate of the second electrolytic cell around a second bipolar plate of the first electrolytic cell to a third bipolar plate of the first electrolytic cell, the single switch preventing current from passing through an individual bipolar plate of the second electrolytic cell to the second bipolar plate when the single switch is closed.

[0010] In some aspects, the techniques described herein relate to a system, further including: a second electrolyzer stack including a second plurality of electrolytic cells coupled to the control circuitry, the second plurality of electrolytic cells including the second electrolytic cell, and the first electrolyzer stack being electrically coupled in parallel with the second electrolyzer stack.

[0011] In some aspects, the techniques described herein relate to a system, wherein the operations further include: determining that the first electrolyzer stack is aging at a different rate from the second electrolyzer stack, wherein the first electrolytic cell and the second electrolytic cell are bypassed to balance aging across the first and second electrolyzer stacks.

[0012] In some aspects, the techniques described herein relate to a system, wherein the operations further include: determining that the first electrolyzer stack is associated with a different amount of current or voltage from the second electrolyzer stack, wherein the first electrolytic cell and the second electrolytic cell are bypassed to balance current or voltage across the first and second electrolyzer stacks.

[0013] In some aspects, the techniques described herein relate to a system, wherein the operations further include: determining that the second electrolytic cell has been bypassed with the first electrolytic cell for a threshold period of time; and in response to determining that the second electrolytic cell has been bypassed with the first electrolytic cell for the threshold period of time: identifying a third electrolytic cell in the second electrolyzer stack that is associated with a third set of performance criteria that satisfies the one or more operating conditions; and bypassing the third electrolytic cell instead of the second electrolytic cell to bypass the first electrolytic cell and the third electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions.

[0014] In some aspects, the techniques described herein relate to a system, wherein the operations further include: selecting the second electrolytic cell from the second plurality of electrolytic cells of the second electrolyzer stack to bypass based on one or more cell selection criteria.

[0015] In some aspects, the techniques described herein relate to a system, wherein the one or more cell selection criteria includes at least one of voltage or current associated with the second electrolytic cell relative to voltage or current of other electrolytic cells, an alignment property associated with the first and second electrolyzer stacks, or an aging profile of the second electrolytic cell.

[0016] In some aspects, the techniques described herein relate to a system, wherein the operations further include: determining that a third electrolytic cell of the second plurality of electrolytic cells of the second electrolyzer stack is associated with a third set of performance criteria that fails to satisfy the one or more operating conditions; and in response to determining that the third electrolytic cell of the second plurality of electrolytic cells of the second electrolyzer stack is associated with the third set of performance criteria that fails to satisfy the one or more operating conditions: bypassing the third electrolytic cell instead of the second electrolytic cell to bypass the first electrolytic cell and the third electrolytic cell.

[0017] In some aspects, the techniques described herein relate to a system, wherein the operations further include: initializing operation of the first and second electrolyzer stacks by bypassing a first good electrolytic cell (and/or a first collection of good electrolytic cells) of the first electrolyzer stack and bypassing a second good electrolytic cell (and/or a second collection of good electrolytic cells) of the second electrolyzer stack; after initializing operation of the first and second electrolyzer stacks, determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy one or more operating conditions; and replacing bypass of the first good electrolytic cell of the first electrolyzer stack with bypass of the first electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy one or more operating conditions while maintaining bypass of the second good electrolytic cell of the second electrolyzer stack.

[0018] In some aspects, the techniques described herein relate to a system, wherein the first set of performance criteria includes at least one of pinhole formation, catalyst degradation or dissolution, porous transport layer (PTL) coating degradation, current through the first electrolytic cell, or bipolar plate degradation, and wherein the one or more operating conditions includes at least one of a pinhole formation threshold, maximum catalyst degradation or dissolution value, PTL coating degradation threshold, maximum current threshold, or a bipolar plate degradation threshold.

[0019] In some aspects, the techniques described herein relate to a method including: determining that a first electrolytic cell in a first electrolyzer stack is associated with a first set of performance criteria that fails to satisfy one or more operating conditions; identifying a second electrolytic cell that is associated with a second set of performance criteria that satisfies the one or more operating conditions; and bypassing the first electrolytic cell and the second electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions and based on identifying the second electrolytic cell that is associated with the second set of performance criteria that satisfies the one or more operating conditions.

[0020] In some aspects, the techniques described herein relate to a method, wherein the second electrolytic cell is in the first electrolyzer stack and is adjacent to the first electrolytic cell on a first side of the first electrolytic cell.

[0021] In some aspects, the techniques described herein relate to a method, further including: identifying a third electrolytic cell in the first electrolyzer stack that is adjacent to the first electrolytic cell on a second side of the first electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions.

[0022] In some aspects, the techniques described herein relate to an apparatus including: means for determining that a first electrolytic cell in a first electrolyzer stack is associated with a first set of performance criteria that fails to satisfy one or more operating conditions; means for identifying a second electrolytic cell that is associated with a second set of performance criteria that satisfies the one or more operating conditions; and means for bypassing the first electrolytic cell and the second electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions and based on identifying the second electrolytic cell that is associated with the second set of performance criteria that satisfies the one or more operating conditions.

[0023] In some aspects, the techniques described herein relate to an apparatus, wherein the second electrolytic cell is in the first electrolyzer stack and is adjacent to the first electrolytic cell on a first side of the first electrolytic cell.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] In the drawings, which are not necessarily drawn to scale, like numerals may describe similar components in different views. Like numerals having different letter suffixes may represent different instances of similar components. The drawings illustrate generally, by way of example, but not by way of limitation, various examples discussed in the present document.

FIG. 1 is a block diagram of an example of an electrolyzer system including parallel connected electrolyzer cells, in accordance with various examples.

FIG. 2 is a block diagram of an example of an electrolyzer system including parallel connected electrolyzer cells, in accordance with various examples.

FIG. 3 is a block diagram of an example of an electrolyzer system including multiple stacks of parallel connected electrolyzer cells with bypass switches, in accordance with various examples.

FIG. 4 is a block diagram of an example of an electrolyzer system including multiple stacks of parallel connected electrolyzer cells with bypass switches, in accordance with various examples.

FIG. 5 is a block diagram of an example of an electrolyzer system including a single stack of parallel connected electrolyzer cells with bypass switches, in accordance with various examples.

FIG. 6 is a flow diagram depicting an example process for operating an electrolyzer, in accordance with various examples.

FIG. 7 is a block diagram illustrating an example of a machine upon which one or more examples may be implemented.

DETAILED DESCRIPTION

[0025] This disclosure describes, among other things, techniques to configure an electrolyzer or hydrolyzer to generate hydrogen and/or oxygen.

[0026] An electrolyzer typically includes one or more electrolytic cells. Each electrolytic cell has three component parts: an electrolyte and two electrodes (a cathode and an anode). The electrolyte is usually a solution of water or other solvents in which ions are dissolved. Molten salts such as sodium chloride are also electrolytes. When driven by an external voltage applied to the electrodes, the ions in the electrolyte are attracted to an electrode with the opposite charge, where charge-transferring (also called faradaic or redox) reactions can take place. Only with an external electrical potential (e.g., voltage) of correct polarity and sufficient magnitude can an electrolytic cell decompose a normally stable, or inert, chemical compound in the solution. The electrical energy provided can produce a chemical reaction, which would not occur spontaneously otherwise. Water, particularly when ions are added (salt water or acidic water), can be electrolyzed (subject to electrolysis). When driven by an external source of voltage, H+ ions flow to the cathode to combine with electrons to produce hydrogen gas in a reduction reaction. Likewise, OH- ions flow to the anode to release electrons and an H+ ion to produce oxygen gas in an oxidation reaction.

[0027] A system that generates hydrogen through electrolysis is called an electrolyzer or a hydrolyzer. A power generation system produces a high voltage (e.g., between 50V and 200V) and a high current (e.g., 100A to 4000A) that is provided to a cell stack that includes electrolytic cells that each include an electrolyte and two electrodes. With water as the other input, the cell stack produces hydrogen and oxygen as outputs. If the source of power is a renewable such as solar, wind, or hydroelectric, then the entire cycle is completely carbon free. Electrolyzer cells are typically electrically connected in series. However, such configurations have several shortcomings. For example, one challenge of electrolyzers is durability. There is a specific voltage across a cell that produces an optimum combination of efficiency and durability. If the supply voltage is too high, corrosion in the electrodes can result in an increase in impedance and a shorter lifetime of the electrolyzers. The increase in impedance in one cell changes the voltage in other cells and can degrade efficiency and/or durability.

[0028] In addition, configuring the electrolyzers in series limits the scalability of the overall system, because adding or replacing electrolytic cells introduces additional challenges. For example, if one electrolytic cell in the electrolyzer breaks down, the power distribution through the system to other cells can be impacted and the overall system may also stop functioning. Namely, when the cells are in a series configuration, when one cell fails then the entire stack fails.

[0029] Some systems provide multiple stacks of electrolyzers each having its own set of electrolytic cells coupled in series. Namely, a first stack of electrolytic cells that are part of a first electrolyzer stack can be coupled in series to each other but in parallel with a second stack of electrolytic cells that are part of a second electrolyzer stack. While this improves the functionality of the overall electrolyzer, managing the operations of two or more separate electrolyzer stacks introduces other challenges. Particularly, the output of one electrolyzer stack needs to be balanced with the output of another electrolyzer stack in order to ensure that the stacks age at similar rates.

[0030] An electrolyzer stack can include multiple cells coupled electrically in series, each having some minimum (e.g., thermoneutral) voltage at which the splitting of water occurs and producing increasing current at higher voltages; the specifics depend on the cell construction and chemistry (e.g., thermoneutral voltage is around 1.5V for a proton-exchange membrane cell). Initially, the stacks can be "balanced" with respect to some desired operating regime (for instance, a similar amount of current flows through each stack that is derived as a nominal amount of current per cm2 of cell area (e.g., current density)).

[0031] In some examples, electrolyzer plants include many electrolyzer stacks which may be connected and operated in parallel. In the parallel configuration, the constituent stacks share a single power supply and hence the same stack voltage. At the outset, the stacks can initially be balanced such that the voltage and stack currents achieve some targeted levels with roughly equal currents flowing through each of the stacks. Over time, the performance of the stacks will diverge from these target levels, potentially arising from differences between stacks in terms of cell aging or cell failures. This can arise from degradation of the constituent electrolytic cells which change the cells' (and the stack's) current-voltage relationship. Alternatively, it can occur if one stack simply has higher current and/or voltage than the other, potentially due to wiring or mismatch reason. It can also arise from the operator intentionally bypassing specific cells that have failed where the number of these cells may not be balanced across stacks. This can cause the parallel stacks to operate in an unbalanced manner, where one or more of the stacks begin to operate at currents that significantly diverge from the target current. The plant operator has little existing control over the individual stack performances. Namely, the operator can control the stack voltage for all stacks in parallel but has little to no differential control over the operation of individual stacks within the parallel configuration.

[0032] While the parallel connected stacks operate at the same voltage, the stacks' operating currents may vary, depending on the number of constituent cells and their performance. More current may be directed through some stacks and less in others, which can push some stacks outside their desired operating regime. For example, at higher current density, cells degrade faster and are less efficient. In some cases, individual cells in an electrolyzer stack may fail and result in the need for a stack replacement. If the cell impedance increases because of these failures, bypassing a defective cell can allow the stack to continue running without replacement with slightly reduced efficiency and no safety concerns. Specifically, by bypassing one or more cells in some stacks, the operator can fine tune the operation of parallel stacks. When bypassing a cell within a stack, the overall stack voltage remains the same, but it is dropped across fewer cells; this increases the stack current. Conversely, if a stack already contains a bypassed cell, undoing the bypass may increase the number of cells within that stack and decrease the stack current.

[0033] Bypassing a failing cell implicitly assumes that cell resistance is much higher than bypass path, and/or there are no adverse effects from shunting current through bipolar plate, and/or there are no adverse effects from leakage current through the cell. Bypassing of a defective cell can be ineffective when these assumptions do not hold. Electrolyzer cell bypassing has been considered for shunting stack currents around defective cells, thus allowing continued operation despite cells being single points of failure. However, bypassing one cell in one stack without considering the impact on the output or balance of the other stack can introduce inefficiencies and damage the overall electrolyzer plant.

[0034] According to the disclosed examples, a novel and resource efficient approach to operating and configuring electrolyzers is provided. The disclosed approach bypasses one or more good electrolytic cells (e.g., bypassing non-failing electrolytic cells) using bypass circuitry to provide the operator with additional control over the operating conditions of individual stacks within a parallel configuration. Bypassing good cells allows for power balancing across stacks and for modifying the operating conditions to reduce degradation of the electrolytic cells. When used in conjunction with bypassing of failed or failing cells, the disclosed examples allow for safe and stable continued operation of the stacks regardless of the distribution of the failed cells (for instance in the case when they are concentrated within a single stack). As referred to herein, failing cells or failing electrolytic cells can correspond to cells that are associated with a respective set of performance criteria that fails to satisfy one or more operating conditions. As referred to herein, good cells or non-failing electrolytic cells can correspond to cells that are associated with a respective set of performance criteria that satisfies one or more operating conditions.

[0035] There are a variety of schemes available to choose the good (non-failing) cell to bypass. Bypassing may be cycled around all the good cells to balance the aging of cells across the full stack. For instance, the first good cell may be bypassed for a day, following by the second good cell the next day; eventually, over the course of many days, all the good cells will have been bypassed at least once and the cycle can repeat. Alternatively, the good cell for bypassing could be selected based on parameters of the cell (for instance, when one cell has a different voltage or aging profile that makes it more desirable to bypass). Another example is when the cell's properties results in better alignment across the stacks when bypassed as compared to other candidate cells.

[0036] The bypassing of individual electrolytic cells that are failing along with bypassing select one or more healthy (e.g., good or non-failing) electrolytic cells (of the same electrolyzer stack and/or a different electrolyzer stack) allows performance of the electrolyzer system to be improved and optimized and increases durability of the cells and electrolyzer system.

[0037] **FIG. 1** is a block diagram of an example of an electrolyzer system 100 that includes cell stacks coupled to each other in parallel, in accordance with various examples. Namely, in this example, the cell stacks are connected electrically in parallel and each cell stack is driven by a common voltage source. Each cell stack includes a respective plurality of electrolysis cells. The electrolyzer system 100 includes a main high-voltage distribution device 110 configured to provide an intermediate voltage to a point-of-load voltage converter 120. For example, the high-voltage distribution device 110 can provide a voltage between 10 and 50 volts. The intermediate voltage converter 120 reduces (steps down) the voltage to a range of 1 volt and 2 volts.

[0038] The intermediate voltage converter 120 (common voltage converter) can generate a voltage between 1-2 volts and distribute that power to a plurality of electrolyzer cell stacks 140 in parallel. Each electrolyzer cell stack 140 includes a plurality of electrolytic cells, with each electrolytic cell having an electrolyte coupled to receive a solution (e.g., water) and two bipolar plates. The bipolar plates can be connected to the intermediate voltage converter 120. Each electrolyzer cell stack 140 outputs oxygen and hydrogen through the respective electrolytic cells. The rate of output depends on the power received by the bipolar plates of the electrolyzer cell stacks 140. In some cases, a higher power can generate oxygen and hydrogen at a faster rate, but this reduces durability of the system. On the other hand, a lower power can generate oxygen and hydrogen at a slower rate but increase durability of the system.

[0039] Each of the electrolyzer cell stacks 140 are coupled electrically in parallel to each other and to the intermediate voltage converter 120. A monitor control circuit 130 (e.g., a local monitor circuit) is associated with (and implemented by) each of the electrolyzer cell stacks 140. The monitor control circuit 130 collects parameters of the respective electrolyzer cell stacks 140 on an individual basis. For example, the monitor control circuit 130 associated with a first electrolyzer cell stack 140 implements an analog-to-digital converter (ADC) to measure voltages across various cell stack components to collect any one or combination of parameters, including voltage across one or more of the plurality of electrolytic cells, electro impedance spectroscopy (EIS), current, temperature, and gas or fluid flow. In some cases, the monitor control circuit 130 includes a processor that implements a model for the respective cell stack that predicts or determines performance of the cell stack and/or predicts or determines a failure of the cell stack. The monitor control circuit 130 can disable the associated cell stack in response to determining that the current parameters are indicative and associated with an upcoming failure of the cell stack.

[0040] **FIG. 2** is a block diagram of an example of an electrolyzer system 200, in accordance with various examples. The operation of electrolyzer system 200 is similar to that of electrolyzer system 100. Instead of delivering the same power and voltage to all of the electrolyzer cell stacks 140 in parallel, each electrolyzer cell stack 140 includes an independent power supply and monitor control circuit 210. Specifically, the intermediate voltage converter 120 provides a voltage between 10 and 50 volts to each of the independent power supply and monitor control circuits 210 in parallel. The independent power supply and monitor control circuit 210 then convert the voltage of 10 and 50 volts to an individual supply voltage between 1 and 2 volts for the given cell. In this way, one of the electrolyzer cell stacks 140 can receive and operate at a first voltage (e.g., 1 volt) while a second of the electrolyzer cell stacks 140 can receive and operate at a different second voltage (e.g., 2 volts).

[0041] According to this configuration, when the monitor control circuit 210 of a given electrolyzer cell stack 140 predicts, based on measured parameters of the given electrolyzer cell stack 140, that the given electrolyzer cell stack 140 is being operated under conditions associated with an upcoming failure, the independent power supply and monitor control circuit 210 of the electrolyzer cell stack 140 can reduce the power and voltage being delivered to the corresponding electrolyzer cell stack 140 to increase the durability and lifetime of the cell stack or to temporarily disable operation of the electrolyzer cell stack 140. At the same time, when a given electrolyzer cell stack 140 is predicted by the associated monitor control circuit 210 to have parameters that indicate or are associated with a low performance, the independent power supply and monitor control circuit 210 of the electrolyzer cell stack 140 can increase the power and voltage being delivered to the corresponding electrolyzer cell stack 140 to increase the performance without reducing the durability and lifetime of the electrolyzer cell stack 140.

[0042] **FIG. 3** is a block diagram of an example of an electrolyzer system 300, in accordance with various examples. Electrolyzer system 300 operates in a similar manner as electrolyzer systems 100 and 200. The electrolyzer system 300 includes a first electrolyzer stack 310 (which corresponds to one of the electrolyzer cell stacks 140) and includes a second electrolyzer stack 320 (which corresponds to a second one of the electrolyzer cell stacks 140). The second electrolyzer stack 320 and the first electrolyzer stack 310 are coupled in parallel to a common power (voltage/current) source 340 (corresponding to the intermediate voltage converter 120 and/or the main high-voltage distribution device 110).

[0043] The first electrolyzer stack 310 includes a first plurality of cells, such as electrolytic cell 312 and electrolytic cell 316. The second electrolyzer stack 320 includes a second plurality of cells, such as electrolytic cell 322 and electrolytic cell 332. The first electrolyzer stack 310 includes a first set of bypass switches 314 (e.g., a first bypass circuit). The first set of bypass switches 314 enable a control circuitry (e.g., monitor control circuit 130) to selectively bypass any one or more of the first plurality of cells of the first electrolyzer stack 310. For example, a first switch of the first set of bypass switches 314 can be enabled (closed), which causes electric current/voltage to be routed around an electrolytic cell associated with the first switch. In such cases, the current/voltage that is connected to a first bipolar plate of the electrolytic cell is shunted to a second bipolar plate of the electrolytic cell to avoid or prevent the current/voltage from passing through internal components (e.g., the solution) that are housed between the first and second bipolar plates. When the first switch of the first set of bypass switches 314 is disabled (open), the electric current/voltage is routed from the first bipolar plate of the electrolytic cell through components of the electrolytic cell to the second bipolar plate.

[0044] Similarly, second electrolyzer stack 320 includes a second set of bypass switches 324 (e.g., a second bypass circuit). The second set of bypass switches 324 enable the control circuitry (e.g., monitor control circuit 130) to selectively bypass any one or more of the second plurality of cells of the second electrolyzer stack 320. For example, a first switch of the second set of bypass switches 324 can be enabled (closed), which causes electric current/voltage to be routed around an electrolytic cell of the second electrolyzer stack 320 associated with the first switch. In such cases, the current/voltage that is connected to a first bipolar plate of the electrolytic cell is shunted to a second bipolar plate of the electrolytic cell to avoid or prevent the current/voltage from passing through internal components (e.g., the solution) that are housed between the first and second bipolar plates. When the first switch of the second set of bypass switches 324 is disabled (open), the electric current/voltage is routed from the first bipolar plate of the electrolytic cell through components of the electrolytic cell to the second bipolar plate.

[0045] The bypass circuitry can be implemented outside or external to the components of a given cell. The bypass circuitry can be configured to bypass the elements of the given cell when the switch is closed. This causes the given cell to be electrically removed from the series of cells of a particular electrolyzer stack because current is shunted from one bipolar plate to another of the cell. Several bypass circuitries can be associated, each with respect to a given one of the many cells of the electrolyzer. The bipolar plates can be circular or any suitable shape, such as rectangular or octangular in shape.

[0046] In some implementations, the bypass circuitry is integrated within each of the cells to avoid implementing or running physical wires around the cells. In such cases, the bipolar plates are extended to make room for the bypass circuitry. For example, the bypass circuitry can be disposed around the perimeter of the cell to avoid interfering with water and gas flow among the elements of the cell. The bypass circuitry can include a printed circuit board (PCB), system-on-chip, integrated circuit, or some other device on which a processing element is integrated. The PCB (processing element) is coupled to wiring, such as copper or other conductive metal. The PCB (processing element) controls whether current flows from one bipolar plate to another through the copper. Namely, when the PCB (processing element) closes a switch, the current flows from one bipolar plate to another through the copper and avoids flowing through other elements of the cell.

[0047] In some cases, multiple bypass circuitries can be disposed around the perimeter of the cell. This causes the current flowing between the bipolar plates to be divided among multiple bypass circuitries when the switches of the bypass circuitries are closed. In such cases, a first set of the bypass circuitries can be configured to allow a certain amount of current to flow between the bipolar plates while a remaining amount of current continues to flow through other elements of the cell. Specifically, there may be a given amount of current that is received by a given bipolar plate, and each bypass circuitry is only configured to allow flow of a maximum portion of current that is less than the total given amount of current that is received. In such cases, the total given amount of current is divided such that an amount equal to the maximum portion accumulated across the subset of bypass circuitries that are enabled (e.g., in which the switches are closed) flows directly between the bipolar plates while the remaining portion of the given amount of current flows through other elements of the cell. In this way, the cell can be partially removed from the series connection of cells.

[0048] In some examples, the control circuitry determines that the electrolytic cell 322 is a bad or failing electrolytic cell. This can be determined by comparing a set of performance criteria of the electrolytic cell 322 to one or more operating conditions. If the performance criteria matches or satisfies the operating conditions, the cell is good or not failing. If the performance criteria fails to match or satisfy the operation conditions, the cell is bad or failing. The first set of performance criteria can include at least one of pinhole formation, catalyst degradation or dissolution, PTL coating degradation, current through the first electrolytic cell, and/or bipolar plate degradation. The one or more operating conditions can include at least one of a pinhole formation threshold, maximum catalyst degradation or dissolution value, PTL coating degradation threshold, maximum current threshold, and/or a bipolar plate degradation threshold.

[0049] For example, the control circuitry can determine that the amount of current drawn by the electrolytic cell 322 transgresses a threshold, indicating that some of the current is being shunted across the cell. As another example, the control circuitry can determine that a pinhole formation across or associated with the electrolytic cell 322 transgresses a pinhole formation threshold (e.g., maximum allowable size). As another example, the control circuitry can determine that the catalyst degradation or dissolution associated with the electrolytic cell 322 transgresses a maximum catalyst degradation or dissolution value. As another example, the control circuitry can determine that the PTL coating degradation associated with the electrolytic cell 322 transgresses a PTL coating degradation threshold. As another example, the control circuitry can determine that the bipolar plate degradation associated with the electrolytic cell 322 transgresses a bipolar plate degradation threshold. Any other criteria can also be used in conjunction with or in the alternative to these criteria to determine that the electrolytic cell 322 is failing, such as age of the electrolytic cell 322.

[0050] In some examples, in response to determining that the electrolytic cell 322 is failing, the control circuitry can enable or close a switch of the second set of bypass switches 324 associated with the electrolytic cell 322. This causes the electrolytic cell 322 to be bypassed and removed from the second electrolyzer stack 320. In order to balance the output, age, current, and/or voltage associated with the second electrolyzer stack 320 relative to the first electrolyzer stack 310, the control circuitry can select a good cell, such as electrolytic cell 312 from the first electrolyzer stack 310, to also bypass. This way, the number of cells that are active and operating between the first electrolyzer stack 310 and the second electrolyzer stack 320 remain the same or balanced. For example, the control circuitry can enable or close a switch of the first set of bypass switches 314 associated with the electrolytic cell 312. This causes the electrolytic cell 312 to be bypassed and removed from the first electrolyzer stack 310 while the electrolytic cell 322 is also being bypassed.

[0051] In some examples, as discussed in more detail below in connection with FIG. 5, one or more adjacent cells 330 and/or 332 can be bypassed automatically when the electrolytic cell 322 is being bypassed. This can prevent leakage of current through pinholes of the electrolytic cell 322 while the electrolytic cell 322 is being bypassed. Namely, by preventing current from reaching any of the bipolar plates or certain bipolar plates of the failing cell (e.g., electrolytic cell 322), the current cannot leak through (e.g., shunted through) any portion of the electrolytic cell 322 while the electrolytic cell 322 is being bypassed.

[0052] The control circuitry can select the electrolytic cell 312 from the various cells of the first electrolyzer stack 310 based on various criteria. For example, the control circuitry can select the electrolytic cell 312 randomly from the various cells of the first electrolyzer stack 310. As another example, the control circuitry can select the first cell in the first electrolyzer stack 310 at a first point in time. After a specified period of time elapses (e.g., one hour, one day, one week, one month, and so forth), the control circuitry can select a different cell, such as electrolytic cell 316 to bypass from the first electrolyzer stack 310 instead of the electrolytic cell 312. This way, the electrolytic cell 316 can be bypassed while the electrolytic cell 322 is being bypassed instead of the electrolytic cell 312. The control circuitry can continue traversing the first electrolyzer stack 310 switching which good cells are being bypassed periodically until the last cell in the first electrolyzer stack 310 is bypassed. Then, the control circuitry can cycle back to bypassing the electrolytic cell 312 after the last cell is bypassed for the specified period of time.

[0053] As another example, the control circuitry can search through performance criteria of each of the cells of the first electrolyzer stack 310. The control circuitry can select the weakest good cell as the good cell to bypass together with bypassing the failing electrolytic cell 322. Namely, the control circuitry can select the good cell to bypass together with bypassing the failing electrolytic cell 322 based on the aging profile of the good cell. The good cell can also or alternatively be selected based on alignment across the stacks when bypassed as compared to other good cells.

[0054] In some examples, after the good cell is bypassed (e.g., after the electrolytic cell 312 is bypassed together with the electrolytic cell 322), the control circuitry can determine that the electrolytic cell 316 has begun to fail and is now a bad or failing cell. In response to determining that the electrolytic cell 316 has begun to fail and is now a bad or failing cell, the control circuitry can select electrolytic cell 316 to bypass from the first electrolyzer stack 310 instead of the electrolytic cell 312. This way, the electrolytic cell 316 can be bypassed as a failing cell while the electrolytic cell 322 is being bypassed instead of the electrolytic cell 312.

[0055] As shown in the diagram 400 of **FIG. 4,** the control circuitry can initially balance the first electrolyzer stack 310 and the second electrolyzer stack 320 by bypassing good cells 410 and 420 from each of the first electrolyzer stack 310 and the second electrolyzer stack 320. For example, the control circuitry can bypass a first good cell 410 of the first electrolyzer stack 310 and can bypass a second good cell 420 of the second electrolyzer stack 320. This can be done to balance the voltage and/or current being consumed and passed through the first electrolyzer stack 310 and the second electrolyzer stack 320.

[0056] The control circuitry, at some later point, can determine that the second electrolyzer stack 320 includes a failing cell 430. In such cases, the control circuitry can maintain the good cell 410 as being bypassed in the first electrolyzer stack 310. The control circuitry can switch from bypassing the good cell 420 in the second electrolyzer stack 320 to bypassing the failing cell 430. Specifically, operation of the electrolyzer may be initialized with one or more "good" cells bypassed in each stack. If a non-bypassed cell fails, that non-bypassed cell may now be bypassed while simultaneously removing the bypass of a "good" cell in the same stack. In this way, current balance between stacks is maintained while also maintaining the desired stack voltage.

[0057] As mentioned before, failure of individual cells within an electrolyzer stack can arise from a variety of mechanisms such as pinhole formation, catalyst degradation or dissolution, PTL coating degradation, bipolar plate degradation, and so forth. Routing the stack current around the defective cell through bypass switches or other equivalent mechanisms connected to the bipolar plates that sandwich the membrane electrode assembly (MEA) can allow stack operation to continue without having to replace stacks due to such failures.

[0058] Typically, when a cell develops a pinhole defect (or develops a thinned membrane with the potential to develop into a pinhole), continuing to operate the cell within the stack can result in continued pinhole growth and/or mixing of H2 and O2 in the outlet stream with potential risk of safety incidents. In such a scenario, a stack would ordinarily be taken offline and replaced unless bypassing capability was available for the defective cell to prevent safety incidents. Similarly, when cells develop defects such as catalyst degradation, PTL coating degradation, or bipolar plate degradation, the resulting decrease in cell efficiency can generate a positive feedback loop that can accelerate cell degradation, which eventually leads to stack failure. This can be prevented/delayed using bypassing capabilities to switch off the defective cell.

[0059] However, if the bypassed cell has an impedance similar to the bypass path at low voltages due to any internal cell/MEA defects, some shunt current may continue flowing through the cell. Depending on the defect type, this may lead to continued or accelerated cell degradation and possibly result in cell failure. Certain defects manifest as membrane shorts, which if left unchecked can lead to pinhole growth. If cell current is bypassed, the continued leakage current through the cell membrane short can cause resistive heating and further grow the pinhole, which can lead to safety incidents. In case of mechanical discontinuities in bipolar plates due to impurities/cracks, etc., shunt current path to switches may be much higher resistance or inaccessible leading to unsuccessful bypass of the single defective cell.

[0060] To address these challenges, as shown in diagrams 500 and 501 of FIG. **5,** the disclosed techniques bypass either one or both cells adjacent to the defective (failing) cell in addition to the defective cell itself to more completely and robustly prevent current flow within the cell. In a typical scenario, the electrical resistance provided by switches is a couple of orders of magnitude lower than the resistance of the bipolar plate, thus making the shunt current flow through the switch path, avoiding the defective cell including its bipolar plates. In some cases, an arbitrary number of cells adjacent to the defective cell may be used for effective bypass. This may be just one good cell adjacent to the defective cell or two or more good cells. In some cases, a stack level alternative to reduce switch related cost and to implement effective bypassing may include implementing switching mechanisms that bypass two or more good and bad cells at a time instead of allowing bypass at an individual cell level.

[0061] For example, as shown in diagram 500, a single electrolyzer stack (e.g., second electrolyzer stack 320) is shown that includes multiple cells 540, 520, 510, 530, and 546. The control circuitry can determine that the cell 510 is a bad cell that is failing and needs to be bypassed. In some cases, the control circuitry determines that the cell 510 is failing because of a certain type of defect, such as pinhole formation, that transgresses a threshold amount. In such cases, the control circuitry can select one or more good cells that are adjacent to the cell 510 that is failing to bypass in addition to the cell 510. For example, in addition to bypassing the failing cell 510, the control circuitry can bypass the good cell 520 that is adjacent on a first side (e.g., on top of) the failing cell 510 that is failing and/or the good cell 530 that is adjacent to the failing cell on a second side of the failing cell 510 (e.g., below the failing cell). The control circuitry can close a switch 522 to route current from the top bipolar plate 542 of the good cell 520 via another switch 524 to a bottom bipolar plate 544 of the good cell 530. This way, current passes through the good cell 540; bypasses cells 520, 510, and 530; and passes through the good cell 546.

[0062] In some cases, as shown in diagram 501, a single switch can be associated with multiple cells, such as cells 510 and 520. In such cases, rather than closing two switches 522 and 524 to route current around the cells 520 and 510, the single switch can be closed, which simultaneously bypasses the current around the cells 520 and 510. The single switch can be associated with any number or quantity of cells, such that when the single switch is closed or enabled all of the associated cells are simultaneously bypassed. In some cases, complexity/-design challenges of switches can be saved by having the switches across every two cells instead of (or in addition to) every cell of the multiple cells.

[0063] In some examples, a first quantity of good cells (e.g., two or more good cells) on a first side of the failing cell 510 can be bypassed by the control circuitry while a second quantity of good cells 530 (e.g., one or less) that are on a second side of the failing cell 510 are bypassed, as shown in diagram 501. This results in an uneven quantity of good cells on first and second sides of the failing cell being bypassed.

[0064] FIG. 6 is a flow diagram depicting example process or method 600 for operating or configuring an electrolyzer, in accordance with various examples. The operations of the process or method 600 may be performed in parallel or in a different sequence, or may be entirely omitted. In some examples, some or all of the operations of the process or method 600 may be embodied on a computer-readable medium and executed by one or more processors.

[0065] At operation 610, control circuitry determines that a first electrolytic cell in a first electrolyzer stack is associated with a first set of performance criteria that fails to satisfy one or more operating conditions, as discussed above.

[0066] At operation 610, control circuitry identifies a second electrolytic cell that is associated with a second set of performance criteria that satisfies the one or more operating conditions, as discussed above. The second electrolytic cell can be in the same stack of electrolytic cells as the first electrolytic cell or can be in a different stack than the first electrolytic cell which is in the vicinity of (e.g., within a threshold proximity of) the second electrolytic cell.

[0067] At operation 610, control circuitry bypasses the first electrolytic cell and the second electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions and based on identifying the second electrolytic cell that is associated with the second set of performance criteria that satisfies the one or more operating conditions, as discussed above.

[0068] **FIG. 7** is a block diagram of an example machine 700 upon which any one or more of the techniques (e.g., methodologies) discussed herein may be performed. In alternative examples, the machine 700 may operate as a standalone device or may be connected (e.g., networked) to other machines. In a networked deployment, the machine 700 may operate in the capacity of a server machine, a client machine, or both in server-client network environments. In an example, the machine 700 may act as a peer machine in a peer-to-peer (P2P) (or other distributed) network environment. The machine 700 may be a personal computer (PC), a tablet PC, a set-top box (STB), a personal digital assistant (PDA), a mobile telephone, a web appliance, an IoT device, an automotive system, an aerospace system, or any machine capable of executing instructions (sequential or otherwise) that specify actions to be taken by that machine. Further, while only a single machine is illustrated, the term "machine" shall also be taken to include any collection of machines that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein, such as via cloud computing, software as a service (SaaS), or other computer cluster configurations.

[0069] Examples, as described herein, may include, or may operate by, logic, components, devices, packages, or mechanisms. Circuitry is a collection (e.g., set) of circuits implemented in tangible entities that include hardware (e.g., simple circuits, gates, logic, etc.). Circuitry membership may be flexible over time and underlying hardware variability. Circuitries include members that may, alone or in combination, perform specific tasks when operating. In an example, hardware of the circuitry may be immutably designed to carry out a specific operation (e.g., hardwired). In an example, the hardware of the circuitry may include variably connected physical components (e.g., execution units, transistors, simple circuits, etc.) including a computer-readable medium physically modified (e.g., magnetically, electrically, by moveable placement of invariant-massed particles, etc.) to encode instructions of the specific operation. In connecting the physical components, the underlying electrical properties of a hardware constituent are changed, for example, from an insulator to a conductor or vice versa. The instructions enable participating hardware (e.g., the execution units or a loading mechanism) to create members of the circuitry in hardware via the variable connections to carry out portions of the specific tasks when in operation. Accordingly, the computer-readable medium is communicatively coupled to the other components of the circuitry when the device is operating. In an example, any of the physical components may be used in more than one member of more than one circuitry. For example, under operation, execution units may be used in a first circuit of a first circuitry at one point in time and reused by a second circuit in the first circuitry, or by a third circuit in a second circuitry, at a different time.

[0070] The machine (e.g., computer system) 700 may include a hardware processor 702 (e.g., a central processing unit (CPU), a graphics processing unit (GPU), a hardware processor core, or any combination thereof, such as a memory controller, etc.), a main memory 704, and a static memory 706, some or all of which may communicate with each other via an interlink (e.g., bus) 708. The machine 700 may further include a display device 710, an alphanumeric input device 712 (e.g., a keyboard), and a user interface (UI) navigation device 714 (e.g., a mouse). In an example, the display device 710, alphanumeric input device 712, and UI navigation device 714 may be a touchscreen display. The machine 700 may additionally include a storage device 722 (e.g., drive unit); a signal generation device 718 (e.g., a speaker); a network interface device 720; one or more sensors 716, such as a Global Positioning System (GPS) sensor, wing sensor, mechanical device sensor, temperature sensor, bridge sensor, audio sensor, industrial sensor, a compass, an accelerometer, or other sensors; and one or more electrolyzer stack(s) 790. The electrolyzer stack(s) 790 may implement some or all of the functionality of the electrolyzer systems, discussed above. The machine 700 may include an output controller 728, such as a serial (e.g., universal serial bus (USB)), parallel, or other wired or wireless (e.g., infrared (IR), near field communication (NFC), etc.) connection to communicate with or control one or more peripheral devices (e.g., a printer, card reader, etc.).

[0071] The storage device 722 may include a machine-readable medium on which is stored one or more sets of data structures or instructions 724 (e.g., software) embodying or utilized by any one or more of the techniques or functions described herein. The instructions 724 may also reside, completely or at least partially, within the main memory 704, within the static memory 706, or within the hardware processor 702 during execution thereof by the machine 700. In an example, one or any combination of the hardware processor 702, the main memory 704, the static memory 706, or the storage device 722 may constitute the machine-readable medium.

[0072] While the machine-readable medium is illustrated as a single medium, the term "machine-readable medium" may include a single medium or multiple media (e.g., a centralized or distributed database, or associated caches and servers) configured to store the one or more instructions 724.

[0073] The term "machine-readable medium" may include any transitory or non-transitory medium that is capable of storing, encoding, or carrying transitory or non-transitory instructions for execution by the machine 700 and that cause the machine 700 to perform any one or more of the techniques of the present disclosure, or that is capable of storing, encoding, or carrying data structures used by or associated with such instructions. Non-limiting machine-readable medium examples may include solid-state memories and optical and magnetic media. In an example, a massed machine-readable medium comprises a machine-readable medium with a plurality of particles having invariant (e.g., rest) mass. Accordingly, massed machine-readable media are not transitory propagating signals. Specific examples of massed machine-readable media may include non-volatile memory, such as semiconductor memory devices (e.g., Electrically Programmable Read-Only Memory (EPROM), Electrically Erasable Programmable Read-Only Memory (EEPROM)) and flash memory devices; magnetic disks, such as internal hard disks and removable disks; magnetooptical disks; and CD-ROM and DVD-ROM disks.

[0074] The instructions 724 (e.g., software, programs, an operating system (OS), etc.) or other data that are stored on the storage device 721 can be accessed by the main memory 704 for use by the hardware processor 702. The main memory 704 (e.g., DRAM) is typically fast, but volatile, and thus a different type of storage from the storage device 721 (e.g., an SSD), which is suitable for longterm storage, including while in an "off" condition. The instructions 724 or data in use by a user or the machine 700 are typically loaded in the main memory 704 for use by the hardware processor 702. When the main memory 704 is full, virtual space from the storage device 721 can be allocated to supplement the main memory 704; however, because the storage device 721 is typically slower than the main memory 704, and write speeds are typically at least twice as slow as read speeds, use of virtual memory can greatly reduce user experience due to storage device latency (in contrast to the main memory 704, e.g., DRAM). Further, use of the storage device 721 for virtual memory can greatly reduce the usable lifespan of the storage device 721.

[0075] The instructions 724 may further be transmitted or received over a communications network 726 using a transmission medium via the network interface device 720 utilizing any one of a number of transfer protocols (e.g., frame relay, internet protocol (IP), transmission control protocol (TCP), user datagram protocol (UDP), hypertext transfer protocol (HTTP), etc.). Example communication networks may include a local area network (LAN), a wide area network (WAN), a packet data network (e.g., the Internet), mobile telephone networks (e.g., cellular networks), Plain Old Telephone Service (POTS) networks, and wireless data networks (e.g., Institute of Electrical and Electronics Engineers (IEEE) 802.11 family of standards known as Wi-Fi®, IEEE 802.16 family of standards known as WiMax®, IEEE 802.15.4 family of standards, P2P networks), among others. In an example, the network interface device 720 may include one or more physical jacks (e.g., Ethernet, coaxial, or phone jacks) or one or more antennas to connect to the communications network 726. In an example, the network interface device 720 may include a plurality of antennas to wirelessly communicate using at least one of single-input multiple-output (SIMO), multiple-input multiple-output (MIMO), or multiple-input single-output (MISO) techniques. The term "transmission medium" shall be taken to include any tangible or intangible medium that is capable of storing, encoding, or carrying instructions for execution by the machine 700, and includes digital or analog communications signals or other tangible or intangible media to facilitate communication of such software.

[0076] Each of the non-limiting aspects or examples described herein may stand on its own, or may be combined in various permutations or combinations with one or more of the other examples.

[0077] The above detailed description includes references to the accompanying drawings, which form a part of the detailed description. The drawings show, by way of illustration, specific examples in which the inventive subject matter may be practiced. These examples are also referred to herein as "examples." Such examples may include elements in addition to those shown or described. However, the present inventors also contemplate examples in which only those elements shown or described are provided. Moreover, the present inventors also contemplate examples using any combination or permutation of those elements shown or described (or one or more aspects thereof), either with respect to a particular example (or one or more aspects thereof), or with respect to other examples (or one or more aspects thereof) shown or described herein.

[0078] In the event of inconsistent usages between this document and any documents so incorporated by reference, the usage in this document controls.

[0079] In this document, the terms "a" or "an" are used, as is common in patent documents, to include one or more than one, independent of any other instances or usages of "at least one" or "one or more." In this document, the term "or" is used to refer to a nonexclusive or, such that "A or B" includes "A but not B," "B but not A," and "A and B," unless otherwise indicated. In this document, the terms "including" and "in which" are used as the plain-English equivalents of the respective terms "comprising" and "wherein." Also, in the following aspects, the terms "including" and "comprising" are open-ended; that is, a system, device, article, composition, formulation, or process that includes elements in addition to those listed after such a term in an aspect are still deemed to fall within the scope of that aspect. Moreover, in the following aspects, the terms "first," "second," "third," and so forth are used merely as labels and are not intended to impose numerical requirements on their objects.

[0080] Method examples described herein may be machine- or computerimplemented at least in part. Some examples may include a computer-readable medium or machine-readable medium encoded with transitory or non-transitory instructions operable to configure an electronic device to perform methods as described in the above examples. An implementation of such methods may include code, such as microcode, assembly-language code, a higher-level-language code, or the like. Such code may include transitory or non-transitory computer-readable instructions for performing various methods. The code may form portions of computer program products. Further, in an example, the code may be tangibly stored on one or more volatile, non-transitory, or non-volatile tangible computer-readable media, such as during execution or at other times. Examples of these tangible computer-readable media may include, but are not limited to, hard disks, removable magnetic disks, removable optical disks (e.g., compact discs and digital video discs), magnetic cassettes, memory cards or sticks, random access memories (RAMs), read-only memories (ROMs), and the like.

[0081] The above description is intended to be illustrative, and not restrictive. For example, the above-described examples (or one or more aspects thereof) may be used in combination with each other. Other examples may be used, such as by one of ordinary skill in the art upon reviewing the above description. It is submitted with the understanding that it will not be used to interpret or limit the scope or meaning of the claims. Also, in the above detailed description, various features may be grouped together to streamline the disclosure. This should not be interpreted as intending that a disclosed feature not listed in the list of claims is essential to any aspect. Rather, inventive subject matter may lie in less than all features of a particular disclosed example. Thus, the following aspects are hereby incorporated into the detailed description as examples or examples, with each claim standing on its own as a separate example, and it is contemplated that such examples may be combined with each other in various combinations or permutations. The scope of the inventive subject matter should be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

[0082] There follows a list of numbered features defining particular embodiments of the present disclosure. Where a numbered feature refers to one or more earlier numbered features then those features should be considered together in combination.

1. A system comprising:

    a first electrolyzer stack comprising a first plurality of electrolytic cells; and
    control circuitry coupled to the first electrolyzer stack and configured to perform operations comprising:

        determining that a first electrolytic cell in the first electrolyzer stack is associated with a first set of performance criteria that fails to satisfy one or more operating conditions;
        determining that a second electrolytic cell is associated with a second set of performance criteria that satisfies the one or more operating conditions; and
        bypassing the first electrolytic cell and the second electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions and based on determining that the second electrolytic cell is associated with the second set of performance criteria that satisfies the one or more operating conditions.

2. The system of feature 1, wherein the second electrolytic cell is in the first electrolyzer stack and is adjacent to the first electrolytic cell on a first side of the first electrolytic cell.

3. The system of feature 2, wherein the operations further comprise:
identifying a third electrolytic cell in the first electrolyzer stack that is adjacent to the first electrolytic cell on a second side of the first electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions.

4. The system of feature 3, wherein the operations further comprise:

    determining that the third electrolytic cell is associated with a third set of performance criteria that satisfies the one or more operating conditions; and
    bypassing the third electrolytic cell along with the first electrolytic cell and the second electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions and based on identifying the third electrolytic cell in the first electrolyzer stack that is adjacent to the first electrolytic cell on a second side of the first electrolytic cell.

5. The system of any of features 2 to 4, wherein the operations further comprise:
bypassing multiple adjacent electrolytic cells along with the first electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance

criteria that fails to satisfy the one or more operating conditions, the multiple adjacent electrolytic cells being on a same side relative to the first electrolytic cell and being associated with respective sets of performance criteria that satisfies the one or more operating conditions.

6. The system of any of features 2 to 5, wherein the operations for bypassing the first electrolytic cell and the second electrolytic cell comprise closing a single switch that is associated with the first electrolytic cell for routing current from a first bipolar plate of the second electrolytic cell around a second bipolar plate of the first electrolytic cell to a third bipolar plate of the first electrolytic cell, the single switch preventing current from passing through an individual bipolar plate of the second electrolytic cell to the second bipolar plate when the single switch is closed.

7. The system of any of the preceding features, further comprising:
a second electrolyzer stack comprising a second plurality of electrolytic cells coupled to the control circuitry, the second plurality of electrolytic cells comprising the second electrolytic cell, and the first electrolyzer stack being electrically coupled in parallel with the second electrolyzer stack.

8. The system of feature 7, wherein the operations further comprise:
determining that the first electrolyzer stack is aging at a different rate from the second electrolyzer stack, wherein the first electrolytic cell and the second electrolytic cell are bypassed to balance aging across the first and second electrolyzer stacks.

9. The system of feature 7 or 8, wherein the operations further comprise:
determining that the first electrolyzer stack is associated with a different amount of current or voltage from the second electrolyzer stack, wherein the first electrolytic cell and the second electrolytic cell are bypassed to balance current or voltage across the first and second electrolyzer stacks.

10. The system of any of features 7 to 9, wherein the operations further comprise:

> determining that the second electrolytic cell has been bypassed with the first electrolytic cell for a threshold period of time; and
> in response to determining that the second electrolytic cell has been bypassed with the first electrolytic cell for the threshold period of time:
>
> > identifying a third electrolytic cell in the second electrolyzer stack that is associated with a third set of performance criteria that satisfies the one or more operating conditions; and
> > bypassing the third electrolytic cell instead of the second electrolytic cell to bypass the first electrolytic cell and the third electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions.

11. The system of any of features 7 to 10, wherein the operations further comprise:
selecting the second electrolytic cell from the second plurality of electrolytic cells of the second electrolyzer stack to bypass based on one or more cell selection criteria.

12. The system of feature 11, wherein the one or more cell selection criteria comprises at least one of voltage or current associated with the second electrolytic cell relative to voltage or current of other electrolytic cells, an alignment property associated with the first and second electrolyzer stacks, or an aging profile of the second electrolytic cell.

13. The system of any of features 7 to 12, wherein the operations further comprise:

> determining that a third electrolytic cell of the second plurality of electrolytic cells of the second electrolyzer stack is associated with a third set of performance criteria that fails to satisfy the one or more operating conditions; and
> in response to determining that the third electrolytic cell of the second plurality of electrolytic cells of the second electrolyzer stack is associated with the third set of performance criteria that fails to satisfy the one or more operating conditions:
> bypassing the third electrolytic cell instead of the second electrolytic cell to bypass the first electrolytic cell and the third electrolytic cell.

14. The system of any of features 7 to13, wherein the operations further comprise:

> initializing operation of the first and second electrolyzer stacks by bypassing a first good electrolytic cell of the first electrolyzer stack and bypassing a second good electrolytic cell of the second electrolyzer stack;
> after initializing operation of the first and second electrolyzer stacks, determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy one or more operating conditions; and

replacing bypass of the first good electrolytic cell of the first electrolyzer stack with bypass of the first electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy one or more operating conditions while maintaining bypass of the second good electrolytic cell of the second electrolyzer stack.

15. The system of any of features 1 to 14, wherein the first set of performance criteria comprises at least one of pinhole formation, catalyst degradation or dissolution, porous transport layer (PTL) coating degradation, current through the first electrolytic cell, or bipolar plate degradation; and
wherein the one or more operating conditions comprise at least one of a pinhole formation threshold, maximum catalyst degradation or dissolution value, porous transport layer (PTL) coating degradation threshold, maximum current threshold, or a bipolar plate degradation threshold.

16. A method comprising:

determining that a first electrolytic cell in a first electrolyzer stack is associated with a first set of performance criteria that fails to satisfy one or more operating conditions;
identifying a second electrolytic cell that is associated with a second set of performance criteria that satisfies the one or more operating conditions; and
bypassing the first electrolytic cell and the second electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions and based on identifying the second electrolytic cell that is associated with the second set of performance criteria that satisfies the one or more operating conditions.

17. The method of feature 16, wherein the second electrolytic cell is in the first electrolyzer stack and is adjacent to the first electrolytic cell on a first side of the first electrolytic cell.

18. The method of feature 17, further comprising: identifying a third electrolytic cell in the first electrolyzer stack that is adjacent to the first electrolytic cell on a second side of the first electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions.

19. An apparatus comprising:

means for determining that a first electrolytic cell in a first electrolyzer stack is associated with a first set of performance criteria that fails to satisfy one or more operating conditions;
means for identifying a second electrolytic cell that is associated with a second set of performance criteria that satisfies the one or more operating conditions; and
means for bypassing the first electrolytic cell and the second electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions and based on identifying the second electrolytic cell that is associated with the second set of performance criteria that satisfies the one or more operating conditions.

20. The apparatus of feature 19, wherein the second electrolytic cell is in the first electrolyzer stack and is adjacent to the first electrolytic cell on a first side of the first electrolytic cell.

Claims

1. A system comprising:

a first electrolyzer stack comprising a first plurality of electrolytic cells; and
control circuitry coupled to the first electrolyzer stack and configured to perform operations comprising:

determining that a first electrolytic cell in the first electrolyzer stack is associated with a first set of performance criteria that fails to satisfy one or more operating conditions;
determining that a second electrolytic cell is associated with a second set of performance criteria that satisfies the one or more operating conditions; and
bypassing the first electrolytic cell and the second electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions and based on determining that the second electrolytic cell is associated with the second set of performance criteria that satisfies the one or more operating conditions.

2. The system of claim 1, wherein the second electrolytic cell is in the first electrolyzer stack and is adjacent to the first electrolytic cell on a first side of the first electrolytic cell.

3. The system of claim 2, wherein the operations further comprise:

identifying a third electrolytic cell in the first electrolyzer stack that is adjacent to the first electrolytic cell on a second side of the first electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions;
wherein the operations optionally further comprise:

a) determining that the third electrolytic cell is associated with a third set of performance criteria that satisfies the one or more operating conditions; and
b) bypassing the third electrolytic cell along with the first electrolytic cell and the second electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions and based on identifying the third electrolytic cell in the first electrolyzer stack that is adjacent to the first electrolytic cell on a second side of the first electrolytic cell.

4. The system of any of claims 2 or 3, wherein the operations further comprise:
bypassing multiple adjacent electrolytic cells along with the first electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions, the multiple adjacent electrolytic cells being on a same side relative to the first electrolytic cell and being associated with respective sets of performance criteria that satisfies the one or more operating conditions.

5. The system of any of claims 2 to 4, wherein the operations for bypassing the first electrolytic cell and the second electrolytic cell comprise closing a single switch that is associated with the first electrolytic cell for routing current from a first bipolar plate of the second electrolytic cell around a second bipolar plate of the first electrolytic cell to a third bipolar plate of the first electrolytic cell, the single switch preventing current from passing through an individual bipolar plate of the second electrolytic cell to the second bipolar plate when the single switch is closed.

6. The system of any of the preceding claims, further comprising:
a second electrolyzer stack comprising a second plurality of electrolytic cells coupled to the control circuitry, the second plurality of electrolytic cells comprising the second electrolytic cell, and the first electrolyzer stack being electrically coupled in parallel with the second electrolyzer stack.

7. The system of claim 6, wherein the operations further comprise one or more of:

a) determining that the first electrolyzer stack is aging at a different rate from the second electrolyzer stack, wherein the first electrolytic cell and the second electrolytic cell are bypassed to balance aging across the first and second electrolyzer stacks; and/or
b) determining that the first electrolyzer stack is associated with a different amount of current or voltage from the second electrolyzer stack, wherein the first electrolytic cell and the second electrolytic cell are bypassed to balance current or voltage across the first and second electrolyzer stacks.

8. The system of any of claims 6 or 7, wherein the operations further comprise:

determining that the second electrolytic cell has been bypassed with the first electrolytic cell for a threshold period of time; and
in response to determining that the second electrolytic cell has been bypassed with the first electrolytic cell for the threshold period of time:

identifying a third electrolytic cell in the second electrolyzer stack that is associated with a third set of performance criteria that satisfies the one or more operating conditions; and
bypassing the third electrolytic cell instead of the second electrolytic cell to bypass the first electrolytic cell and the third electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions.

9. The system of any of claims 6 to 8, wherein the operations further comprise:

selecting the second electrolytic cell from the second plurality of electrolytic cells of the second electrolyzer stack to bypass based on one or more cell selection criteria;
wherein optionally the one or more cell selection

criteria comprises at least one of voltage or current associated with the second electrolytic cell relative to voltage or current of other electrolytic cells, an alignment property associated with the first and second electrolyzer stacks, or an aging profile of the second electrolytic cell.

10. The system of any of claims 6 to 9, wherein the operations further comprise:

determining that a third electrolytic cell of the second plurality of electrolytic cells of the second electrolyzer stack is associated with a third set of performance criteria that fails to satisfy the one or more operating conditions; and
in response to determining that the third electrolytic cell of the second plurality of electrolytic cells of the second electrolyzer stack is associated with the third set of performance criteria that fails to satisfy the one or more operating conditions:
bypassing the third electrolytic cell instead of the second electrolytic cell to bypass the first electrolytic cell and the third electrolytic cell.

11. The system of any of claims 6 to 10, wherein the operations further comprise:

initializing operation of the first and second electrolyzer stacks by bypassing a first good electrolytic cell of the first electrolyzer stack and bypassing a second good electrolytic cell of the second electrolyzer stack;
after initializing operation of the first and second electrolyzer stacks, determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy one or more operating conditions; and
replacing bypass of the first good electrolytic cell of the first electrolyzer stack with bypass of the first electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy one or more operating conditions while maintaining bypass of the second good electrolytic cell of the second electrolyzer stack.

12. The system of any of claims 1 to 11, wherein the first set of performance criteria comprises at least one of pinhole formation, catalyst degradation or dissolution, porous transport layer (PTL) coating degradation, current through the first electrolytic cell, or bipolar plate degradation; and
wherein the one or more operating conditions comprise at least one of a pinhole formation threshold, maximum catalyst degradation or dissolution value, porous transport layer (PTL) coating degradation threshold, maximum current threshold, or a bipolar plate degradation threshold.

13. A method comprising:

determining that a first electrolytic cell in a first electrolyzer stack is associated with a first set of performance criteria that fails to satisfy one or more operating conditions;
identifying a second electrolytic cell that is associated with a second set of performance criteria that satisfies the one or more operating conditions; and
bypassing the first electrolytic cell and the second electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions and based on identifying the second electrolytic cell that is associated with the second set of performance criteria that satisfies the one or more operating conditions.

14. The method of claim 13, wherein the second electrolytic cell is in the first electrolyzer stack and is adjacent to the first electrolytic cell on a first side of the first electrolytic cell.

15. The method of claim 14, further comprising:
identifying a third electrolytic cell in the first electrolyzer stack that is adjacent to the first electrolytic cell on a second side of the first electrolytic cell in response to determining that the first electrolytic cell in the first electrolyzer stack is associated with the first set of performance criteria that fails to satisfy the one or more operating conditions.

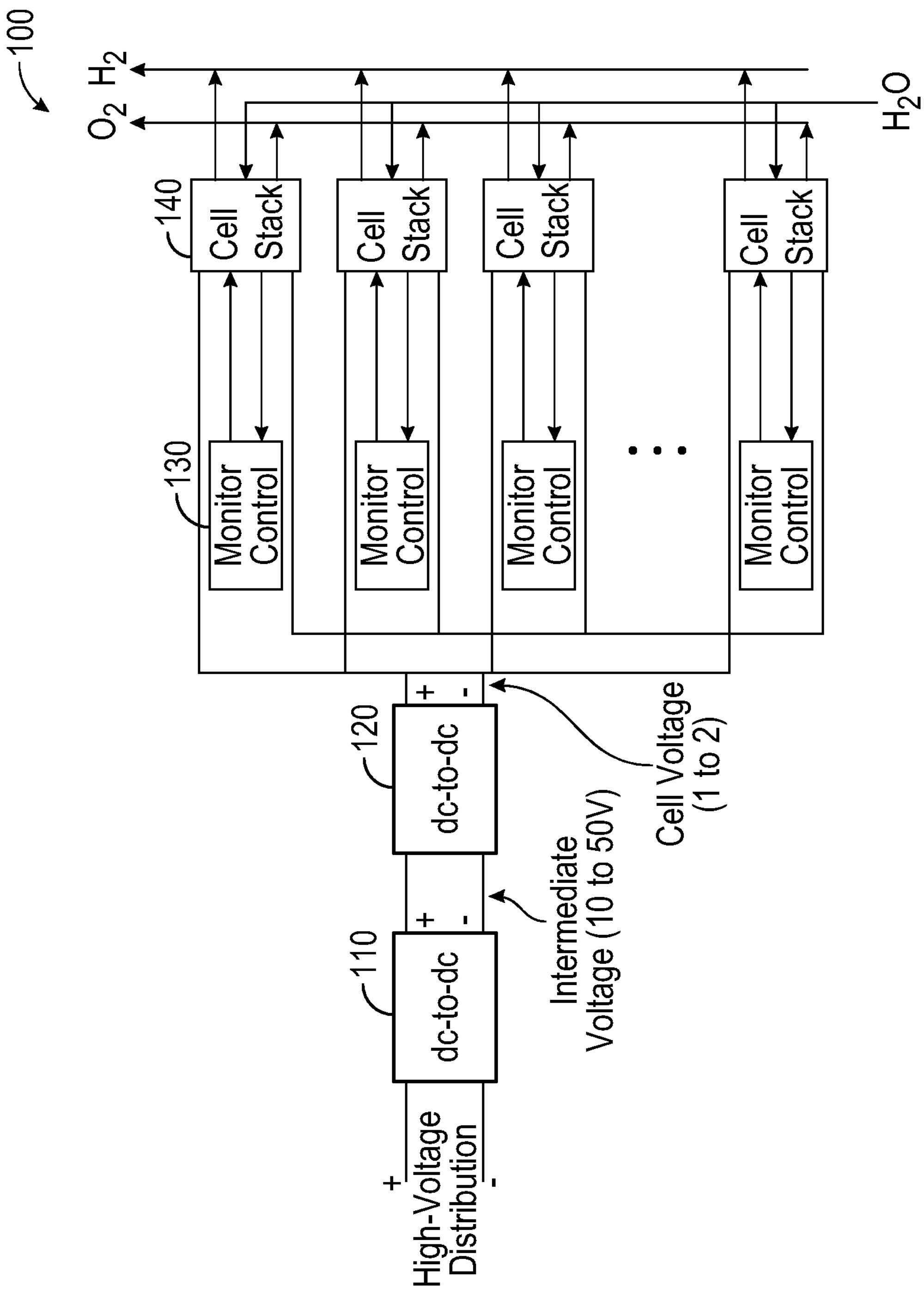
100
O2
H2
H2O
140
Cell Stack
Cell Stack
Cell Stack
Cell Stack
130
Monitor Control
Monitor Control
Monitor Control
Monitor Control
120
dc-to-dc
110
dc-to-dc
High-Voltage Distribution
Intermediate Voltage (10 to 50V)
Cell Voltage (1 to 2)

FIG. 1

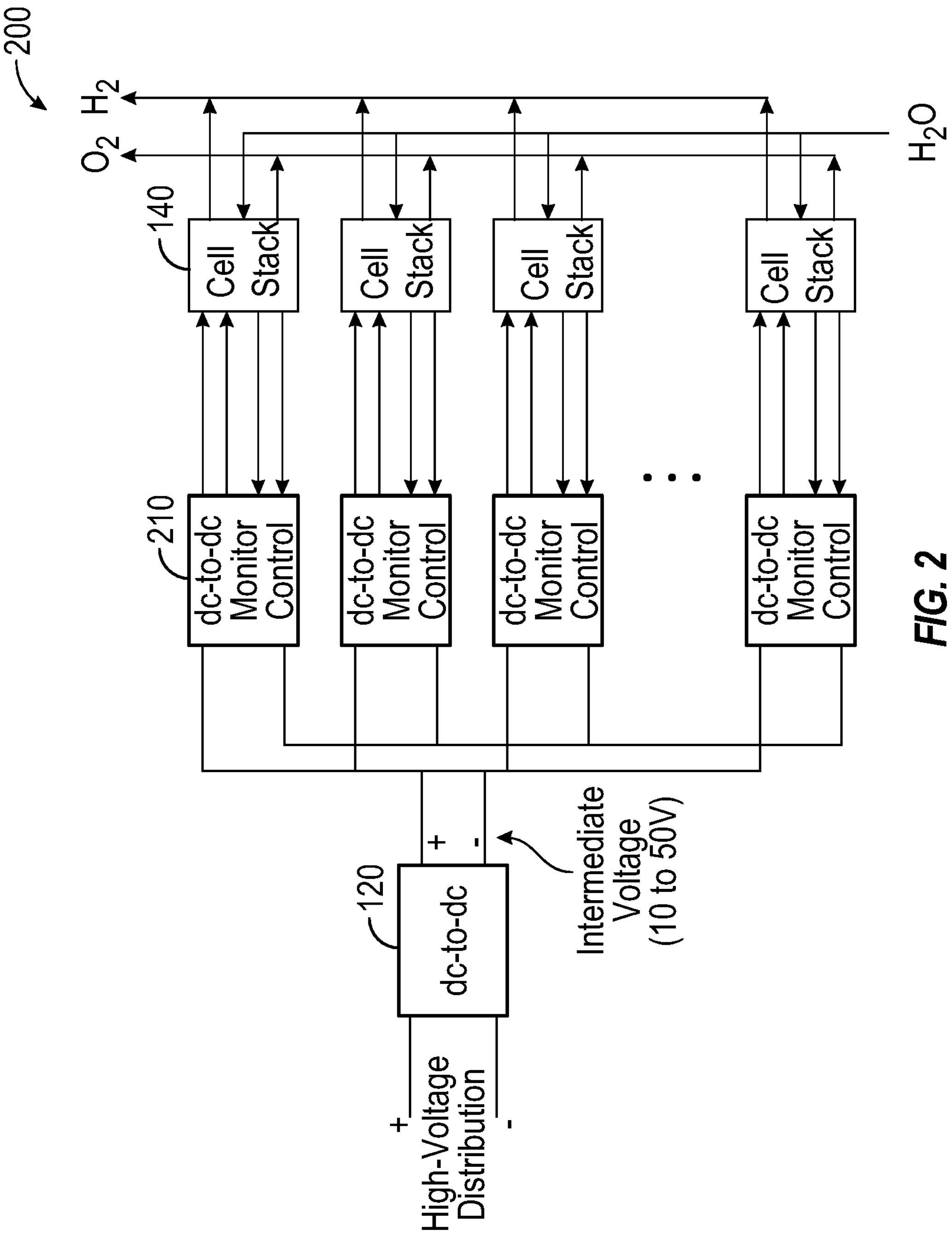
200
H_2
O_2
H_2O
140
Cell Stack
210
dc-to-dc Monitor Control
120
dc-to-dc
+
-
Intermediate Voltage (10 to 50V)
High-Voltage Distribution

FIG. 2

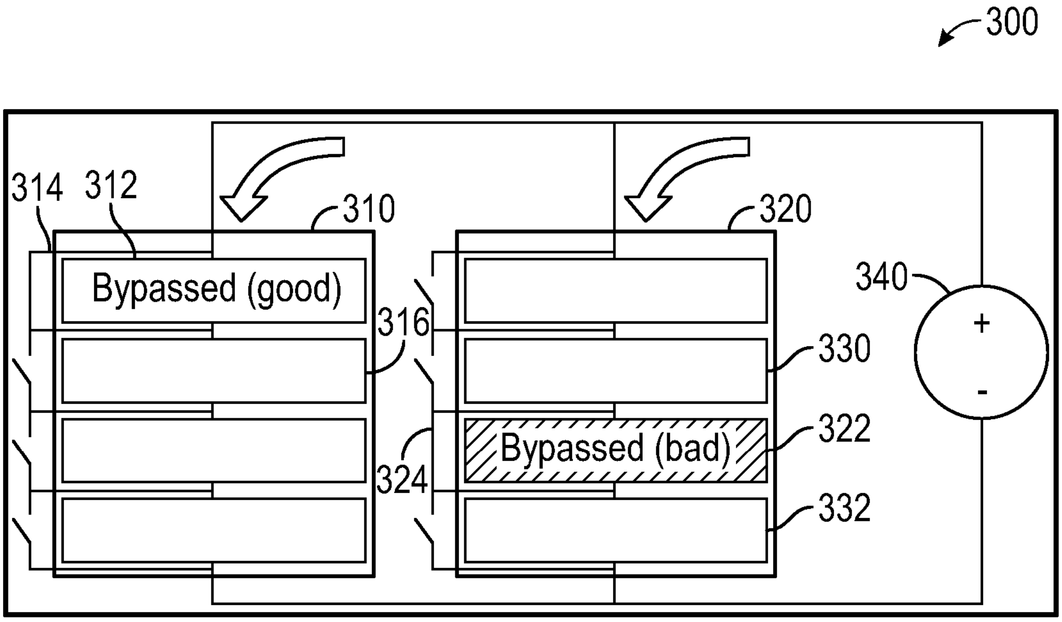
300
314
312
310
320
Bypassed (good)
316
340
+
-
330
Bypassed (bad)
322
324
332

FIG. 3

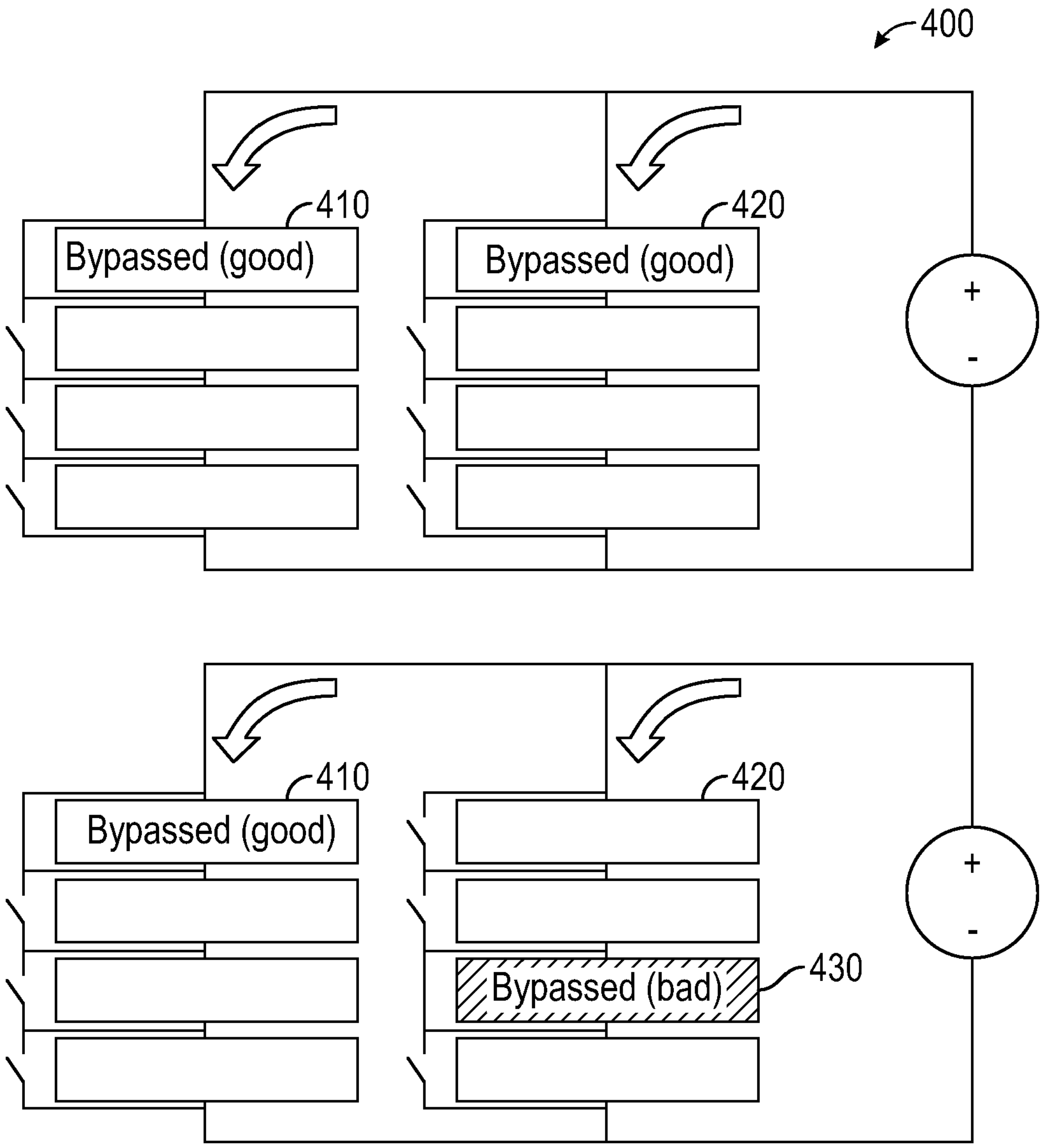
400
410
Bypassed (good)
420
Bypassed (good)
+
-
410
Bypassed (good)
420
Bypassed (bad)
430
+
-

FIG. 4

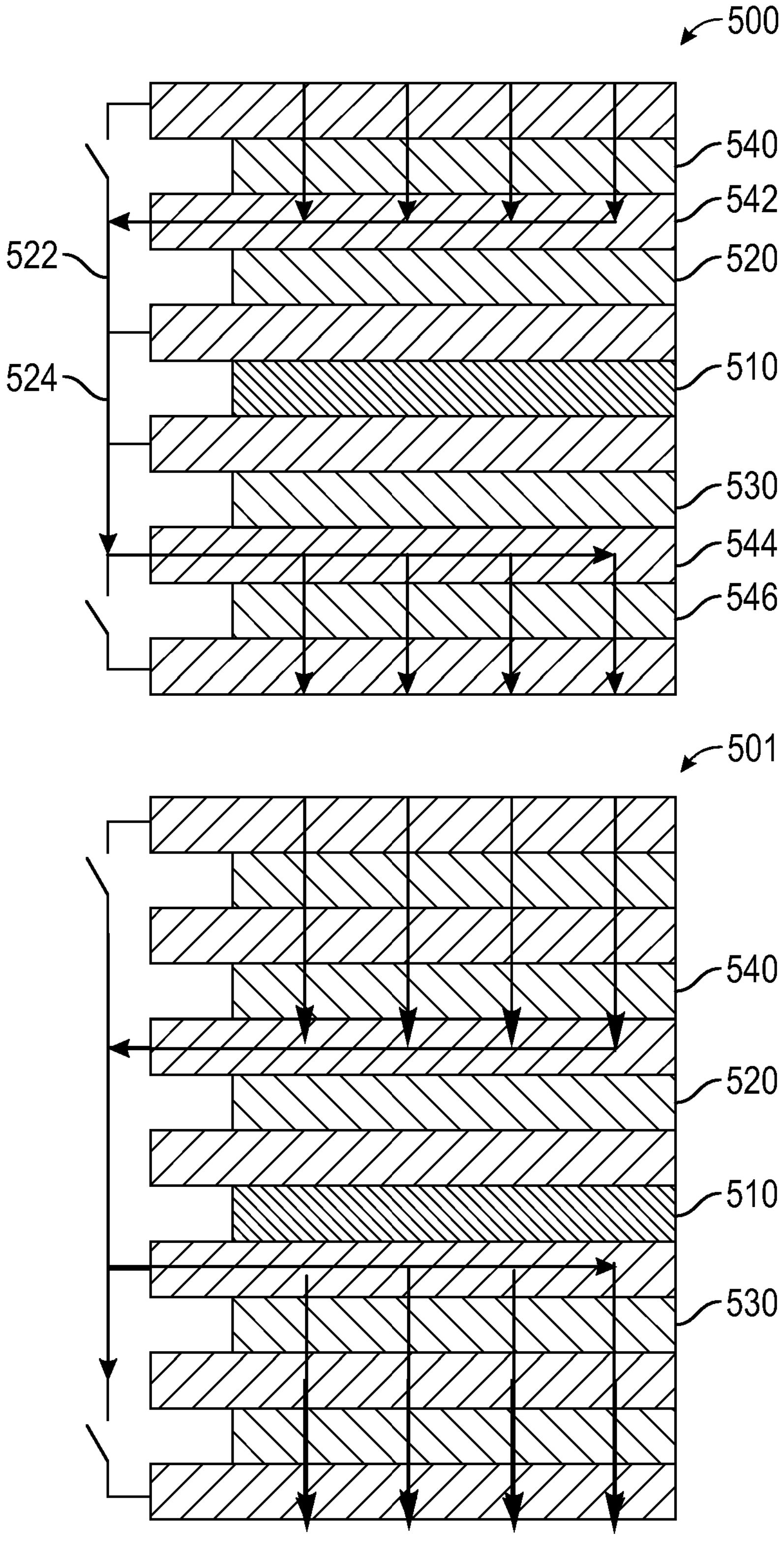

FIG. 5

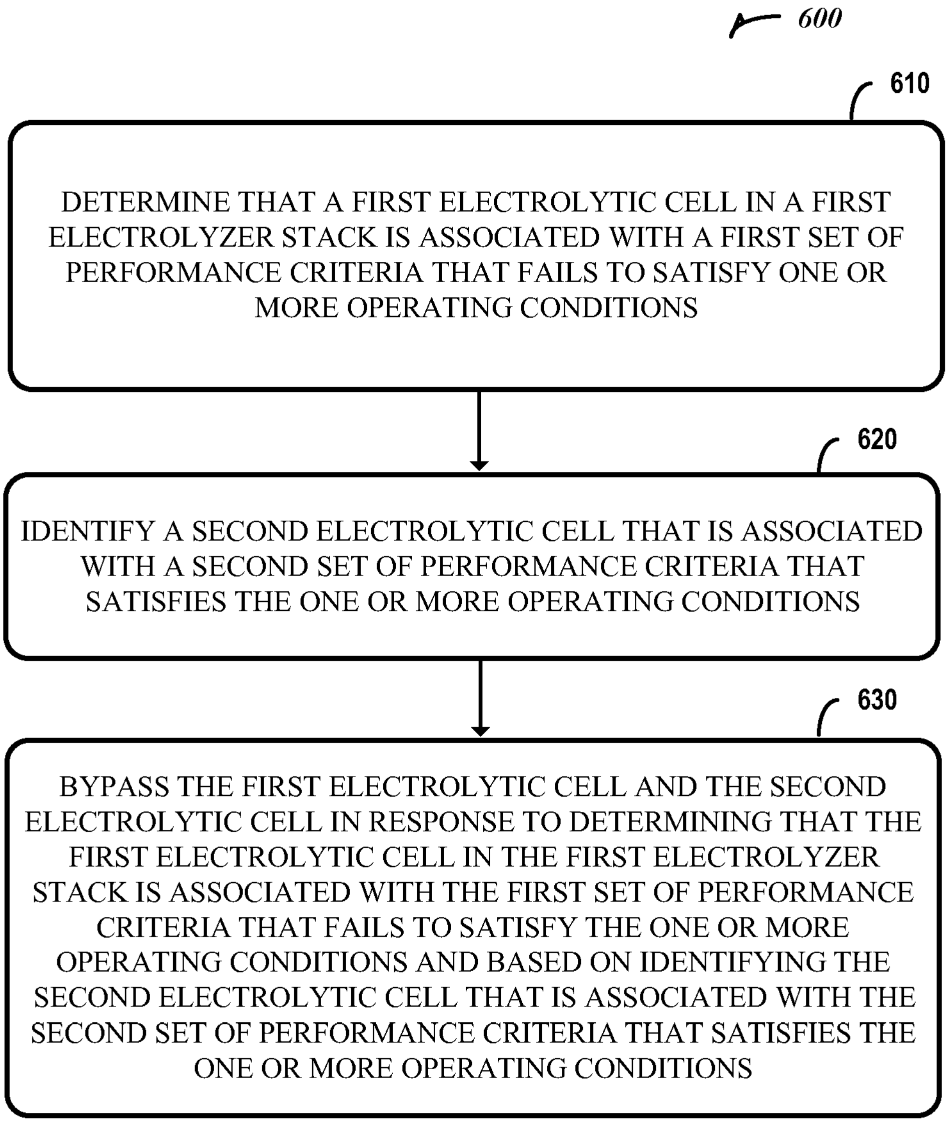
600
610
DETERMINE THAT A FIRST ELECTROLYTIC CELL IN A FIRST ELECTROLYZER STACK IS ASSOCIATED WITH A FIRST SET OF PERFORMANCE CRITERIA THAT FAILS TO SATISFY ONE OR MORE OPERATING CONDITIONS
620
IDENTIFY A SECOND ELECTROLYTIC CELL THAT IS ASSOCIATED WITH A SECOND SET OF PERFORMANCE CRITERIA THAT SATISFIES THE ONE OR MORE OPERATING CONDITIONS
630
BYPASS THE FIRST ELECTROLYTIC CELL AND THE SECOND ELECTROLYTIC CELL IN RESPONSE TO DETERMINING THAT THE FIRST ELECTROLYTIC CELL IN THE FIRST ELECTROLYZER STACK IS ASSOCIATED WITH THE FIRST SET OF PERFORMANCE CRITERIA THAT FAILS TO SATISFY THE ONE OR MORE OPERATING CONDITIONS AND BASED ON IDENTIFYING THE SECOND ELECTROLYTIC CELL THAT IS ASSOCIATED WITH THE SECOND SET OF PERFORMANCE CRITERIA THAT SATISFIES THE ONE OR MORE OPERATING CONDITIONS

FIG. 6

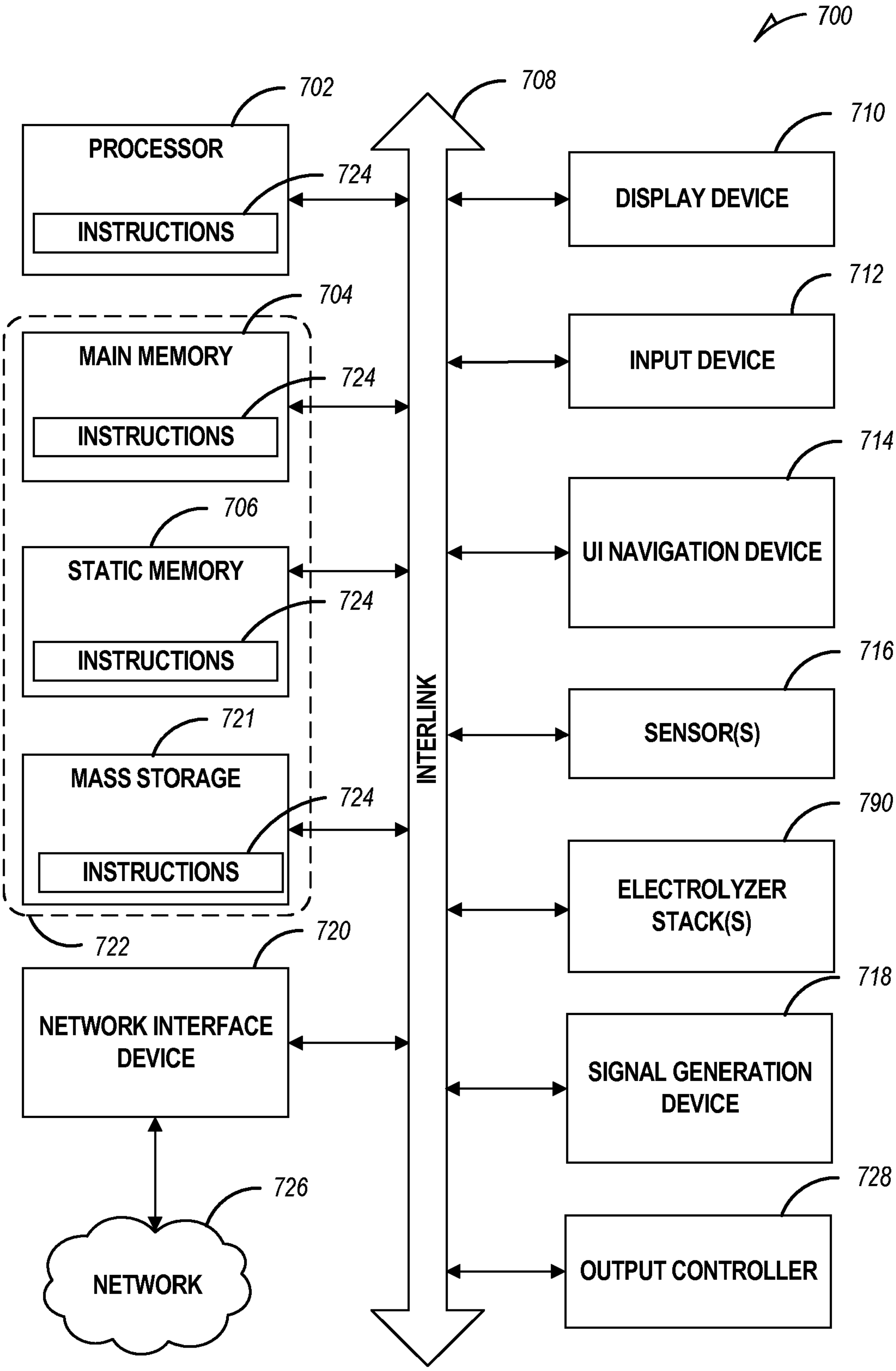
700
702
PROCESSOR
INSTRUCTIONS
724
708
710
DISPLAY DEVICE
704
MAIN MEMORY
INSTRUCTIONS
724
712
INPUT DEVICE
714
UI NAVIGATION DEVICE
706
STATIC MEMORY
INSTRUCTIONS
724
INTERLINK
716
SENSOR(S)
721
MASS STORAGE
INSTRUCTIONS
724
790
ELECTROLYZER STACK(S)
722
720
NETWORK INTERFACE DEVICE
718
SIGNAL GENERATION DEVICE
726
NETWORK
728
OUTPUT CONTROLLER

FIG. 7