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Systems and circuits for connecting components of a hydrogen plant to a power source

Abstract

The present disclosure relates to circuits for connecting components of a hydrogen plant to a power grid to power the components in an efficient manner. In one implementation, power-side alternate current (AC) to direct current (DC) converters may be connected to a source power grid without the need for an isolation transformer by providing separate buses between the power-side AC-DC converters and load-side DC-DC converters instead of a shared DC bus between the converters. Other implementations for connecting components of a hydrogen plant to a power grid may include an adjustable transformer, such as a tappable transformer or an autotransformer, to connect any number of auxiliary loads of the plant to the power grid. The adjustable transformer may provide for various types of auxiliary load devices to connect to the power provided by the transformer at the same time, including both three-phase devices and one-phase devices.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION (1) This application is related to and claims priority under 35 U.S.C. § 119(e) from U.S. Patent Application No. 63/416,290, filed Oct. 14, 2022, titled "Systems and Circuits for Electrical Balance of Components of a Hydrogen Plant," the entire contents of which is incorporated herein by reference for all purposes.

FIELD OF THE DISCLOSURE
(1) The present disclosure relates to systems and methods for controlling hydrogen generation, and more specifically for systems and circuits for connecting components to one or more power sources.
BACKGROUND
(2) Hydrogen is a common gas that has many industrial uses, such as petroleum refining, metal treatment, food processing, and ammonia production. Although hydrogen is abundant and can be formed from a variety of renewable and non-renewable energy sources, the combustibility of hydrogen in air makes hydrogen difficult to store and ship. As a result, hydrogen is generally not amenable to large-scale production at a centralized facility for subsequent distribution across large geographical regions. Rather, hydrogen is generally used at or near the site of its production. Thus, many hydrogen producing plants consume the input resources, such as renewable power sources and nonrenewable power sources, that are available at the location or site of production. In many instances, this results in powering the components of the hydrogen from a local power grid.
SUMMARY
(3) One aspect of the present disclosure relates to a hydrogen-generating plant comprising a plurality of alternate current (AC) to direct current (DC) converters each comprising an input in electrical communication with a power source and an output, each of the plurality of AC-DC converters converting an AC power signal from the power source to a DC power signal and a plurality of DC-DC converters each comprising an input in electrical connection to at least one of the plurality of AC-DC converters and an output in electrical communication with a load. A first subset of the plurality of DC-DC converters is connected in parallel to an output of a first AC-DC converter and a second, distinct subset of the plurality of DC-DC converters is connected in parallel to an output of a second AC-DC converter to electrically isolate the first AC-DC converter from the second AC-DC converter.
(4) Another aspect of the present disclosure relates to a method for operating a hydrogen generator.

The method may include the operations of electrically connecting a plurality of alternate current (AC) to direct current (DC) converters to a power source, electrically connecting a first subset of a plurality of DC-DC converters between an output of a first AC-DC converter of the plurality of AC-DC converters and a load circuit, the first subset of the plurality of DC-DC converters in parallel to each other, and electrically connecting a second subset of the plurality of DC-DC converters between an output of a second AC-DC converter of the plurality of AC-DC converters and the load circuit, the second subset of the plurality of DC-DC converters in parallel to each other. The method may electrically isolate the first AC-DC converter from the second AC-DC converter.
(5) Some aspects of the present disclosure relate to the plurality of AC-DC converters comprising non-isolated, bi-directional AC-DC converters, the plurality of DC-DC converters comprising isolated, uni-directional DC-DC converters, and/or the load comprising an electro-chemical load, such as at least one electrolyzer.
(6) Some aspects of the present disclosure relate to the power source being one of a grid power source or a renewable power source.
(7) Still some aspects of the present disclosure relate to a transformer comprising a primary winding in electrical communication with the power source and a secondary winding in electrical communication with one or more auxiliary loads. The transformer may be an adjustable transformer comprising one or more taps on the primary winding or the secondary winding to adjust a windings ratio of the transformer. In some other aspects, the transformer may be a solid-state transformer.
(8) In some aspects of the present disclosure, the one or more auxiliary loads comprise three-phase loads and single-phase loads and/or the transformer may be configured to provide power to the three-phase loads and single-phase loads. An uninterruptible power supply may also be in electrical communication with the one or more auxiliary loads.

Description

BRIEF DESCRIPTION OF THE FIGURES
(1) The foregoing and other objects, features, and advantages of the present disclosure set forth herein should be apparent from the following description of particular embodiments of those inventive concepts, as illustrated in the accompanying drawings. The drawings depict only typical embodiments of the present disclosure and, therefore, are not to be considered limiting in scope.
(2) FIG. **1** shows an exemplary environment for hydrogen production according to aspects of the present disclosure.
(3) FIG. **2**A shows a first exemplary circuit for connecting hydrogen plant components to a power grid according to aspects of the present disclosure.
(4) FIG. **2**B shows a second exemplary circuit for connecting hydrogen plant components to a power grid according to aspects of the present disclosure.
(5) FIG. **3** shows an exemplary circuit for connecting auxiliary load components of a hydrogen plant to a power grid according to aspects of the present disclosure.
DETAILED DESCRIPTION
(6) Various embodiments of the disclosure are discussed in detail below. While specific implementations are discussed, it should be understood that this is done for illustration purposes only. A person skilled in the relevant art will recognize that other components and configurations may be used without parting from the spirit and scope of the disclosure. Thus, the following description and drawings are illustrative and are not to be construed as limiting. Numerous specific details are described to provide a thorough understanding of the disclosure. However, in certain instances, well-known or conventional details are not described in order to avoid obscuring the

description.

(7) Reference to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the disclosure. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment, nor are separate or alternative embodiments mutually exclusive of other embodiments. Moreover, various features are described which may be exhibited by some embodiments and not by others. Thus, references to one or an embodiment in the present disclosure can be references to the same embodiment or any embodiment; and such references mean at least one of the embodiments.

(8) The terms used in this specification generally have their ordinary meanings in the art, within the context of the disclosure, and in the specific context where each term is used. Alternative language and synonyms may be used for any one or more of the terms discussed herein, and no special significance should be placed upon whether or not a term is elaborated or discussed herein. In some cases, synonyms for certain terms are provided. A recital of one or more synonyms does not exclude the use of other synonyms. The use of examples anywhere in this specification including examples of any terms discussed herein is illustrative only and is not intended to further limit the scope and meaning of the disclosure or of any example term. Likewise, the disclosure is not limited to various embodiments given in this specification.

(9) Additional features and advantages of the disclosure will be set forth in the description which follows, and in part will be obvious from the description, or can be learned by practice of the herein disclosed principles. The features and advantages of the disclosure can be realized and obtained by means of the instruments and combinations particularly pointed out in the appended claims. These and other features of the disclosure will become more fully apparent from the following description and appended claims or can be learned by the practice of the principles set forth herein.

(10) Described herein are systems and circuits for connecting components of a hydrogen plant to a power grid to power the components in an efficient manner. In one implementation, power-side alternate current (AC) to direct current (DC) converters may be connected to a source power grid without the need for an isolation transformer by providing separate buses between the power-side AC-DC converters and load-side DC-DC converters instead of a shared DC bus between the converters. By separating the DC-DC converters of the grid interface circuit among the power-side AC-DC converters, isolation of the power-side converters may be maintained while providing the necessary power signal to the load. Such a configuration is an improvement over previous circuits as an isolation transformer may be a very large and expensive component of the circuit, thereby improving the efficiency and cost of connecting the hydrogen plant components to the power grid by separating the output of the power-side converters to an isolated subset of the load-side converters.

(11) Other implementations for connecting components of a hydrogen plant to a power grid may include an adjustable transformer, such as a tappable transformer or an autotransformer, to connect any number of auxiliary loads of the plant to the power grid. The adjustable transformer may provide for various types of auxiliary load devices to connect to the grid at the same time, including both three-phase devices and one-phase devices. Also, the hydrogen plant may not be dependent on the neutral/auxiliary power support. Rather, single-phase loads or devices can be fed by the local neutral created using the (tappable) transformer/autotransformer. For example, the hydrogen plant may be located in various locations around the world and connect to a power grid that is local to the site. However, due to the (tappable) transformer, the auxiliary loads can be powered with any grid voltage. Changes to a grid voltage or main power architecture will also not demand changes to the circuit downstream of the transformer. As such, installation of the hydrogen plant can be easily adopted to wide grid networks, as the isolated secondary windings of the transformer gives the flexibility to have a grounding mechanism, as per the local grid codes or designer choice.

(12) FIG. **1** shows an exemplary environment **100** for hydrogen production according to aspects of

the present disclosure. The environment **100** may include more or fewer components than illustrated in FIG. **1**, which is included to provide context for the operations and configurations of the plant modeling tool described herein. Additional components and/or configurations of the hydrogen production environment **100** are described in greater detail below.
(13) The environment **100** may include a hydrogen plant **106** designed and configured to generate hydrogen. The hydrogen plant **106** may include a system housed in a container, outdoor-rated cabinets, or multiple systems contained within a plant site. In one implementation, the hydrogen plant **106** may be a clean hydrogen facility. Such clean hydrogen facility installations are at the early stages of the industry with a significant market growth projection that may scale to much larger production capacity and higher integration adaptation to the upstream and downstream required configurations over time.
(14) Often, clean hydrogen facilities **106** generate hydrogen through a process known as electrolysis. In general, electrolysis (i.e., in the context of zero-carbon production of hydrogen) is a rapidly growing and enabling technology that provides a preferable and sustainable alternative to fossil fuels and the resulting environmentally harmful CO.sub.2 emissions. Electrolysis is the process of using electricity to split water into hydrogen and oxygen, with this reaction taking place in a unit called an “electrolyzer” **108**. Through the electrolysis process, the electrolyzer **108** creates hydrogen gas. Most electrolyzers **108** include an anode and a cathode separated by an electrolyte in the presence of water. As energy, such as a direct-current (DC) power, is applied, the water molecules react at the anode to form oxygen and positively charged hydrogen ions. The hydrogen ions flow through the electrolyte to the cathode to bond with electrons and form hydrogen gas. The leftover oxygen may be released into the atmosphere or can be captured or stored to supply other industrial processes or even medical gases, in some cases. The hydrogen gas can either be stored as a compressed gas or liquefied, and since hydrogen is an energy carrier, it can be used to power such hydrogen fuel cell electric applications as trains, buses, trucks, or data centers. In some instances, the generated hydrogen may be provided to one or more downstream industrial plants **112** for asset production, such as steel, cement, oil, fertilizer, and the like. In one example, liquefied hydrogen may be piped to a downstream industrial plant **112** or carried by tanker. In another example, hydrogen gas may be provided to one or more downstream industrial plants **112**.
(15) Electrolyzers **108** can range in size from small equipment, well-suited for modest-scale distributed hydrogen production to large-scale, central production facilities, capable of being sequenced directly to renewable or other non-greenhouse-gas-emitting forms of electricity production. Electrolyzers **108** offer a route to produce clean hydrogen to power hydrogen fuel cells, supply industrial processes or produce green chemicals like fertilizers, renewable natural gas, and methanol. Some electrolyzers **108** may be configured through a connection of various electrolytic cells, with each cell comprising a small electrolyzer. This configuration is sometimes referred to as an electrolyzer stack. In one implementation, the electrolyzer stack may include the multiple cells connected in series in a bipolar design, although other configurations are possible.
(16) As should be appreciated, the hydrogen plant **106** may utilize several input resources **110** for generation of hydrogen. For example, various forms of energy sources (grid electricity, natural gas, wind, solar, hydro, etc.) may be provided to the hydrogen facility **106** for use by the components of the plant. Other input resources **110**, such as water for use by the electrolyzer **108** may also be provided to the hydrogen plant **106** for producing hydrogen.
(17) Once a hydrogen plant **106** is built, control over the various components, systems, programs, and/or sensors of the plant may be executed through a site controller **114**. For example, a Supervisory Control and Data Acquisition (SCADA) control system may be integrated with the hydrogen plant **106** to monitor plant conditions and/or control various aspects or parameters of the components of the plant. In one particular instance, a sensor may be associated with a pipe containing gas generated from the electrolysis process to measure to pressure within the pipe. The sensor may provide readings or measurements to the site controller **114** which may, in response,

adjust one or more valves within the gas piping system to adjust the pressure within the piping system. In general, any adjustable aspect or parameter of the hydrogen plant, the components within the plant, input resources **110**, sensors, executable program associated with the plant, or any other aspect of the hydrogen plant **106** may be adjustable by the site controller **114**. In some instances, the site controller **114** may also include an interface through which a plant operator may access components of the plant **106** and make one or more adjustments to the components. In another instance, the site controller **114** may be configured to automatically adjust the parameters or aspects of the hydrogen plant **106** based on inputs from one or more sensors or any other source of operational data of the plant.

(18) The environment **100** may also, in some instances, include a remote monitoring system **102** that communicates with the hydrogen plant **106** through a network **104** connection. In one example, the remote monitoring system **102** may be in communication with the electrolyzer **108** to monitor one or more operational states of the electrolyzer and adjust one or more parameters of the electrolyzer accordingly. The network **104** connects the remote monitoring system **102** to one or more communication interface devices of the hydrogen plant **106** and may be configured to transmit and/or receive information between the remote monitoring system and other devices by way of one or more wired or wireless communication networks or connections. Examples of such networks or connections include, without limitation, wireline communication over serial or Ethernet in copper or fiber medium or wireless communication over USB, Wi-Fi, Bluetooth, Zigbee mesh network, or a cellular wireless network. One or more such communication interface devices may be utilized to communicate with the remote monitoring system **102** and/or the hydrogen plant **106**, either directly over a point-to-point communication path, over a wide area network (WAN) (e.g., the Internet), over a local area network (LAN), over a cellular (e.g., third generation (3G), fourth generation (4G), fifth generation (5G)) network, or over another communication means.

(19) As mentioned above, one of the input resources **110** provided to the hydrogen plant **106** may be some type of power source, such as a nonrenewable power source (e.g., a power grid connection) or a renewable power source (e.g., solar or wind power sources). FIG. **2**A shows a first exemplary circuit for connecting hydrogen plant components to a power grid according to aspects of the present disclosure. In general, the components of the hydrogen plant **106** are represented in FIG. **2**A as the load **202**. Thus, the load **202** may include some or all of the components of the hydrogen plant **106**, including the electrolyzer stack **108**. In other implementations, the load **202** may not be associated with a hydrogen plant specifically, but may be any electro-chemical load that receives constant current and/or constant voltage. For the hydrogen plant **106** example, the plant may connect to a power grid **204** (represented as 3-phase grid in FIG. **2**A) to power the components of the plant. In one implementation, the power grid **204** may provide an alternating current (AC) power signal, such as a three-phase AC signal. Many components of the load **202**, however, may require a direct current (DC) power signal. Thus, a series of converter devices may be connected between the power source **204** and the load **202** to provide a DC power signal, among other advantages.

(20) In the implementation illustrated in FIG. **2**A, one or more AC-DC converters **206** (also referred to herein as “power source converters”) may be connected to power source **204** through an isolation transformer **208**. The purpose of the isolation transformer **208** is discussed in more detail below. The number of power source converters **206** may vary depending on the power requirements of the load **202**. The power source converters **206** may be connected in parallel such that the such that the inputs to the AC-DC converters are connected through the isolation transformer **208** and the outputs are connected through an intermediate DC bus **212**. The outputs of the power source converters **206** may connect, through the intermediate DC bus **212**, to one or more DC-DC converters **210** (also referred to herein as “load-side converters”). The DC-DC converters **210** may also be connected in parallel such that each input is connected to the intermediate DC bus **212** and

the output of each DC-DC connects to the load **202**. In one implementation, the power source converters **206** may include one or more non-isolated, bidirectional, AC-DC converters. In the same or other implementation, the load-side converters **210** may include one or more isolated, unidirectional DC-DC converters. Other types of converters are contemplated for use in the circuit **200** in the same or different configurations.

(21) As mentioned, the power source converters **206** connect to the power grid **204** via isolation transformer **208**. In one implementation, the isolation transformer **208** may include a primary winding **214** in electrical communication to receive the power signal from the grid **204** and two secondary windings **216** in electrical communication with the two power source converters **206**. In general, one concern for parallel connected power source converters **206** is that current may circulate between the units. For example, when the power source converters **206** share an input and an output connection, current from a first power source converter **218** may be provided to a second power source converter **220**, and vice versa, such that current may circulate between the connected converters. To limit the circulating current between the power source converters **220**, additional passive components may be included in the circuit **200**, such as large filter inductors and/or current sharing inductors. However, in cases in which the power converter ratings of the power source converters **206** are large, these solutions become more inefficient, due to high cost for the components and the potential power loss. Also, circulating currents may be more pronounced in some circumstances due to lower filter inductors, along with low switching frequency operation demanded by power devices and converters. Further, hard switch parallel operating in which the converters are paralleled may require derating due to nonlinear and parasitic effects that creates differences in the current sharing. To address these inefficiencies, some circuits may include isolation among the converters, which is typically added at the input side. For example, circuit **200** includes isolation transformer **208** to provide isolation at the input side to the power source converters **206**. The power frequency isolation transformer **208** enables use of a large number of power source AC/DC converters **206** with a common output, such as intermediate DC bus **212**. The isolated converters **206** may be treated as each unit delivering power to the load **202** without having any implication on other power source converters **206** connected to the same output **212**.

(22) In some circumstances, isolation of the power source converters **206** may be avoided. For example, the use of high-frequency isolated DC-DC converters **210** to provide high currents to the load **202** may be used to avoid the problems associated with paralleling of the AC-DC power source converters **206**. FIG. **2**B shows a first exemplary circuit **250** for connecting hydrogen plant components to a power grid according to aspects of the present disclosure. Many of the components of the circuit **250** of FIG. **2**B are the same as described above, such as the grid power source **204** and the load **202**. Also similar to above, the power source **204** may be connected to one or more power source converters **252**, which may be non-isolated bidirectional AC-DC converters. One or more load-side converters **256** may also be connected between the power source converters **252** and the load **202**. In one particular implementation, the load-side converters **256** may be isolated bidirectional DC-DC converters. In this circuit **250**, however, the output of the power source converters **252** may not be connected by the intermediate DC bus **254**. Rather, the output of the power source converters **252** may be isolated while providing the required power signal to the load-side converters **256**.

(23) In this configuration, the load-side converters **256** may be divided between the power source converters **252** such that the output from each power source converter is provided to a subset of the load-side converters. For example, power source converter **258** may provide the converted power signal to load-side converters **264**, while power source converter **260** may provide the converted power signal to load-side converters **262**. In this manner, the output of the power source converters **252** may not be shared on a common intermediate DC bus, but are instead connected to one or more load-side converters **256** over separate intermediate DC buses **254**. Through the use of the separate DC buses **254** to provide the converted power signal to the load-side converters **256**,

isolation of the power source converters **252** is maintained without the need of an isolation transformer. Rather, each of the power source converters **252** may connect directly to the power grid **204**. This configuration is an improvement over previous circuits as the isolation transformer may be a very large and expensive component of the circuit, improving the efficiency and cost of connecting the hydrogen plant components to the power grid **204** by separating the output of the power source converters **252** to a subset of the load-side converters **256**.

(24) In addition, the configuration of circuit **250** may be scaled based on the power requirements of the components of the hydrogen plant, without dependency on the isolation transformer **208**. For example, assume a power rating of the load-side DC-DC converters **256** of P.sub.DC-DC and a number (n) of such converters in each block. Also assume a power rating of the power source AC-DC converters **252** of P.sub.AC-DC and a number (m) of such converters. For example, in the circuit **250** of FIG. **2**B, n=2 as each converter block includes two DC-DC load-side converters to one AC-DC power source converter. In this case, P.sub.AC-DC>=n*P.sub.DC-DC.

(25) The number m of power source converters **252** needed for a circuit may be calculated based on the required load power. For example, for a power rating of the load at P.sub.LOAD, the number of AC-DC power source converters **252** may be based on the equation m=P.sub.LOAD/P.sub.AC-DC. Thus, for an application of 300 kW power delivery and assuming the number of load-side converters **256** is two per power source converter, seven AC-DC power source converters **252** may be utilized in the circuit. For an application of 400 kW power delivery and again assuming the number of load-side converters **256** is two per power source converter, nine AC-DC power source converters **252** may be utilized in the circuit. In this manner, the configuration of power source converters **252** is highly scalable based on the power rating requirement of the load **202** to adjust to all types of loads and components of the hydrogen plant.

(26) Other components of the hydrogen plant **106** may also connect to the grid power but not require the high current or voltage of the load **202** discussed above. For example, one or more auxiliary loads (such as pumps, fans, telemetry devices etc.) may be used within the hydrogen plant **106** and powered from the power grid **204**. However, such auxiliary components may be decoupled from the main load (plant load **202**) and the large power converters discussed above. Decoupling the auxiliary components from the large power converters provides a more efficient manner to power such devices. FIG. **3** shows an exemplary circuit **300** for connecting auxiliary load components **312** of a hydrogen plant to a power grid according to aspects of the present disclosure. In general, auxiliary load devices **312** may require lower current and/or voltage to operate compared to the plant load devices **202**. However, the auxiliary load devices **312** may require three-phase power or one-phase power. Thus, the circuit **300** of FIG. **3** may include one or more components to provide power in three-phases or in one-phase power. In addition, the circuit **300** may include components that provides for connection to various types of grid power **204**. For example, the hydrogen plant **106** discussed above may be located in various locations around the world and connect to a power grid that is local to the site. Power grids around the world provide different levels of power, such as the United States providing a 120 volt AC power signal, several European countries providing a 230 volt AC power signal, and Japan providing a 100 volt AC power signal. Thus, the components of the connection circuit **300** of FIG. **3** may be selected and/or configured such that connection may be made to various types of power grids.

(27) The circuit **300** may include several components described above, such as a connection to a power grid **204**, one or more AC-DC converters **206**, one or more DC-DC converters **210**, and a plant load **202**, which may include one or more electrolyzer devices. In addition, one or more auxiliary load devices **312** may receive power from the power grid **204**. To provide a power signal to the auxiliary loads **312** with the flexibility to connect to various types of grid power signals, a transformer **304** may connect to the power grid **204**. In one implementation, the transformer **304** may be a tappable transformer, such as an isolation or auto-type transformer, that is configurable for the various grid sources to bring the grid voltage level to a suitable range for the auxiliary loads

312. For example, the tappable transformer **304** may include a mechanism to allow for variable turn ratios to be selected, perhaps through a mechanical switching device. Other examples may utilize an automatic system to adjust the turns ratio of the transformer **304**, with fixed and/or multiple taps. The tap changer may connect to any number of access points on the transformer, either along the primary or secondary side, to adjust the turns ratio of the device and the transformation of the input power signal to the output power signal. In other implementations, the transformer **304** may have fixed primary and/or secondary windings with isolation or have adjustable taps on one or both windings. In another implementation, the transformer **304** may be a solid-state transformer comprising one or more power electronic components which provide the same functionality of the tappable transformer described above. Such a solid-state transformer may include high-frequency isolation. Further, the transformer **304** may be configured to provide output power from the transformer **304** on each of the three-phases of the power signal for power to each of the auxiliary load devices **312**. In one particular implementation, the transformer **304** may connect to the power grid **204** over a three-wire connection and output a four-wire connection.

(28) In addition to powering the auxiliary loads **312** from the local power grid **204**, the circuit **300** may include components to ensure power to the devices if grid power is lost. In particular, the circuit **300** may include an uninterruptible power supply (UPS) **306** connected to the auxiliary loads **312** that may store and provide power to the auxiliary loads when needed. The UPS **306** may receive the stored power from the transformer **304** and/or a battery **308** connected to the UPS, in some instances. In other implementations, the UPS **306** may be connected to a continuous generator (such as a fuel cell generator, a photovoltaic generator, a piston-type engine generator, etc.) may be connected in parallel to or instead of the battery **308** to provide power to the UPS. A bypass switch (not shown) may be included that alternately connects the auxiliary loads **312** to the transformer **304** or the UPS **306** based on a desired source of power. In general, the UPS **306** operates in a stand-by mode until loss of power from the grid source **204** is detected. Upon detection, the switch **310** may be opened and power is provided to the auxiliary loads **312** from the UPS **306**. In this manner, power may continually be provided to the auxiliary loads **312**, even during a power loss of the grid source **204** or shutdown of the other components of the hydrogen plant.

(29) The components of the circuit **300** of FIG. **3** may provide power to the auxiliary loads **312** and allow them to operate without the grid power **204** for reasons such as data logging, freeze protection, hazard mitigation, and the like. The auxiliary leg of the circuit **300** provides the necessary power to the auxiliary loads **312** outside of the 5×-10× larger scale of the plant load **202** power. Further, a right-sizing and design of the power channels for their different needs improves the efficiency of the circuit **300**. For example, providing the UPS **306** downstream of the transformer **304** provides fault tolerance functionality to the circuit.

(30) As mentioned above, the circuit **300** may operate to provide power on each phase of the power signal. This allows for various types of auxiliary load devices **312** to connect to the power provided by the transformer **304**, such as three-phase devices or one-phase devices. Further, these lower voltage devices may comprise high frequency, high efficiency configurations to improve the operation of the circuit **300** and hydrogen plant **106** in general. In one implementation, the devices of the circuit **300** may include Gallium Nitride (GaN)-type components and designs to improve the functionality of the circuit **300**. In this manner, the overall hydrogen plant does not depend on the neutral/auxiliary power support. Rather, single-phase loads or devices can be fed by the local neutral created using the (tappable) transformer/autotransformer **304**. Further, due to the (tappable) transformer **304**, auxiliary load **312** can work with any grid voltage. Changes to a grid voltage or main power architecture will not demand changes to the circuit **300** downstream of the transformer **304**. As such, installation of the hydrogen plant can be easily adopted to wide grid networks, for example the corner grounding in Japan, as the isolated secondary of the transformer **304** gives the flexibility to have a grounding mechanism, as per the local grid codes or designer choice.

(31) In some instances, one or more auxiliary load devices **312** may be powered directly from the battery **308** or other power supply, such as the continuous generators listed above. For example, the battery **308** or generators may supply power to auxiliary devices which have built-in energy storage at the lower voltage (such as 24V) level. Power may be provided to these low-voltage auxiliary device via a simple diode circuit or other power interface circuit. In addition, elements of the battery, **308**, UPS **306**, and/or generators may be interlocked with one or more safety features of the plant load **202** to prevent enabling the power supplies until certain permissive signals are seen by a control computer or embedded control's safety logic (such as confirmation of successful ventilation purge).

EXEMPLARY EMBODIMENTS

Embodiment 1

(32) A hydrogen-generating plant comprising: a plurality of alternate current (AC) to direct current (DC) converters each comprising an input in electrical communication with a power source and an output, each of the plurality of AC-DC converters converting an AC power signal from the power source to a DC power signal; and a plurality of DC-DC converters each comprising an input in electrical connection to at least one of the plurality of AC-DC converters and an output in electrical communication with a load; wherein a first subset of the plurality of DC-DC converters is connected in parallel to an output of a first AC-DC converter and a second, distinct subset of the plurality of DC-DC converters is connected in parallel to an output of a second AC-DC converter to electrically isolate the first AC-DC converter from the second AC-DC converter.

Embodiment 2

(33) The hydrogen-generating plant of embodiment 1 wherein the plurality of AC-DC converters comprises non-isolated, bi-directional AC-DC converters.

Embodiment 3

(34) The hydrogen-generating plant of embodiment 1 or embodiment 2 wherein the plurality of DC-DC converters comprises isolated, uni-directional DC-DC converters.

Embodiment 4

(35) The hydrogen-generating plant of any one of embodiments 1-3 wherein the load is an electro-chemical load.

Embodiment 5

(36) The hydrogen-generating plant of any one of embodiments 1-4 wherein the load comprises at least one electrolyzer.

Embodiment 6

(37) The hydrogen-generating plant of any one of embodiments 1-5 wherein the power source is one of a grid power source or a renewable power source.

Embodiment 7

(38) The hydrogen-generating plant of any one of embodiments 1-6 further comprising: a transformer comprising a primary winding in electrical communication with the power source and a secondary winding in electrical communication with one or more auxiliary loads.

Embodiment 8

(39) The hydrogen-generating plant of embodiment 7 wherein the transformer is an adjustable transformer comprising one or more taps on the primary winding or the secondary winding to adjust a windings ratio of the transformer.

Embodiment 9

(40) The hydrogen-generating plant of embodiment 7 or embodiment 8 wherein the transformer is a solid-state transformer.

Embodiment 10

(41) The hydrogen-generating plant of any one of embodiments 7-9 wherein the one or more auxiliary loads comprise three-phase loads and single-phase loads.

Embodiment 11

(42) The hydrogen-generating plant of embodiment 10 wherein the transformer is configured to provide power to the three-phase loads and single-phase loads.
Embodiment 12
(43) The hydrogen-generating plant of any one of embodiments 7-11 further comprising: an uninterruptible power supply in electrical communication with the one or more auxiliary loads.
Embodiment 13
(44) A method for operating a hydrogen generator, the method comprising: electrically connecting a plurality of alternate current (AC) to direct current (DC) converters to a power source; electrically connecting a first subset of a plurality of DC-DC converters between an output of a first AC-DC converter of the plurality of AC-DC converters and a load circuit, the first subset of the plurality of DC-DC converters in parallel to each other; and electrically connecting a second subset of the plurality of DC-DC converters between an output of a second AC-DC converter of the plurality of AC-DC converters and the load circuit, the second subset of the plurality of DC-DC converters in parallel to each other, wherein the first AC-DC converter is electrically isolated from the second AC-DC converter.
Embodiment 14
(45) The method of embodiment 13 wherein the plurality of AC-DC converters comprises non-isolated, bi-directional AC-DC converters.
Embodiment 15
(46) The method of embodiment 13 or embodiment 14 wherein the plurality of DC-DC converters comprises isolated, uni-directional DC-DC converters.
Embodiment 16
(47) The method of any one of embodiments 13-15 wherein the load comprises at least one electrolyzer.
Embodiment 17
(48) The method of any one of embodiments 13-16 further comprising: electrically connecting one or more auxiliary loads to the power source via a transformer.
Embodiment 18
(49) The method of embodiment 17 wherein the one or more auxiliary loads comprise three-phase loads and single-phase load.
Embodiment 19
(50) The method of embodiment 17 or embodiment 18 wherein the transformer is configured to provide power to the three-phase loads and single-phase loads
Embodiment 20
(51) The method of any one of embodiments 17-19 further comprising: electrically connecting a bypass switch between the one or more auxiliary loads and an uninterruptible power supply (UPS), the bypass switch to switch power to the one or more auxiliary loads from the power source to the UPS in response to a loss of power by the power source.
(52) Embodiments of the present disclosure include various steps, which are described in this specification. The steps may be performed by hardware components or may be embodied in machine-executable instructions, which may be used to cause a general-purpose or special-purpose processor programmed with the instructions to perform the steps. Alternatively, the steps may be performed by a combination of hardware, software and/or firmware.
(53) Various embodiments of the disclosure are discussed in detail below. While specific implementations are discussed, it should be understood that this is done for illustration purposes only. A person skilled in the relevant art will recognize that other components and configurations may be used without parting from the spirit and scope of the disclosure. Thus, the following description and drawings are illustrative and are not to be construed as limiting. Numerous specific details are described to provide a thorough understanding of the disclosure. However, in certain instances, well-known or conventional details are not described in order to avoid obscuring the

description. References to one or an embodiment in the present disclosure can be references to the same embodiment or any embodiment; and, such references mean at least one of the embodiments.
(54) Reference to “one embodiment” or “an embodiment” means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment of the disclosure. The appearances of the phrase “in one embodiment” in various places in the specification are not necessarily all referring to the same embodiment, nor are separate or alternative embodiments mutually exclusive of other embodiments. Moreover, various features are described which may be exhibited by some embodiments and not by others.
(55) The terms used in this specification generally have their ordinary meanings in the art, within the context of the disclosure, and in the specific context where each term is used. Alternative language and synonyms may be used for any one or more of the terms discussed herein, and no special significance should be placed upon whether or not a term is elaborated or discussed herein. In some cases, synonyms for certain terms are provided. A recital of one or more synonyms does not exclude the use of other synonyms. The use of examples anywhere in this specification including examples of any terms discussed herein is illustrative only, and is not intended to further limit the scope and meaning of the disclosure or of any example term. Likewise, the disclosure is not limited to various embodiments given in this specification.
(56) Without intent to limit the scope of the disclosure, examples of instruments, apparatus, methods and their related results according to the embodiments of the present disclosure are given below. Note that titles or subtitles may be used in the examples for convenience of a reader, which in no way should limit the scope of the disclosure. Unless otherwise defined, technical and scientific terms used herein have the meaning as commonly understood by one of ordinary skill in the art to which this disclosure pertains. In the case of conflict, the present document, including definitions will control.

Claims

1. A hydrogen-generating plant comprising: a plurality of non-isolated, bi-directional alternate current (AC) to direct current (DC) converters each comprising an input in electrical communication with a power source and an output, each of the plurality of AC-DC converters converting an AC power signal from the power source to a DC power signal; a first plurality of isolated, uni-directional DC-DC converters each comprising an input in electrical connection to an output of a first one of the plurality of AC-DC converters and an output in electrical communication with a hydrogen-generating device; and a second plurality of isolated, uni-directional DC-DC converters each comprising an input in electrical connection to an output of a second one of the plurality of AC-DC converters and an output in electrical communication with the hydrogen-generating device; wherein the second plurality of DC-DC converters are distinct from the first plurality of DC-DC converters to electrically isolate the first AC-DC converter from the second AC-DC converter.
2. The hydrogen-generating plant of claim 1 wherein the hydrogen-generating device comprises an electro-chemical load.
3. The hydrogen-generating plant of claim 1 wherein the hydrogen-generating device comprises at least one electrolyzer.
4. The hydrogen-generating plant of claim 1 wherein the power source is one of a grid power source or a renewable power source.
5. The hydrogen-generating plant of claim 1 further comprising: a transformer comprising a primary winding in electrical communication with the power source and a secondary winding in electrical communication with one or more auxiliary loads.
6. The hydrogen-generating plant of claim 5 wherein the transformer is an adjustable transformer comprising one or more taps on the primary winding or the secondary winding to adjust a windings

ratio of the transformer.
7. The hydrogen-generating plant of claim 5 wherein the transformer is a solid-state transformer.
8. The hydrogen-generating plant of claim 5 wherein the one or more auxiliary loads comprise three-phase loads and single-phase loads.
9. The hydrogen-generating plant of claim 8 wherein the transformer is configured to provide power to the three-phase loads and single-phase loads.
10. The hydrogen-generating plant of claim 5 further comprising: an uninterruptible power supply in electrical communication with the one or more auxiliary loads.
11. A method for operating a hydrogen generator, the method comprising: electrically connecting a plurality of non-isolated, bi-directional alternate current (AC) to direct current (DC) converters to a power source, each of the plurality of AC-DC converters converting an AC power signal from the power source to a DC power signal; electrically connecting a first subset of a plurality of isolated, uni-directional DC-DC converters between an output of a first AC-DC converter of the plurality of AC-DC converters and a hydrogen-generating device, the first subset of the plurality of DC-DC converters in parallel to each other; and electrically connecting a second subset of the plurality of DC-DC converters between an output of a second AC-DC converter of the plurality of AC-DC converters and the hydrogen-generating device, the second subset of the plurality of DC-DC converters in parallel to each other, wherein the second subset of the DC-DC converters is distinct from the first subset of the DC-DC converters to electrically isolate the first AC-DC converter from the second AC-DC converter.
12. The method of claim 11 wherein the hydrogen-generating device comprises at least one electrolyzer.
13. The method of claim 11 further comprising: electrically connecting a transformer between one or more auxiliary loads and the power source.
14. The method of claim 13 wherein the one or more auxiliary loads comprise three-phase loads and single-phase load.
15. The method of claim 13 wherein the transformer is configured to provide power to the three-phase loads and single-phase loads.
16. The method of claim 13 further comprising: electrically connecting the one or more auxiliary loads and to an uninterruptible power supply (UPS) to provide power to the one or more auxiliary loads from the UPS in response to a loss of power by the power source.