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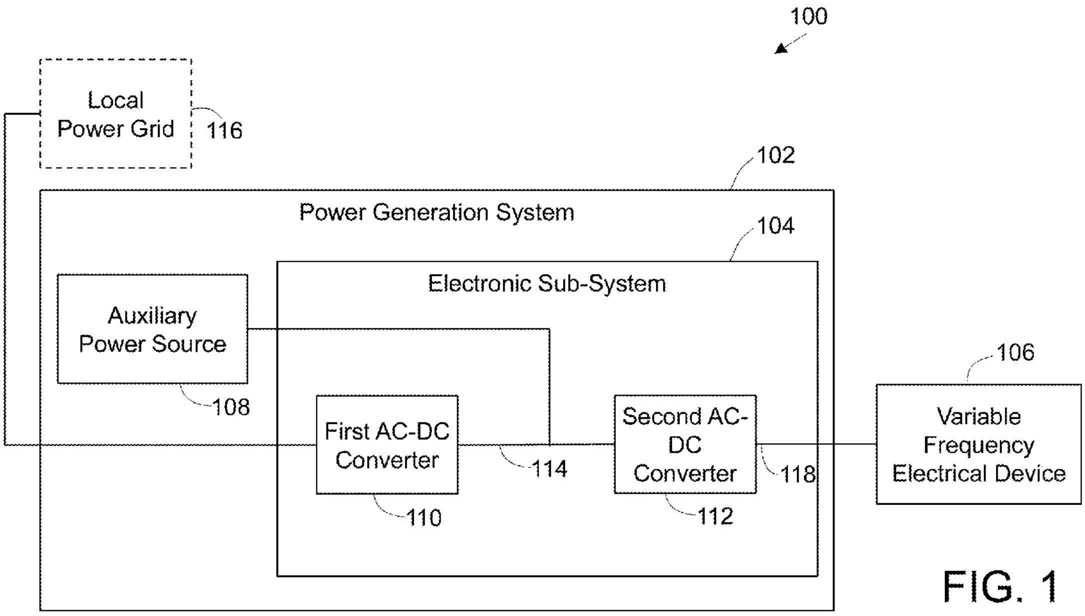

FIG. 1

(57) Abstract: An electronic sub-system (104, 204, 304) is presented. The electronic sub-system includes (104, 204, 304) a first alternating current (AC)-direct current (DC) converter (110, 210) and one or more second AC-DC converters (112, 212, 215) electrically coupled to the first AC-DC converter (110, 210) via a DC-link (114, 214). The electronic sub-system (104, 204, 304) is electrically coupled to at least one of an auxiliary power source (108, 208) to receive an auxiliary electrical power or a local power grid (116) to receive a local grid power, and wherein the at least one second AC-DC converter (112, 212) is configured to supply a variable frequency electrical power to at least one variable frequency electrical device (106, 206) at a frequency determined based on a level of the auxiliary electrical power, the local grid power, or a sum of the auxiliary electrical power and the local grid power.

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ELECTRONIC SUB-SYSTEM AND POWER GENERATION SYSTEM FOR POWERING VARIABLE FREQUENCY ELECTRICAL DEVICES

BACKGROUND

[0001] One or more embodiments of the present application relates generally to a power generation system for generating and supplying electrical power and more particularly relates to an electronic sub-system for facilitating supply of the electrical power to variable frequency electrical devices.

[0002] Typically, power generation systems such as generators use fuels such as diesel, petrol, and the like to generate an electrical power that can be supplied to local electrical loads. Reducing consumption of the fuels is an ongoing effort in achieving low cost and environment friendly power generation systems. To that end, various hybrid power generation systems are available that use a generator operated by a constant speed engine and some form of renewable energy source. In such hybrid power generation systems, as an amount of power generated by the renewable energy source increases, the power generated by the generators operated by the constant speed engine needs to be reduced. Moreover, certain stand-alone renewable energy source based power generation systems, such as, solar farm or wind farm, are also available.

[0003] In general, power generation from such renewable energy sources is widely dependent on weather conditions and is uncertain. Therefore, in certain instances, when increased amount of power is available from such renewable energy sources, management of such excess power becomes a challenging task. In most instances, such excess power is wasted as there may not be sufficient power requirement to consume such excess power. In some cases, a type of electrical loads may not be able to consume such varying power.

BRIEF DESCRIPTION

[0004] In accordance with an embodiment of the present specification, an electronic sub-system is presented. The electronic sub-system includes a first alternating current (AC)-direct current (DC) converter. The electronic sub-system further includes one or more second AC-DC converters electrically coupled to the first AC-DC converter via a DC-link, wherein at least one second AC-DC converter of the one or more second AC-DC converters is configured to be electrically coupled to at least one variable frequency electrical device. The electronic sub-system is configured to be electrically coupled to at least one of an auxiliary power source to receive an auxiliary electrical power or a local power grid to receive a local grid power, and wherein the at least one second AC-DC converter is configured to supply a variable frequency electrical power to the at least one variable frequency electrical device at a frequency determined based on a level of the auxiliary electrical power, the local grid power, or a sum of the auxiliary electrical power and the local grid power.

[0005] In accordance with an embodiment of the present specification, a power generation system is presented. The power generation system includes a generator configured to generate a generator power. The power generation system further includes one or more auxiliary power sources configured to generate an auxiliary electrical power. Furthermore, the power generation system includes an electronic sub-system electrically coupled to the generator and the one or more auxiliary power sources. The electronic sub-system includes a first AC-DC converter electrically coupled to the generator. The electronic sub-system further includes one or more second AC-DC converters electrically coupled to the first AC-DC converter via a DC-link, wherein at least one second AC-DC converter of the one or more second AC-DC converters is configured to be electrically coupled to at least one variable frequency electrical device having a first priority metric, and wherein the DC-link is coupled to at least one of the one or more auxiliary power sources to receive the auxiliary electrical power or a local power grid to receive a local grid power. The at least one second AC-DC converter is configured to supply a variable frequency electrical power to the at least one variable frequency electrical device at a frequency determined based on a level of a surplus electrical power supplied from the one or more auxiliary power sources.

[0006] In accordance with an embodiment of the present specification, a method for supplying electrical power is presented. The method includes receiving an auxiliary electrical power from an auxiliary power source on a DC link between a first AC-DC converter and one or more second AC-DC converters, wherein at least one second AC-DC converter of the one or more second AC-DC converters is coupled to at least one variable frequency electrical device. The method further includes receiving a local grid power from a local power grid by the first AC-DC converter. Furthermore, the method includes generating, by the at least one second AC-DC converter, a variable frequency electrical power having a frequency determined based on at least one of the auxiliary electrical power, the local grid power, or a sum of the auxiliary electrical power and the local grid power. Moreover, the method includes supplying, by the at least one second AC-DC converter, the variable frequency electrical power to the at least one variable frequency electrical device.

DRAWINGS

[0007] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0008] FIG. 1 is a block diagram of an electrical power distribution system including a power generation system having an electronic sub-system, in accordance with one or more embodiments of the present specification;

[0009] FIG. 2 is a block diagram of an electrical power distribution system including a power generation system having an electronic sub-system, in accordance with one or more embodiments of the present specification;

[0010] FIG. 3 is a block diagram of an electrical power distribution system including a power generation system having an electronic sub-system, in accordance with one or more embodiments of the present specification;

[0011] FIG. 4 is a flowchart of a method of supplying a variable frequency electrical power to at least one variable frequency electrical device, in accordance with one or more embodiments of the present specification;

[0012] FIG. 5 is a flowchart of another method of supplying a variable frequency electrical power to at least one variable frequency electrical device, in accordance with one or more embodiments of the present specification;

[0013] FIG. 6 is a block diagram of a doubly-fed induction generator (DFIG) based electrical power distribution system, in accordance with one or more embodiments of the present specification; and

[0014] FIG. 7 is a flowchart of a method of supplying a variable frequency electrical power to at least one variable frequency electrical device using a DFIG based power generation system, in accordance with one or more embodiments of the present specification.

DETAILED DESCRIPTION

[0015] The specification may be best understood with reference to the detailed figures and description set forth herein. Various embodiments are described hereinafter with reference to the figures. However, those skilled in the art will readily appreciate that the detailed description given herein with respect to these figures is for explanatory purposes as the method and the system may extend beyond the described embodiments.

[0016] In the following specification, the singular forms “a”, “an” and “the” include plural referents unless the context clearly dictates otherwise. As used herein, the term “or” is not meant to be exclusive and refers to at least one of the referenced components being present and includes instances in which a combination of the referenced components may be present, unless the context clearly dictates otherwise.

[0017] As used herein, the terms “may” and “may be” indicate a possibility of an occurrence within a set of circumstances; a possession of a specified property, characteristic or function; and/or qualify another verb by expressing one or more of an ability, capability, or possibility associated with the qualified verb. Accordingly, usage of “may” and “may be” indicates that a modified term is apparently appropriate, capable, or suitable for an indicated capacity, function, or usage, while taking into account that in some circumstances, the modified term may sometimes not be appropriate, capable, or suitable.

[0018] The term “variable frequency electrical device” as used herein refers to an electrical device operable using electrical power (e.g., voltage and/or current) having a variable frequency. For example, such variable frequency electrical devices are capable of consuming electrical power having varying frequency. The term “fixed frequency electrical device” as used herein refers to an electrical device operable using electrical power (e.g., voltage and/or current) having a fixed frequency. The term “committed load power” as used herein refers to a power demand/requirement by one or more fixed frequency electrical devices.

[0019] FIG. 1 is a block diagram (100) of a power generation system (102) having an electronic sub-system (104) configured to be electrically coupled to a variable frequency electrical device (106), in accordance with one or more embodiments of the present specification. In some embodiments, the electronic sub-system (104) includes a first AC-DC converter (110) and one or more second AC-DC converters, such as, a second AC-DC converter (112). For ease of illustration, a single second AC-DC converter (112) is shown in FIG. 1. It is to be noted that additional second AC-DC converters may also be employed, without limiting the scope of the present specification. As depicted in FIG. 1, in some embodiments, the second AC-DC converter (112) is electrically coupled to the first AC-DC converter (110) via a direct current (DC) link (114). The second AC-DC converter (112) is further configured to be electrically coupled to at least one variable frequency electrical device, such as, the variable frequency electrical device (106). In some embodiments, the first AC-DC converter (110) and/or the second AC-DC converter (112) are configured to convert

AC power into DC power. In some embodiments, the first AC-DC converter (110) and/or the second AC-DC converter (112) are configured to convert DC power into AC power. In some embodiments, the electronic sub-system (104) is configured to be electrically coupled to at least one of an auxiliary power source (108) and a local power grid (116).

[0020] In some embodiments, the DC-link (114) may be electrically coupled to one or more auxiliary power sources, such as, an auxiliary power source (108). For ease of illustration, a single auxiliary power source (108) is shown in FIG. 1. Various examples of the auxiliary power source (108) may include but are not limited to renewable energy based power sources such as but not limited to a photo-voltaic power source. The auxiliary power source (108) is configured to supply an auxiliary electrical power (P_s) to the DC-link (114). In some embodiments, the auxiliary electrical power (P_s) is supplied to the DC-link (114) as DC power.

[0021] In certain embodiments, as shown in the configuration of FIG.1, the first AC-DC converter (110) is electrically coupled to the local power grid (116). In certain other embodiments, the local power grid (116) may be coupled to the DC-link (114) (see FIG. 3). Examples of the local power grid (116) may include a utility electric grid, and islanded power grids such as a micro grid or a mini grid. The term "micro-grid," as used herein refers to a power generation and supply system that is capable of generating and supplying electrical power of less than 10 kW. The term "mini-grid," as used herein refers to a power generation and supply system that is capable of generating and supplying electrical power of 10 kW and above.

[0022] The local power grid (116) may also be coupled to certain primary electric loads (not shown in FIG. 1) to which the local power grid (116) is configured to supply electrical power. Accordingly, in some embodiments, the local power grid (116) may be configured to supply an electrical power to the first AC-DC converter (110) which is in excess of a power requirement of the primary electric loads. The electric power received by the first AC-DC converter (110) from the local power grid (116) is hereinafter referred to as a local grid power (P_{lg}).

[0023] In some embodiments, when the first AC-DC converter (110) is not coupled to an external power source including but not limited to the local power grid (116) or when there is no power from the local power grid (116), the first AC-DC converter (110) may not perform any power conversion. In certain embodiments, when the first AC-DC converter (110) is coupled to the local power grid (116), the first AC-DC converter is configured to convert the local grid power (P_{lg}) into DC power and supply the DC power to the DC-link (114).

[0024] The second AC-DC converter (112) is configured to convert the DC power from the DC-link (114) into AC power, hereinafter referred to as an output power. The DC power from the DC-link (114) is in turn based on the auxiliary electrical power (P_s) supplied to the DC-link (114) from the auxiliary power source (108) and/or the local grid power (P_{lg}) supplied from the local power grid (116). In some embodiments, the second AC-DC converter (112) is configured to generate and apply variable frequency electrical power to the variable frequency electrical device (106) based on an input power to the second AC-DC converter (112). For example, in a configuration where the variable frequency electrical device (106) is an electric motor, the second AC-DC converter (112) may be configured to vary a frequency and/or magnitude of the variable frequency electrical power such that the variable frequency electrical device (106) may be operated at variable speed. In some embodiments, the frequency and/or the magnitude of the variable frequency electrical power may be adjusted by the second AC-DC converter (112) such that the variable frequency electrical device (106) may be operated at determined revolutions per minute (rpm) and/or determined torque. In some embodiments, in order to maintain the torque, the second AC-DC converter (112) may be configured to maintain a ratio of the magnitude and the frequency of the variable frequency electrical power at a constant level.

[0025] In one embodiment, the second AC-DC converter (112) may be configured to generate a variable frequency electrical power at its output (118) such that a frequency of the output power is based on a level (e.g., a magnitude) of the auxiliary electrical power (P_s). For example, the frequency of the output power of the second AC-DC converter (112) increases with an increase in the magnitude of the auxiliary electrical power (P_s). In another embodiment, the second AC-DC converter (112) may be configured to generate the output power such that the frequency of the output power is based on a magnitude of a sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$). In some embodiments, when the auxiliary electrical power (P_s) is not available and the local grid power (P_{lg}) is available, the second AC-DC converter (112) may be configured to generate the output power such that the frequency of the output power is based on a magnitude of the local grid power (P_{lg}). In some embodiments, the second AC-DC converter (112) may be configured to generate the output power such that the frequency of the output power is based on a magnitude of a DC power on the DC-link (114).

[0026] In some embodiments, the variable frequency electrical device (106) is selected such that the variable frequency electrical device(s) (106) is capable of withstanding/consuming the output power supplied from the second AC-DC converter (112). In some embodiments, additional variable frequency electrical devices may be connected to the second AC-DC converter (112) such that the auxiliary electrical power (P_s) generated by the auxiliary power source (108) and/or the local grid power (P_{lg}) received from the local power grid (116) is utilized and wastage of the auxiliary electrical power (P_s) and/or the local grid power (P_{lg}) is minimized. Various examples of the variable frequency electrical device (106) include but are not limited to an electrical motor, electrical heating element, electromechanical drive systems, or combinations thereof. The electrical motors generally find applications in fluid pumps, condensers units of refrigeration systems, flourmills, etc.

[0027] FIG. 2 is a block diagram (200) of a power generation system (202) having an electronic sub-system (204) configured to be electrically coupled to a variable frequency electrical device (206) and a fixed frequency electrical device (207), in accordance with one or more embodiments of the present specification. In comparison to the power generation system (102) of FIG. 1, the power generation system (202) of FIG. 2 is additionally configured to supply an electrical power to the fixed frequency electrical device (207), in some embodiments. A power demand from the fixed frequency electrical device (207) is hereinafter referred to as a committed load power (P_{cmt}).

[0028] In certain embodiments, each of the variable frequency electrical device (206) and the fixed frequency electrical device (207) is assigned a priority metric. For example, the variable frequency electrical device (206) is assigned a first priority metric and the fixed frequency electrical device (207) is assigned a second priority metric, where the second priority metric is different from the first priority metric. For instance, the second priority metric may indicate that the supply of the electrical power to the fixed frequency electrical device (207) is prioritized over variable frequency electrical device (206). Accordingly, the electronic sub-system (204) is configured to supply electrical power desirable to meet the committed load power (P_{cmt}) to the fixed frequency electrical device (207). Moreover, in some embodiments, the electronic sub-system (204) is configured to supply electrical power to the variable frequency electrical device (206) if a surplus electrical power in excess of the committed load power (P_{cmt}) is available to the electronic sub-system (204).

[0029] In some embodiments, the electronic sub-system (204) of FIG. 2, may include one or more of a first AC-DC converter (210), one or more second AC-DC converters (212, 215), and a controller (220). The one or more second AC-DC converters (212, 215) are electrically coupled to the first AC-DC converter (210) via a DC-link (214). The first AC-DC converter (210) may be similar to the first AC-DC converter (110) of FIG. 1. Similarly, the second AC-DC converter (212) may be similar to the second AC-DC converter (112) of FIG. 1 and configured to supply a variable frequency electrical power to the variable frequency electrical device (206). The second AC-DC converter (215) is configured to supply a fixed frequency AC power to the fixed frequency electrical device (207).

[0030] The controller (220) may be operatively coupled to the first AC-DC converter (210) and the one or more second AC-DC converters (212, 215) to control their respective functionalities. In some embodiments, the controller (220) may include a specially programmed general purpose computer, a microprocessor, a digital signal processor, and/or a microcontroller. The controller (220) may also include input/output ports, and a storage medium, such as, an electronic memory. Various examples of the microprocessor include, but are not limited to, a reduced instruction set computing (RISC) architecture type microprocessor or a complex instruction set computing (CISC) architecture type microprocessor. Further, the microprocessor may be a single-core type or multi-core type. Alternatively, the controller (220) may be implemented as hardware elements such as circuit boards with processors or as software running on a processor such as a commercial, off-the-shelf personal computer (PC), or a microcontroller. In certain embodiments, the first AC-DC converter (210) and the second AC-DC converters (212, 215) may include controllers / control units / electronics to control their respective operations under a supervisory control of the controller (220). The controller (220) may be capable of executing program instructions for controlling operations of the power generation system (202).

[0031] In some embodiments, similar to the power generation system (102) of FIG. 1, the power generation system (202) of FIG. 2 also includes an auxiliary power source (208). An example of the auxiliary power source (208) may include but are not limited to a photo-voltaic power source. The auxiliary power source (208) is configured to supply an auxiliary electrical power (P_s) to the DC-link (214). In some embodiments, the auxiliary electrical power (P_s) is supplied to the DC-link (214) as DC power. Furthermore, in some embodiments, the power generation system (202) may be optionally coupled to a local power grid (116). In the embodiment of FIG. 2, the local power grid (116) is shown as being coupled to the first AC-DC converter (210). In some other embodiments, the local power grid (116) may be coupled to the DC-link (214) (see FIG. 3).

[0032] Moreover, in some embodiments, the power generation system (202) may also include a generator (218). The generator (218) may be operated via a prime mover (not shown in FIG. 2) and configured to generate AC electrical power, hereinafter referred to as a generator power (P_g). The generator (218) is coupled to the first AC-DC converter (210) to supply the generator power (P_g) to the first AC-DC converter (210). Various examples of the generator (218) may include but are not limited to a synchronous generator or an asynchronous generator. In certain embodiments, the generator power (P_g) may be utilized to facilitate, partially or fully, the committed load power (P_{cmt}) to the fixed frequency electrical device (207) when a sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$) is lower than the committed load power (P_{cmt}). In certain embodiments, in order to minimize fuel consumption, it may be desirable to restrict a power generated by the generator (218) to a level such that the committed load power (P_{cmt}) requirement is met depending on the level of auxiliary electrical power (P_s) and the local grid power (P_{lg}). Therefore, in some embodiments, the generator (218) may not be operated when the sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$) is sufficient to meet the committed load power (P_{cmt}).

[0033] In some embodiments, the controller (220) of the electronic sub-system (204) is configured to determine a surplus electrical power based on the auxiliary electrical power (P_s) supplied from the auxiliary power source (208) and the committed load power (P_{cmt}). The controller (220) may determine the surplus electrical power as the auxiliary electrical power (P_s) in excess of the committed load power (P_{cmt}). The surplus electrical power may be obtained by subtracting the committed load power (P_{cmt}) from the auxiliary electrical power (P_s).

[0034] In some embodiments, when the power generation system (202) is also coupled to the local power grid (116), the controller (220) is configured to determine a surplus electrical power based on the auxiliary electrical power (P_s), the local grid power (P_{lg}), and the committed load power (P_{cmt}). The controller (220) may determine the surplus electrical power as a sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$) which is in excess of the committed load power (P_{cmt}). The surplus electrical power may be obtained by subtracting the committed load power (P_{cmt}) from the sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$).

[0035] In certain embodiments, in some time durations, no auxiliary electrical power (P_s) may be supplied from the auxiliary power source (108). For example, if the auxiliary power source (108) is a PV power source, the auxiliary electrical power (P_s) may not be available in a night time. However, in certain instances, the local grid power

(P_{lg}) may be available if the power generation system (202) is coupled to the local power grid (116). In such situations, the controller (220) is configured to determine a surplus electrical power based on the local grid power (P_{lg}) and the committed load power (P_{cmt}). The controller (220) may determine the surplus electrical power as the local grid power (P_{lg}) in excess of the committed load power (P_{cmt}). The surplus electrical power may be obtained by subtracting the committed load power (P_{cmt}) from the local grid power (P_{lg}).

[0036] In some embodiments, the generator (218) may also be operated to supply variable frequency electrical power. In such an instance, the controller (220) is configured to determine a surplus electrical power based on the generator power (P_g), the auxiliary electrical power (P_s), the local grid power (P_{lg}), and the committed load power (P_{cmt}). The controller (220) may determine the surplus electrical power as a sum of the generator power, the auxiliary electrical power, and the local grid power ($P_g + P_s + P_{lg}$) which is in excess of the committed load power (P_{cmt}). The surplus electrical power may be obtained by subtracting the committed load power (P_{cmt}) from the sum of the generator power, the auxiliary electrical power, and the local grid power ($P_g + P_s + P_{lg}$).

[0037] The controller (220) is also configured to control the second AC-DC converter (212) to generate variable frequency electrical power having a frequency determined based on a level of the surplus electrical power. The second AC-DC converter (212) then supplies the variable frequency electrical power to the variable frequency electrical device (206).

[0038] FIG. 3 is a block diagram (300) of a power generation system (302) having an electronic sub-system (304) configured to be electrically coupled to a variable frequency electrical device (206) and a fixed frequency electrical device (207), in accordance with one or more embodiments of the present specification. The power generation system (302) of FIG. 3 employs various elements similar to the corresponding elements as used in FIG. 2. Accordingly, description of such elements is not repeated herein.

[0039] In some embodiments, as shown in FIG. 3, the local power grid (116) may be optionally coupled to the DC-link (214). More particularly, the local power grid (116) may be coupled to the DC-link (214) via a third AC-DC converter (306). The third AC-DC converter (306) is configured to convert the local grid power (P_{lg}) from the local power grid (116) into DC power and supply it to the DC-link (214). In some embodiments, when the local power grid (116) is a DC grid, the local power grid (116) may be directly connected to the DC-link (214).

[0040] The electronic sub-system (304) may also include a switching device such as a two-way switch (308). The two-way switch (308) is coupled between the second AC-DC converter (212), and the variable frequency electrical device (206) and the fixed frequency electrical device (207), as depicted in FIG. 3. The controller (220) may be operably coupled to the two-way switch (308) to control switching action of the two-way switch (308). In some embodiments, the controller (220) may operate the two-way switch (308) in a time sequenced fashion. For example, the controller (220) may operate the two-way switch (308) to supply electrical power to the variable frequency electrical device (206) or the fixed frequency electrical device (207), in respective one or more time-slots. In certain embodiments, the controller (220) may operate the two-way switch (308) to supply electrical power to the variable frequency electrical device (206) when power supply to the fixed frequency electrical device (207) is not desired.

[0041] In one embodiment, the controller (220) may be configured to operate the two-way switch (308) such that the fixed frequency electrical device (207) is coupled to the second AC-DC converter (212). In such a configuration, the second AC-DC converter (212) is configured to generate output power at a fixed frequency.

[0042] In another embodiment, the controller (220) may be configured to operate the two-way switch (308) such that the variable frequency electrical device (206) is coupled to the second AC-DC converter (212). In such a configuration, in one embodiment, the second AC-DC converter (212) is configured to generate an output power having a frequency which is determined based on a magnitude of the auxiliary electrical power (P_s), the local grid power (P_{lg}), or the sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$). In certain embodiments, the generator (218) may not be operated when the variable frequency electrical device (206) is coupled to the second AC-DC converter (212).

[0043] FIG. 4 is a flowchart (400) of a method of supplying a variable frequency electrical power to a variable frequency electrical device, in accordance with one or more embodiments of the present specification. The method of FIG. 4 is described in conjunction with FIG. 1. The method of FIG. 5 includes blocks (402) - (408).

[0044] At block (402), the method includes receiving an auxiliary electrical power (P_s). In some embodiments, the auxiliary electrical power (P_s) is received by the electronic sub-system (104) from one or more auxiliary power sources, for example, the auxiliary power source (108). More particularly, the auxiliary electrical power (P_s) may be received on the DC-link (114) of the electronic sub-system (104).

[0045] Optionally, in some embodiments, the method, at block (404), includes receiving a local grid power (P_{lg}). The local grid power (P_{lg}) may be received by the electronic sub-system (104) from a local power grid (for example, the local power grid 116). In one embodiment, the local grid power (P_{lg}) may be received by the first AC-DC converter (110), where the first AC-DC converter (110) is configured to convert the received local grid power (P_{lg}) into DC power. In another embodiment, the local grid power (P_{lg}) may be received on the DC-link (114).

[0046] At block (406), a variable frequency electrical power may be generated by the second AC-DC converter (112). In one embodiment, the variable frequency electrical power may be generated based on the auxiliary electrical power (P_s) when the local grid power (P_{lg}) is not available, where the frequency of the variable frequency electrical power may be based on the magnitude of the auxiliary electrical power (P_s). In another embodiment, the variable frequency electrical power may be generated based on the local grid power (P_{lg}) when the auxiliary electrical power (P_s) is not available, where the frequency of the variable frequency electrical power may be based on the magnitude of the local grid power (P_{lg}). In yet another embodiment, the variable frequency electrical power may be generated based on a sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$), where the frequency of the variable frequency electrical power may be based on the magnitude of the sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$). Subsequently, at block (408) the variable frequency electrical power may be supplied to the variable frequency electrical device (106) from the second AC-DC converter (112).

[0047] FIG. 5 is a flowchart (500) of a method of supplying a variable frequency electrical power to variable frequency electrical devices, in accordance with one or more embodiments of the present specification. The method of FIG. 5 is described in conjunction with FIGs. 2-3. The method of FIG. 5 includes blocks (502) - (528).

[0048] At block (502), the method includes receiving an auxiliary electrical power (P_s). In some embodiments, the auxiliary electrical power (P_s) is received by an electronic sub-system (204, 304) from the auxiliary power source (208). More particularly, the auxiliary electrical power (P_s) may be received on the DC-link (214) of the corresponding electronic sub-system (204, 304).

[0049] Optionally, in some embodiments, the method, at block (504), includes receiving a local grid power (P_{lg}). The local grid power (P_{lg}) may be received by the electronic sub-system (204, 304) from the local power grid (116). In one embodiment, the local grid power (P_{lg}) may be received on the DC-link (214) directly or via an AC-DC converter, such as, the third AC-DC converter (306). In another embodiment, the local grid power may be received by the first AC-DC converter (210), where the first AC-DC converter (210) is configured to convert the received local grid power (P_{lg}) into DC power. The DC power is then supplied to the DC-link (214). Moreover, at block (506), a committed load power (P_{cmt}) of the fixed frequency electrical device (207) may be determined. As previously noted, the committed load power (P_{cmt}) is representative of power demand from the fixed frequency electrical device (207).

[0050] Furthermore, at block (508), a check may be performed by the controller (220) to determine whether the committed load power (P_{cmt}) is 0 (zero). In the embodiment of FIG. 3 when the two-way switch (308) is in a state to establish electrical connection to the variable frequency electrical device (206), the committed load power

(P_{cmt}) is 0 (zero). In some embodiments, the fixed frequency electrical devices 207 may be inactive and does not consume any electrical power. Also, in such situations, the committed load power (P_{cmt}) is zero. At block (508), if it is determined that the committed load power (P_{cmt}) is zero, a variable frequency electrical power may be generated by a second AC-DC converter (212) at block (510). In one embodiment, the variable frequency electrical power may be generated as described in block (406) of FIG. 4 based on the auxiliary electrical power (P_s), the local grid power (P_{lg}), or the sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$). Subsequently, at block (512) the variable frequency electrical power may be supplied to the variable frequency electrical device (206) from respective second AC-DC converter (212).

[0051] At block (508), if it is determined that the committed load power (P_{cmt}) is non-zero, another check may be performed at block (514) to determine whether the sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$) is insufficient to meet the committed load power (P_{cmt}). If it is determined that the sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$) is insufficient to meet the committed load power (P_{cmt}), the generator (218) may be operated to at block (516) to generate a generator power (P_g). In some embodiments, the generator (218) may be operated a determined operating speed such that a sum of the auxiliary electrical power, the local grid power, and the generator power ($P_s + P_{lg} + P_{lg}$) is sufficient to meet the committed load power (P_{cmt}). At block (518), the generator power (P_g) may be received by the first AC-DC converter (210). The generator power (P_g) may be converted into DC power by the first AC-DC converter (210) and supplied to the corresponding DC-link (214).

[0052] Moreover, at block (520) a fixed frequency electrical power may be generated by the second AC-DC converter (215). In one embodiment, the fixed frequency electrical power may be generated based on the generator power (P_g) and the auxiliary electrical power (P_s) when the local grid power (P_{lg}) is not available. In another embodiment, the fixed frequency electrical power may be generated based on the generator power (P_g) and the local grid power (P_{lg}) when the auxiliary electrical power (P_s) is not available. In another embodiment, the fixed frequency electrical power may be generated based on the generator power (P_g) and a sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$) when both the auxiliary electrical power (P_s) and the local grid power (P_{lg}) are available. In yet another embodiment, the fixed frequency electrical power may be generated based on only the generator power (P_g) when none of the auxiliary electrical power (P_s) and the local grid power (P_{lg}) are available. Subsequently, the fixed frequency electrical power may be supplied to the fixed frequency electrical device (207) via the second AC-DC converter (215) at block (522). The control may then be transferred to block (506).

[0053] At block (514), if it is determined that the sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$) is sufficient to meet the committed load power (P_{cmt}), the generator (218) may not need to be operated. In this situation, the committed load power (P_{cmt}) to the fixed frequency electrical device (207) may be provided without operating the generator (218) at blocks (520-522). Also, the variable frequency electrical power may be provided to the variable frequency electrical device (206) based on a surplus power over the committed load power (P_{cmt}) at blocks (524-528).

[0054] In some embodiments, at block (520) fixed frequency electrical power may be generated by the second AC-DC converter (215) based on the auxiliary electrical power (P_s), the local grid power (P_{lg}) and the sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$). Subsequently, the fixed frequency electrical power may be supplied to the fixed frequency electrical device (207) via the second AC-DC converter (215) at block (522).

[0055] At block (524), the surplus power may be determined based on the committed load power (P_{cmt}) and the auxiliary electrical power (P_s), the local grid power (P_{lg}), or the sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$). The surplus electrical power may be referred to as an electrical power in excess of the committed load power (P_{cmt}). In certain embodiments, the surplus electrical power may be obtained by subtracting the committed load power (P_{cmt}) from one of the auxiliary electrical power (P_s) (when the local grid power P_{lg} is not available), the local grid power (P_{lg}) (when the auxiliary electrical power P_s is not available), or the sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$).

[0056] Moreover, at block (526) the variable frequency power may be generated by the second AC-DC converter (212) based on the surplus power. In some embodiments, the frequency of the variable frequency electrical power is based on the surplus electrical power. Subsequently, the variable frequency electrical power may be supplied to the variable frequency electrical devices (206) via the second AC-DC converters (212) at block (528).

[0057] FIG. 6 is a block diagram of a doubly-fed induction generator (DFIG) based electrical power distribution system (600), in accordance with aspects of the present specification. The electrical power distribution system (600) may include a DFIG based power generation system (602) coupled to electrical devices such as variable frequency electrical devices (604, 606) and a fixed frequency electrical device (608). The power generation system (602) is configured to supply electrical power to one or more of the variable frequency electrical devices (604, 606) and the fixed frequency electrical device (608).

[0058] In some embodiments, the power generation system (602) may include a prime mover (610), a DFIG (612), an electronic sub-system (614) one or more auxiliary power sources such as a photo-voltaic (PV) power source (616) and/or an energy storage device (618). The electronic sub-system (614) is configured to be electrically coupled to the variable frequency electrical devices (604, 606) and the fixed frequency electrical device (608).

[0059] The prime mover (610) may refer to any system that may aid in imparting a rotational motion to rotary element(s) (e.g., a rotor) of the DFIG (612). Non-limiting examples of the prime mover (610) may include an engine that may be operable at variable speeds, a gas turbine, a wind turbine, a compressor, or combinations thereof. Hereinafter, for simplicity of illustration, the prime mover (610) is described as the engine capable of being operated at variable speeds. Also, in the description below, the terms “prime mover” and “engine” are interchangeably used. The engine (610) may be an internal combustion engine, an operating speed of which may be varied by the controller (628). More particularly, the engine (610) may be a variable speed reciprocating engine, where the reciprocating motion of a piston is translated into a rotational speed of a crank shaft connected thereto. The engine (610) may be operated by combustion of various fuels including, but not limited to, diesel, natural gas, petrol, liquefied petroleum gas (LPG), biogas, biomass, producer gas, and the like. The engine (610) may also be operated using waste heat cycle. It is to be noted that the scope of the present specification is not limited by the types of fuel and the engine (610) employed in the power generation system (602).

[0060] The DFIG (612) may include a stator (630), a rotor (632), a stator winding (634) disposed on the stator (630), and a rotor winding (636) disposed on the rotor (632). In the DFIG (612), the stator winding (634) and the rotor winding (636) are accessible to facilitate external electrical connections. In some embodiments, both the stator winding (634) and the rotor winding (636) may be multi-phase winding, such as a three-phase winding.

[0061] The DFIG (612) may be mechanically coupled to the engine (610). In some embodiments, the rotor (632) of the DFIG (612) may be mechanically coupled to the crank shaft of the engine (610), such that during operation, rotations of the crank shaft may cause a rotary motion of the rotor (632) of the DFIG (612). In some embodiments, the crank shaft of the engine (610) may be coupled to the rotor (632) of the DFIG (612) through one or more gears. In operation, the DFIG (612) may be configured to generate electrical power, hereafter referred to as a stator power (P_{stator}), at the stator winding (634). Moreover, the DFIG (612) may be configured to generate or absorb a second electrical power, hereafter referred to as a rotor power (P_{rotor}), at the rotor winding (636) depending on an operating speed (ω) of the engine (610). In the embodiment of FIG. 6, a sum of the stator power and the rotor power is hereinafter also referred to as a generator power (P_g).

[0062] The electronic sub-system (614) may include a rotor-side converter (620), one or more line-side converters (622, 624, 626), and a controller (628). The controller

(628) may be representative of one embodiment of the controller (220) of FIG. 2. The controller (628) may be capable of executing program instructions for controlling operations of the power generation system (602). In some embodiments, the prime mover (610), the rotor-side converter (620), and the line-side converters (622, 624, 626) may include controllers / control units / electronics to control their respective operations under a supervisory control of the controller (628). In some embodiments, the controller (628) may be configured to aid in execution of a method of FIG. 7.

[0063] The rotor-side converter (620) may be representative of one embodiment of the first AC-DC converter (210) of FIG. 2. The first line-side converters (622, 624) may be representative of one embodiment of the second AC-DC converter (212) of FIG. 2. Moreover, the second line-side converter (626) may be representative of one embodiment of the second AC-DC converter (215) of FIG. 2. The rotor-side converter (620) may be electrically coupled to the rotor winding (636) of the DFIG (612). Further, the second line-side converter (626) may be electrically coupled to the stator winding (634) of the DFIG (612). In one embodiment, the rotor-side converter (620) and the line-side converters (622, 624, 626) are also coupled to each other. For example, the rotor-side converter (620) is coupled to the line-side converters (622, 624, 626) via a direct-current (DC) link (638).

[0064] In some embodiments, as shown in FIG. 6, the variable frequency electrical devices (604, 606) are electrically coupled to the first line-side converters (622, 624), respectively. Also, the second line-side converter (626) is shown electrically coupled to the fixed frequency electrical device (608). In certain embodiments, the fixed frequency electrical device (608) may be coupled to the stator winding (634) directly or via a transformer.

[0065] In some embodiments, auxiliary power sources, such as a PV power source (616) and/or the energy storage device (618) are electrically coupled to the electronic sub-system (614) at the DC-link (638). The PV power source (616) may include one or more PV arrays (not shown in FIG. 6), where each PV array may include at least one PV module (not shown in FIG. 6). A PV module may include a suitable arrangement of a plurality of PV cells (diodes and/or transistors). The PV power source (616) may generate a DC voltage constituting a solar electrical power (P_s) that depends on solar insolation, weather conditions, and/or time of the day. Accordingly, the PV power source (616) may be configured to supply the solar electrical power (P_s) to the DC-link (638). Although in the ongoing description, the PV power source (616) is described as one embodiment of the auxiliary power source, use of other forms of renewable energy sources capable of generating and/or supplying DC current is also envisioned within the purview of the present specification.

[0066] In some embodiments, the PV power source (616) may be electrically coupled to the electronic sub-system (614) at the DC-link (638) via a first DC-DC converter (640). The first DC-DC converter (640) may be electrically coupled between the PV power source (616) and the DC-link (638). In such embodiments, the solar electrical power (P_s) may be supplied from the PV power source (616) to the DC-link (638) via the first DC-DC converter (640). The first DC-DC converter (640) may be operated as a buck converter, a boost converter, or a buck-boost converter, and may be controlled by the controller (628).

[0067] Although not shown in FIG. 6, in some embodiments, the electronic sub-system (614) may also be coupled to a local power grid, such as, the local power grid (116) as shown in FIGs. 1-3. In one embodiment, the local power grid may be coupled to the DC-link (638), directly or via an AC-DC converter. In such a configuration, a local grid power (P_{lg}) may be supplied to the DC-link (638) from the local power grid directly or via the AC-DC converter. In another embodiment, the local power grid may be coupled to the rotor-side converter (620). In such a configuration, the local grid power (P_{lg}) may be received by the rotor-side converter (620), where the rotor-side converter (620) is configured to convert the received local grid power (P_{lg}) into DC power. The DC power is then supplied to the DC-link (638).

[0068] The energy storage device (618) may include arrangements employing one or more batteries, capacitors, and the like. In some embodiments, the energy storage device (618) may be electrically coupled to the electronic sub-system (614) at the DC-link (638) to supply an energy storage power (P_E) to the DC-link (638). In some embodiments, the energy storage device (618) may be electrically coupled to the electronic sub-system (614) at the DC-link (638) via a second DC-DC converter (642). The second DC-DC converter (642) may be electrically coupled between the energy storage device (618) and the DC-link (638). In such embodiments, the energy storage power (P_E) may be supplied from the energy storage device (618) to the DC-link (638) via the second DC-DC converter (642). The second DC-DC converter (642) may be operated as a buck converter, a boost converter, or a buck-boost converter, and may be controlled by of the controller (628).

[0069] In some embodiments, the power generation system (602) may also include a third DC-DC converter (644). The third DC-DC converter (644) may be electrically coupled between the energy storage device (618) and the PV power source (616). In some embodiments, the third DC-DC converter (644) may be configured to charge the energy storage device (618) via the PV power source (616). For example, in some embodiments, the energy storage device (618) may receive a charging current via the third DC-DC converter (644) from the PV power source (616). The third DC-DC converter (644) may be operated as a buck converter, a boost converter, or a buck-boost converter, and may be controlled by the controller (628). Although in the embodiment of FIG. 6, the first, second, and third DC-DC converters (640, 642, and 644) are shown outside the electronic sub-system (614), some embodiments where one or more of the first, second, and third DC-DC converters (640, 642, and 644) are being part of the electronic sub-system (614) are also envisioned. Moreover, in some embodiments, in addition to being operatively coupled to the engine (610), the DFIG (612), the rotor-side converter (620), and the line-side converters (622, 624, 626), the controller (628) may be operatively coupled to at least one of the first DC-DC converter (640), the second DC-DC converter (642), and the third DC-DC converter (644) to control their respective operations.

[0070] In some embodiments, each of the variable frequency electrical devices (604, 606) and the fixed frequency electrical device (608) are assigned a priority metric. For example, the variable frequency electrical devices (604, 606) are assigned a first priority metric and the fixed frequency electrical device (608) is assigned a second priority metric, where the second priority metric is different from the first priority metric. For instance, the second priority metric may indicate that the supply of the electrical power to the fixed frequency electrical device (608) is prioritized over variable frequency electrical devices (604, 606). Accordingly, the electronic sub-system (614) is configured to supply electrical power desirable to meet the committed load power (P_{cmt}) to the fixed frequency electrical device (608). Moreover, in some embodiments, the electronic sub-system (614) is configured to supply electrical power to the variable frequency electrical devices (604, 606) if a surplus electrical power in excess of the committed load power (P_{cmt}) is available to the electronic sub-system (614).

[0071] The controller (628) is configured to determine the surplus electrical power. In the embodiment of FIG. 6, the surplus electrical power is determined as an amount of the auxiliary electrical power (Ps) which is in excess of the committed load power (P_{cmt}). For example, the auxiliary electrical power (Ps) may be similar to a sum of the solar electrical power (P_s) and the energy storage power (P_E). In configurations where the energy storage device (618) is not present, the auxiliary electrical power (Ps) may be similar to a sum of the solar electrical power (P_s). Moreover, the controller (628) is configured to control the first line-side converters (622, 624) to generate variable frequency electrical power having a frequency determined based on a level of the surplus electrical power.

[0072] In some embodiments, the first line-side converters (622, 624) are configured to generate based on an input power to the first line-side converter (622). For example, in a configuration where the variable frequency electrical device (604) is an electric motor, the first line-side converter (622) may be configured to vary a frequency and/or magnitude of the variable frequency electrical power such that the variable frequency electrical device (604) may be operated at variable speed. In some embodiments, the frequency and/or the magnitude of the variable frequency electrical power may be adjusted by the first line-side converter (622) such that the variable frequency electrical device (604) may be operated at determined revolutions per minute (rpm) and/or determined torque. In some embodiments, in order to maintain the torque, the first line-side converter (622) may be configured to maintain a ratio of the magnitude and the frequency of the variable frequency electrical power at a constant level.

[0073] The first line-side converters (622, 624) then supply the variable frequency electrical power to the variable frequency electrical device (604, 606).

[0074] In some embodiments, the electronic sub-system (614) may include a switch disposed between at least two line-side converters of the one or more line-side converters (622, 624, 626). By way of example, one such switch (646) is shown in FIG. 6. The switch (646) is electrically coupled between the first line-side converter (624) and the second line-side converter (626). The controller (628) may be operatively coupled to the switch (646) and configured to control switching of the switch (646). More particularly, the controller (628) may be configured to turn-on the switch (646) when the variable frequency electrical device (606) and the fixed frequency electrical device (608) are to be operated at a similar frequency.

[0075] In certain embodiments, the second line-side converter (626) may be representative of one embodiment of the second AC-DC converter (212) of FIG. 3. In such configuration, the second line-side converter (626) may be additionally coupled to additional variable frequency electrical devices (not shown in FIG. 6). The second line-side converter (626) may be coupled to the fixed frequency electrical device (608) and the additional variable frequency electrical devices via a two-way switch similar to the two-way switch (308) of FIG. 3. In certain embodiments, the controller (628) may operate the two-way switch (308) to supply electrical power to the additional variable frequency electrical devices when power supply to the fixed frequency electrical device (608) is not desired.

[0076] FIG. 7 is a flowchart (700) of a method of supplying a variable frequency electrical power to a variable frequency electrical device by the DFIG based power generation system (602) of FIG. 6, in accordance with one or more embodiments of the present specification. The method of FIG. 7 is described in conjunction with FIG. 6. The method of FIG. 7 includes blocks (702) - (728).

[0077] At block (702), the method includes receiving an auxiliary electrical power (P_s). In some embodiments, the auxiliary electrical power (P_s) is received by the electronic sub-system (614) from the PV power source (616). More particularly, the auxiliary electrical power (P_s) may be received on the DC-link (638). Optionally, in some embodiments, the method, at block (704), includes receiving a local grid power (P_{lg}). The local grid power (P_{lg}) may be received by the electronic sub-system (614) from a local power grid such as the local power grid (116) [not shown in FIG. 6]. In one embodiment, the local grid power (P_{lg}) may be received on the DC-link (638) directly or via an AC-DC converter, such as, the third AC-DC converter (306). In another embodiment, the local grid power (P_{lg}) may be received by the rotor-side converter (620), where the rotor-side converter (620) is configured to convert the received local grid power (P_{lg}) into DC power. The DC power is then supplied to the DC-link (638). Moreover, at block (706), a committed load power (P_{cmt}) of the fixed frequency electrical device (608) may be determined. The committed load power (P_{cmt}) is representative of power demand from the fixed frequency electrical device (608).

[0078] Furthermore, at block (708), a check may be performed by the controller (628) to determine whether the committed load power (P_{cmt}) is 0 (zero). In some embodiments, the fixed frequency electrical devices 207 may be inactive and does not consume any electrical power. In such situations, the committed load power (P_{cmt}) is zero. At block (708), if it is determined that the committed load power (P_{cmt}) is zero, a variable frequency electrical power may be generated by one or both of the first line-side converters (622, 624) at block (710). In one embodiment, the variable frequency electrical power may be generated as described in block (406) of FIG. 4 based on the auxiliary electrical power (P_s), the local grid power (P_{lg}), or the sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$). Subsequently, at block (712) the variable frequency electrical power may be supplied to the variable frequency electrical devices (604, 606) from the respective first line-side converters (622, 624).

[0079] At block (708), if it is determined that the committed load power (P_{cmt}) is non-zero, another check may be performed by the controller (628) at block (714) to determine whether the sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$) is insufficient to meet the committed load power (P_{cmt}). If it is determined that the sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$) is insufficient to meet the committed load power (P_{cmt}), the DFIG (612) may be operated to at block (716) to generate a generator power (P_g). In some embodiments, the DFIG (612) may be operated at a determined operating speed such that a sum of the auxiliary electrical power, the local grid power, and the generator power ($P_s + P_{lg} + P_g$) is sufficient to meet the committed load power (P_{cmt}). At block (718), the generator power (P_g) may be received by the rotor-side converter (620) and the second line-side converter (626). For example, the stator power may be received by the second line-side converter (626) and the rotor power may be received by the rotor-side converter (620). In some embodiments, the stator power and the rotor power may be converted into DC power by the respective second line-side converter (626) and the rotor-side converter (620) and supplied to the DC-link (638).

[0080] Moreover, at block (720) a fixed frequency electrical power may be generated. In some embodiments, fixed frequency electrical power may be generated at the stator winding (634) of the DFIG (612) based on the operating speed of the DFIG (612). In some embodiments, the fixed frequency electrical power may be generated by the second line-side converter (626) based on the generator power (P_g) and the auxiliary electrical power (P_s) when the local grid power (P_{lg}) is not available. In another embodiment, the fixed frequency electrical power may be generated by the second line-side converter (626) based on the generator power (P_g) and the local grid power (P_{lg}) when the auxiliary electrical power (P_s) is not available. In another embodiment, the fixed frequency electrical power may be generated by the second line-side converter (626) based on the generator power (P_g) and a sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$) when both the auxiliary electrical power (P_s) and the local grid power (P_{lg}) are available. In yet another embodiment, the fixed frequency electrical power may be generated by the second line-side converter

(626) based on only the generator power (P_g) when none of the auxiliary electrical power (P_s) and the local grid power (P_{lg}) are available. Subsequently, the fixed frequency electrical power may be supplied to the fixed frequency electrical device (608) at block (722). In one embodiment, the fixed frequency electrical power may be supplied to the fixed frequency electrical device (608) via the second line-side converter (626). In one embodiment, the fixed frequency electrical power may be supplied to the fixed frequency electrical device (608) via the stator winding (634). The control may then be transferred to block (706).

[0081] At block (714), if it is determined that the sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$) is sufficient to meet the committed load power (P_{cmt}), the DFIG (612) may not need to be operated. In this situation, the committed load power (P_{cmt}) to the fixed frequency electrical device (608) may be provided without operating the DFIG (612) at blocks (720-722). Also, the variable frequency electrical power may be provided to the variable frequency electrical devices (604-606) based on a surplus power over the committed load power (P_{cmt}) at blocks (724-728).

[0082] In some embodiments, at block (720) fixed frequency electrical power may be generated by the second line-side converter (626) based on the auxiliary electrical power (P_s), the local grid power (P_{lg}) and the sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$). Subsequently, the fixed frequency electrical power may be supplied to the fixed frequency electrical device (608) via the second line-side converter (626) at block (722).

[0083] At block (724), the surplus power may be determined by the controller (628) based on the committed load power (P_{cmt}) and the auxiliary electrical power (P_s), the local grid power (P_{lg}), or the sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$). The surplus electrical power may be referred to as an electrical power in excess of the committed load power (P_{cmt}). In certain embodiments, the surplus electrical power may be obtained by subtracting the committed load power (P_{cmt}) from one of the auxiliary electrical power (P_s) (when the local grid power P_{lg} is not available), the local grid power (P_s) (when the auxiliary electrical power P_s is not available), or the sum of the auxiliary electrical power and the local grid power ($P_s + P_{lg}$).

[0084] Moreover, at block (726) the variable frequency power may be generated by one or both of the first line-side converters (622, 624) based on the surplus power. In some embodiments, the frequency of the variable frequency electrical power is based on the surplus electrical power. Subsequently, the variable frequency electrical power may be supplied to the variable frequency electrical devices (604, 606) via the corresponding first line-side converters (622, 624) at block (728).

[0085] Any of the foregoing method blocks and/or system elements may be suitably replaced, reordered, or removed, and additional blocks and/or system elements may be inserted, depending on the needs of a particular application, and that the systems of the foregoing embodiments may be implemented using a wide variety of suitable processes and system elements and are not limited to any particular computer hardware, software, middleware, firmware, microcode, etc.

[0086] Furthermore, in some embodiments, one of more of the foregoing examples, demonstrations, and method blocks may be implemented by suitable code on a processor-based system, such as a general-purpose or special-purpose computer. Different implementations of the systems and methods may perform some or all of the blocks described herein in different orders, parallel, or substantially concurrently. Furthermore, the functions may be implemented in a variety of programming languages, including but not limited to C++ or Java. Such code may be stored or adapted for storage on one or more tangible or non-transitory computer readable media, such as on data repository chips, local or remote hard disks, optical disks (that is, CDs or DVDs), memory or other media, which may be accessed by a processor-based system to execute the stored code. Note that the tangible media may include paper or another suitable medium upon which the instructions are printed. For instance, the instructions may be electronically captured via optical scanning of the paper or other medium, then compiled, interpreted or otherwise processed in a suitable manner if necessary, and then stored in the data repository or memory.

[0087] Systems and methods, in accordance with one or more embodiments, may be used to power some critical and non-critical loads. In one non-limiting example application, a variable frequency electrical device may be a fluid pump for use in irrigation in a farm. In another non-limiting example application, the variable frequency electrical device may be a refrigeration unit of a cold-storage used to store farm produce. In yet another non-limiting example application, the variable frequency electrical device may be a motor employed in a flourmill. In an instance, when a fixed frequency electrical device having higher priority is not present, the variable frequency electrical devices may be supplied with variable frequency electrical power based on the available auxiliary electrical power (P_s) and/or the local grid power (P_{lg}).

[0088] In an instance when one or more fixed frequency electrical device having higher priority are also coupled to the electronic sub-system, such variable frequency electrical devices may be supplied with variable frequency electrical power by the corresponding electronic sub-systems. In such an instance, the frequency of the variable frequency electrical power to be supplied to the variable frequency electrical devices is determined based on the surplus electrical power. In certain embodiments, because of an uncertain nature of a power generation from the auxiliary power source and availability of the local grid power (Plg), there may not be any specific commitment by the owner of the power generation system to the consumers of such variable frequency electrical devices. Accordingly, such variable frequency electrical power may be priced at a rate lower than a rate of a regular utility electrical power or the fixed frequency electrical power. Consequently, use of such excess/surplus electrical power in accordance with some embodiments facilitates electricity at reduced cost. In addition, since the systems and methods, in accordance with one or more embodiments, aids in utilizing the excess/surplus electrical power from the auxiliary/renewable energy power sources, use of fuels such as gasoline, diesel, coal, can be greatly reduced leading to greener environment.

[0089] The present specification has been described in terms of some specific embodiments. They are intended for illustration only, and should not be construed as being limiting in any way. Thus, it should be understood that modifications can be made thereto, which are within the scope of the present specification and the appended claims.

[0090] It will be appreciated that variants of the above disclosed and other features and functions, or alternatives thereof, may be combined to create many other different systems or applications. Various unanticipated alternatives, modifications, variations, or improvements therein may be subsequently made by those skilled in the art and are also intended to be encompassed by the following claims.

CLAIMS

1. An electronic sub-system (104, 204, 304), comprising:

a first alternating current (AC)-direct current (DC) converter (110, 210); and

one or more second AC-DC converters (112, 212, 215) electrically coupled to the first AC-DC converter (110, 210) via a DC-link (114, 214), wherein at least one second AC-DC converter (112, 212) of the one or more second AC-DC converters (112, 212, 215) is configured to be electrically coupled to at least one variable frequency electrical device (106, 206),

wherein the electronic sub-system (104, 204, 304) is configured to be electrically coupled to at least one of an auxiliary power source (108, 208) to receive an auxiliary electrical power or a local power grid (116) to receive a local grid power, and wherein the at least one second AC-DC converter (112, 212) is configured to supply a variable frequency electrical power to the at least one variable frequency electrical device (106, 206) at a frequency determined based on a level of the auxiliary electrical power, the local grid power, or a sum of the auxiliary electrical power and the local grid power.

2. The electronic sub-system (104, 204, 304) of claim 1, wherein the first AC-DC converter (110, 210) and one or more second AC-DC converters (112, 212, 215) are configured to convert a DC power into an AC power, or the AC power into DC power.

3. The electronic sub-system (104, 204, 304) of claim 1, wherein the DC-link (114, 214) is electrically coupled to the auxiliary power source (108, 208).

4. The electronic sub-system (104, 204, 304) of claim 3, wherein the first AC-DC converter (110, 210) is electrically coupled to the local power grid (116) and configured to:

convert the local grid power into DC power; and

supply the DC power to the DC-link.

5. The electronic sub-system (104, 204, 304) of claim 3, wherein the DC-link (114, 214) is electrically coupled to the local power grid (116).

6. The electronic sub-system (104, 204, 304) of claim 1, wherein at least one other second AC-DC converter (212, 215) is electrically coupled to at least one fixed frequency electrical device, and the first AC-DC converter (210) is electrically coupled to a generator (218) to receive a generator power, wherein the at least one other second AC-DC converter (212, 215) is configured to:

generate a fixed frequency electrical power based on the generator power, the auxiliary electrical power, the local grid power, or a sum of one or more of the generator power, the auxiliary electrical power, and the local grid power; and

supply the fixed frequency electrical power to the at least one fixed frequency electrical device (207).

7. The electronic sub-system (104, 204, 304) of claim 6, wherein the generator (218) is a synchronous generator or asynchronous generator.

8. The electronic sub-system (104, 204, 304) of claim 6, further comprising a controller (220) operatively coupled to one or more of the first AC-DC converter (110, 210), the one or more second AC-DC converters (112, 212, 215), and the at least one auxiliary power sources (108, 208), wherein the controller (220) is configured to determine a surplus electrical power based on a committed load power to the at least one fixed frequency electrical device and one or more of the auxiliary electrical power, the local grid power, or a sum of the auxiliary electrical power and the local grid power.

9. The electronic sub-system (104, 204, 304) of claim 8, wherein the surplus electrical power is an electrical power in excess of the committed load power, and wherein the frequency of the variable frequency electrical power is determined based on the surplus electrical power.

10. The electronic sub-system (104, 204, 304) of claim 1, wherein the at least one second AC-DC converter (212) is coupled to the at least one variable frequency electrical device (206) via a two-way switch (308).

11. A power generation system (102, 202, 302), comprising:

a generator (218) configured to generate a generator power;

one or more auxiliary power sources (108, 208) configured to generate an auxiliary electrical power;

an electronic sub-system (104, 204, 304) electrically coupled to the generator (218) and the one or more auxiliary power sources (108, 208), and comprising:

a first alternating current (AC)-direct current (DC) converter (110, 210) electrically coupled to the generator; and

one or more second AC-DC converters (112, 212, 215) electrically coupled to the first AC-DC converter (110, 210) via a DC-link (114, 214), wherein at least one second AC-DC converter (112, 212) of the one or more second AC-DC converters is configured to be electrically coupled to at least one variable frequency electrical device (106, 206) having a first priority metric, and wherein the DC-link (114, 214) is coupled to at least one of the one or more auxiliary power sources (108, 208) to receive the auxiliary electrical power or a local power grid (116) to receive a local grid power, and

wherein the at least one second AC-DC converter (112, 212) is configured to supply a variable frequency electrical power to the at least one variable frequency electrical device (106, 206) at a frequency determined based on a level of a surplus electrical power.

12. The power generation system (102, 202, 302) of claim 11, wherein at least one second AC-DC converter (212, 215) of the one or more second AC-DC converters (112, 212, 215) is electrically coupled to at least one fixed frequency electrical device (207) having a second priority metric, wherein the second priority metric is different from the first priority metric.

13. The power generation system (102, 202, 302) of claim 12, wherein the electronic sub-system further (104, 204, 304) comprises a controller (220) operably coupled to the first AC-DC converter (110, 210), the one or more second AC-DC converters (112, 212, 215), and the one or more auxiliary power sources (108, 208), wherein the controller (220) is configured to determine the surplus electrical power

based on a committed load power to the at least one fixed frequency electrical device (207), and one or more of the generator power, the auxiliary electrical power, the local grid power, or a sum of the auxiliary electrical power and the local grid power.

14. The power generation system (102, 202, 302) of claim 12, wherein the electronic sub-system (104, 204, 304) further comprises a controller (220) operably coupled to the first AC-DC converter (110, 210), the one or more second AC-DC converters (112, 212, 215), and the one or more auxiliary power sources (108, 208), wherein the controller (220) is configured to determine the surplus electrical power based on a committed load power to the at least one fixed frequency electrical device (207), and one or more of the auxiliary electrical power, the local grid power, or a sum of the auxiliary electrical power and the local grid power.

15. The power generation system (102, 202, 302) of claim 14, wherein the electronic sub-system (104, 204, 304) further comprises a switch between at least two second AC-DC converters of the one or more second AC-DC converters, wherein the controller is configured to control switching of the switch.

16. The power generation system (102, 202, 302) of claim 15, wherein the controller is configured to turn-on the switch when the at least one variable frequency electrical device and the at least one fixed frequency electrical device are to be operated at a similar frequency.

17. A method comprising:

receiving (502) at least one of an auxiliary electrical power and a local grid power, wherein the auxiliary electrical power is received from an auxiliary power source (108, 208) by a direct current (DC) link (114, 214) between a first alternating current (AC)-DC converter (110, 210) and one or more second AC-DC converters (112, 212, 215) and the local grid power is received by the DC-link (114, 214) or by the first AC-DC converter (110, 210) from a local power grid (116), and wherein at least one second AC-DC converter (112, 212) of the one or more second AC-DC converters is coupled to at least one variable frequency electrical device (106, 206);

generating (510, 526), by the at least one second AC-DC converter (112, 212), a variable frequency electrical power having a frequency determined based on at least one of the auxiliary electrical power, the local grid power, or a sum of the auxiliary electrical power and the local grid power; and

supplying (512, 528), by the at least one second AC-DC converter (112, 212), the variable frequency electrical power to the at least one variable frequency electrical device (106, 206).

18. The method of claim 17, wherein the first AC-DC converter (110, 210) is coupled to a generator (218), and wherein one or more other second AC-DC converters (215) are coupled to at least one fixed frequency electrical device, and wherein the method further comprises:

operating (516) the generator (218) to generate a generator power when a sum of the auxiliary electrical power and the local grid power is insufficient to meet a committed load power to the at least one fixed frequency electrical device (207); and

supplying (522) a fixed frequency electrical power to the at least one fixed frequency electrical device (207) via the one or more other second AC-DC converters (215).

19. The method of claim 18, wherein generating the variable frequency electrical power comprises determining (524) a surplus electrical power based on the committed load power and the at least one of the auxiliary electrical power, the local grid power, or the sum of the auxiliary electrical power and the local grid power, wherein the frequency of the variable frequency electrical power is determined based on the surplus electrical power.

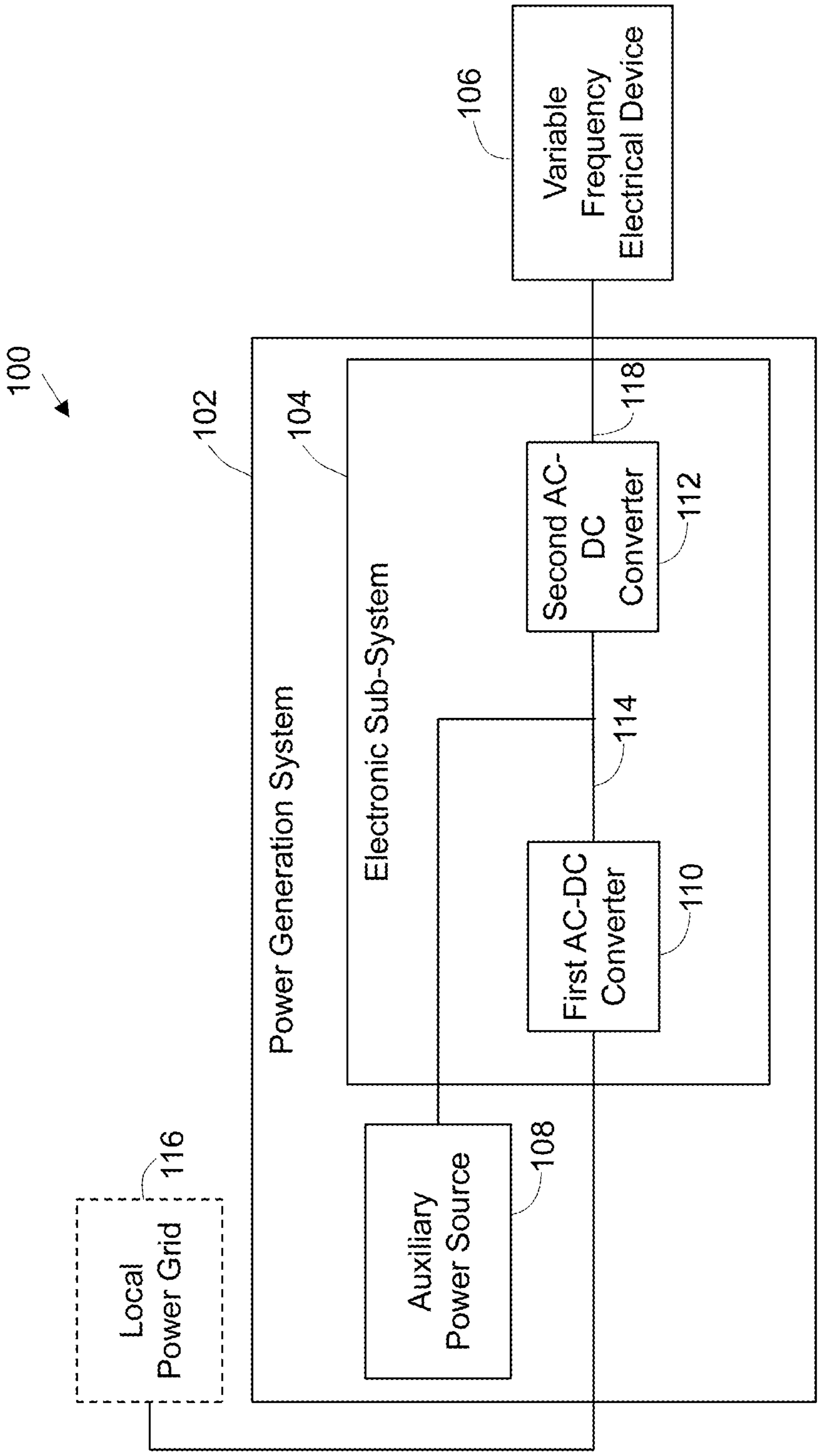
100
102
104
106
Variable Frequency Electrical Device
118
Second AC-DC Converter
112
Power Generation System
Electronic Sub-System
114
First AC-DC Converter
110
116
Local Power Grid
Auxiliary Power Source
108

FIG. 1

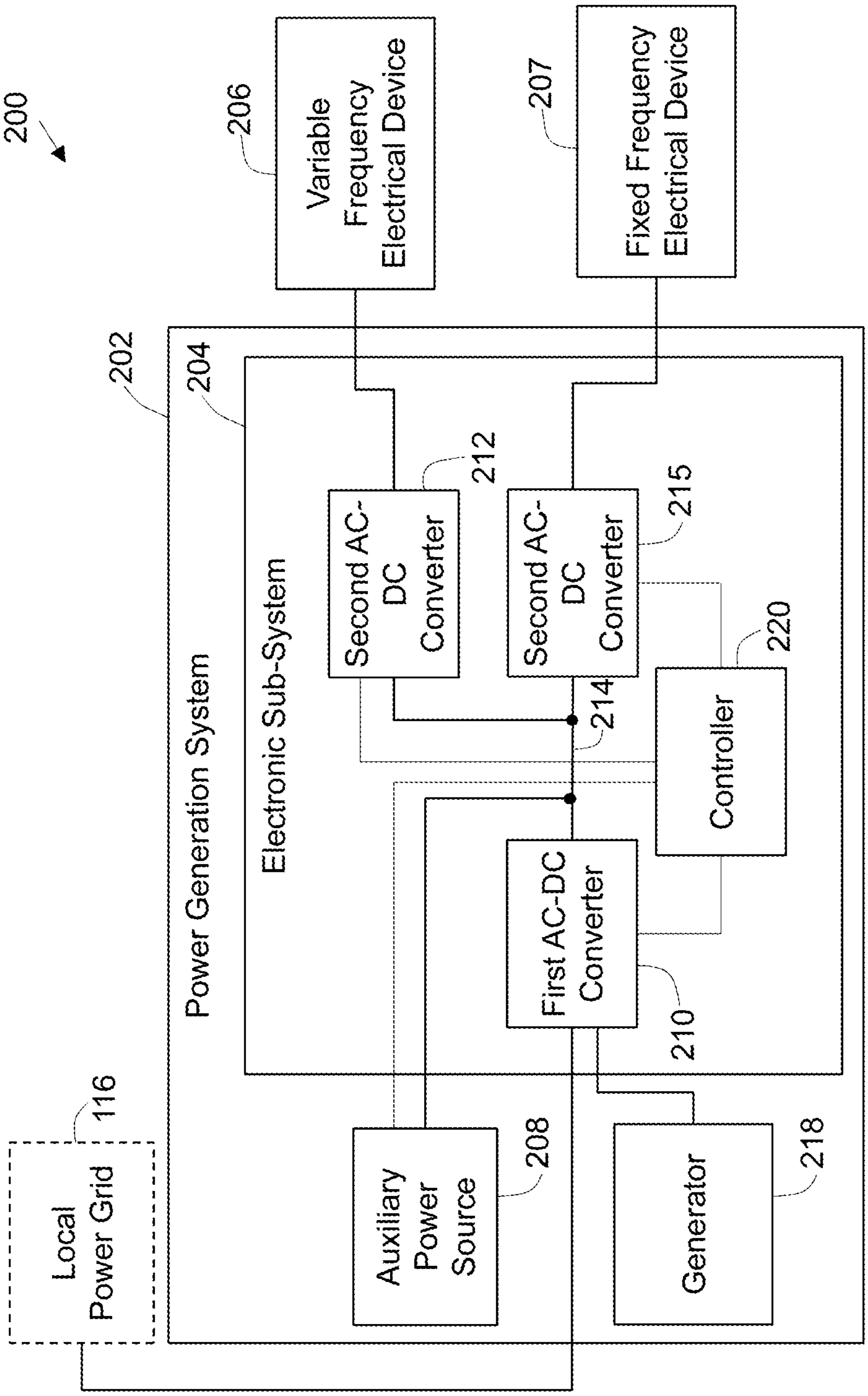
200
206
Variable Frequency Electrical Device
207
Fixed Frequency Electrical Device
202
Power Generation System
204
Electronic Sub-System
212
Second AC-DC Converter
215
Second AC-DC Converter
214
220
Controller
First AC-DC Converter
210
116
Local Power Grid
Auxiliary Power Source
208
Generator
218

FIG. 2

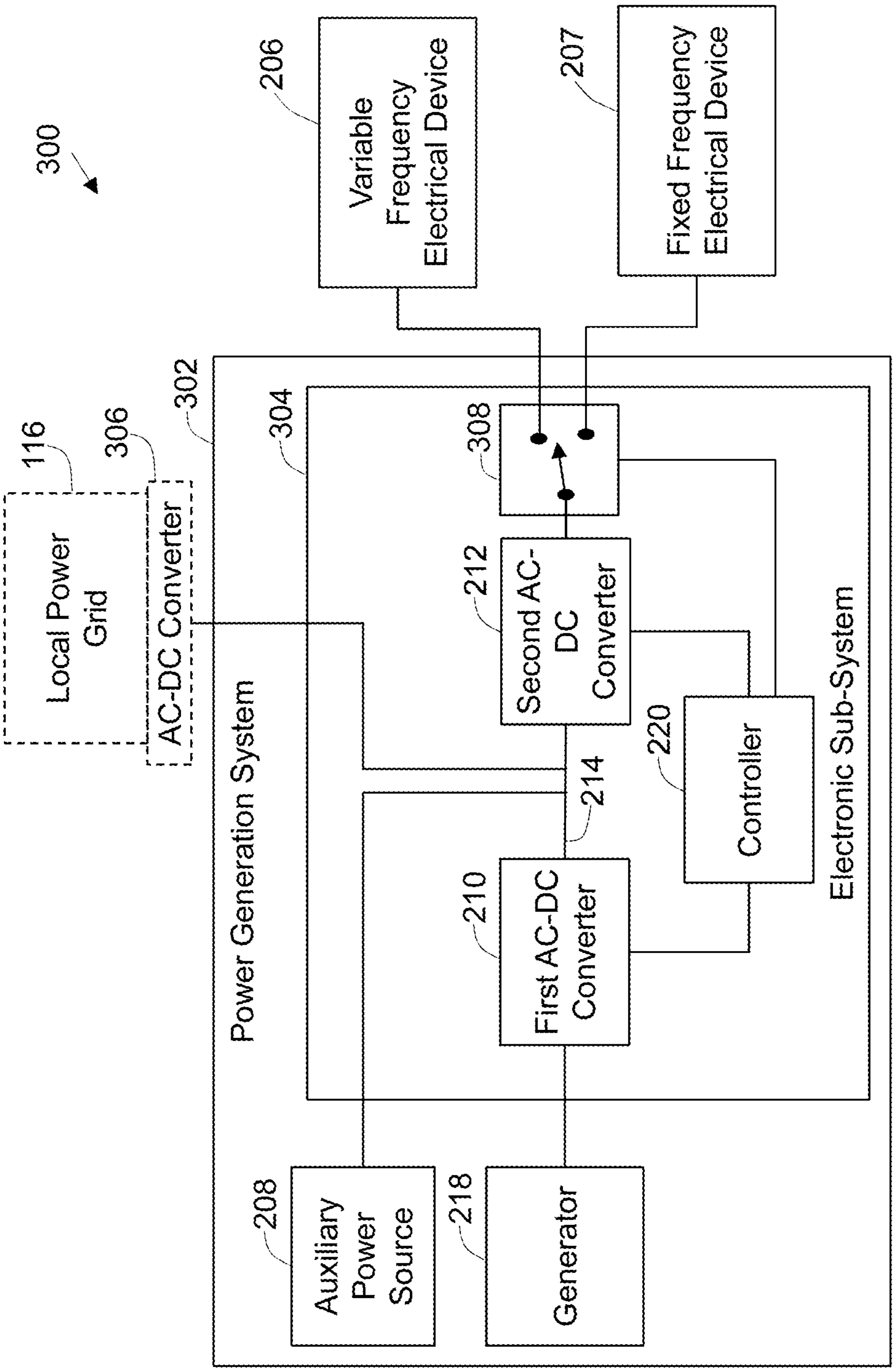
300
206
Variable Frequency Electrical Device
207
Fixed Frequency Electrical Device
116
Local Power Grid
306
AC-DC Converter
302
304
308
212
Second AC-DC Converter
214
220
Controller
210
First AC-DC Converter
Power Generation System
Electronic Sub-System
208
Auxiliary Power Source
218
Generator

FIG. 3

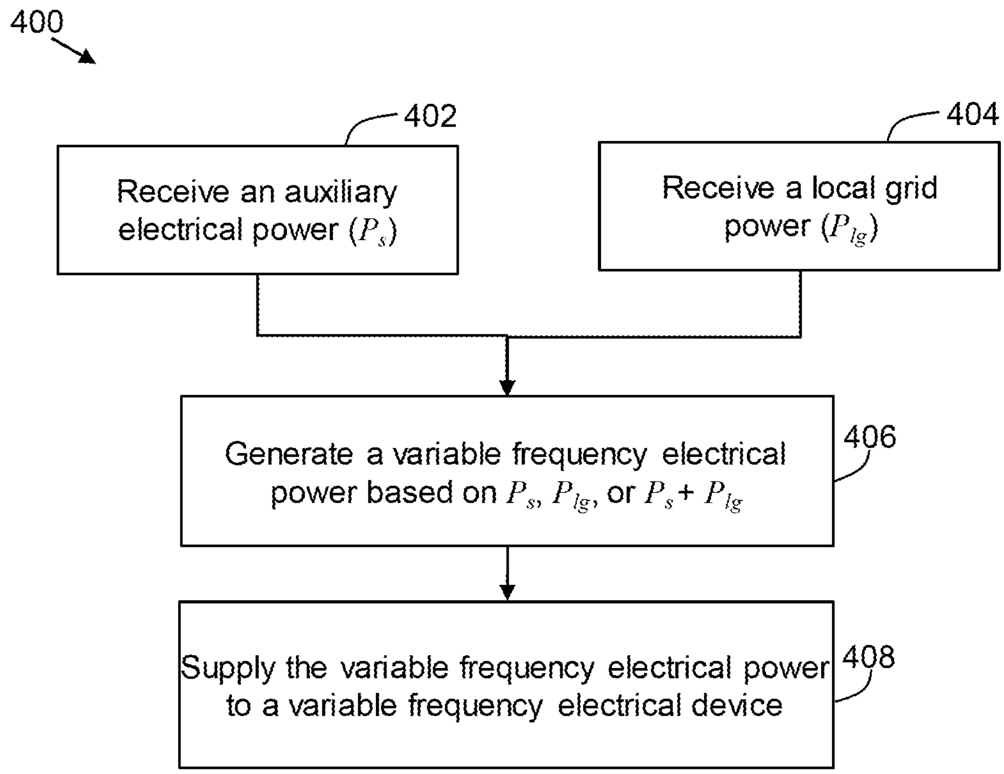
400
402
Receive an auxiliary electrical power (P_s)
404
Receive a local grid power (P_{lg})
Generate a variable frequency electrical power based on P_s, P_{lg}, or $P_s + P_{lg}$
406
Supply the variable frequency electrical power to a variable frequency electrical device
408

FIG. 4

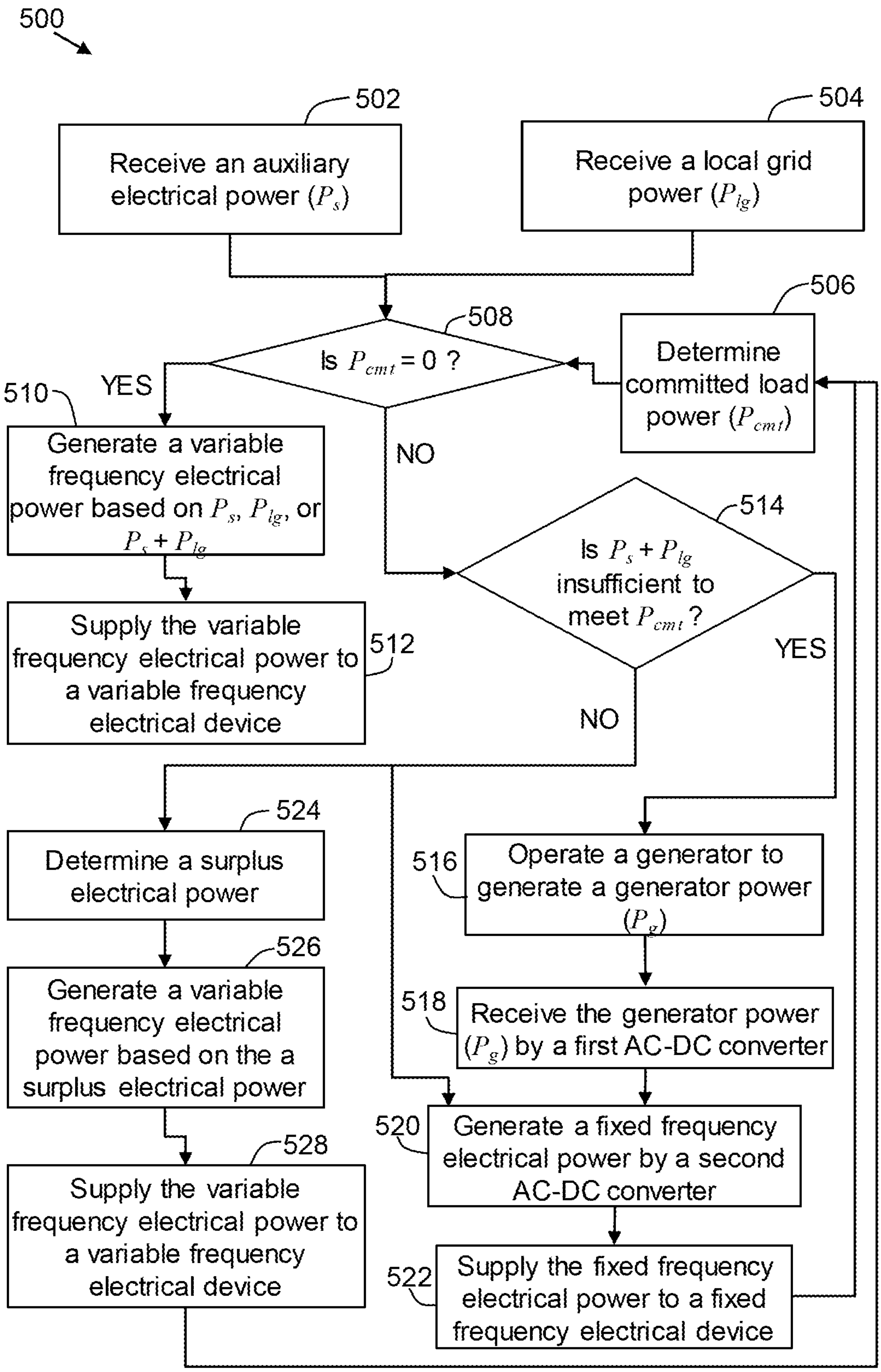
500
502
Receive an auxiliary electrical power (P_s)
504
Receive a local grid power (P_{lg})
506
Determine committed load power (P_{cmt})
508
Is $P_{cmt} = 0$?
YES
NO
510
Generate a variable frequency electrical power based on P_s, P_{lg}, or $P_s + P_{lg}$
512
Supply the variable frequency electrical power to a variable frequency electrical device
514
Is $P_s + P_{lg}$ insufficient to meet P_{cmt} ?
YES
NO
516
Operate a generator to generate a generator power (P_g)
518
Receive the generator power (P_g) by a first AC-DC converter
520
Generate a fixed frequency electrical power by a second AC-DC converter
522
Supply the fixed frequency electrical power to a fixed frequency electrical device
524
Determine a surplus electrical power
526
Generate a variable frequency electrical power based on the a surplus electrical power
528
Supply the variable frequency electrical power to a variable frequency electrical device

FIG. 5

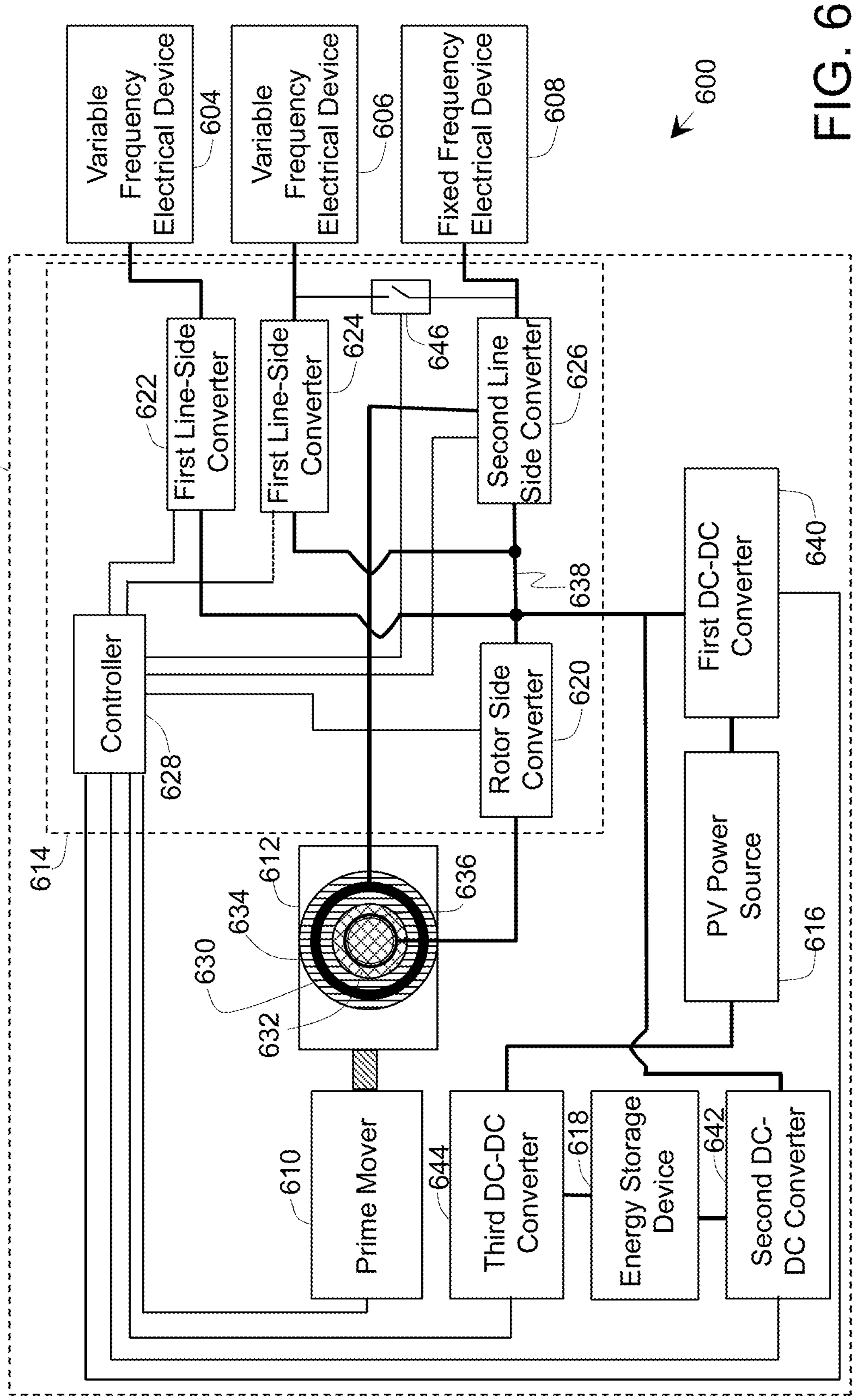
Variable Frequency Electrical Device
604
Variable Frequency Electrical Device
606
Fixed Frequency Electrical Device
608
600
602
First Line-Side Converter
622
First Line-Side Converter
624
646
Second Line Side Converter
626
638
First DC-DC Converter
640
Controller
628
Rotor Side Converter
620
614
612
636
634
630
632
PV Power Source
616
Prime Mover
610
Third DC-DC Converter
644
618
Energy Storage Device
642
Second DC-DC Converter

FIG. 6

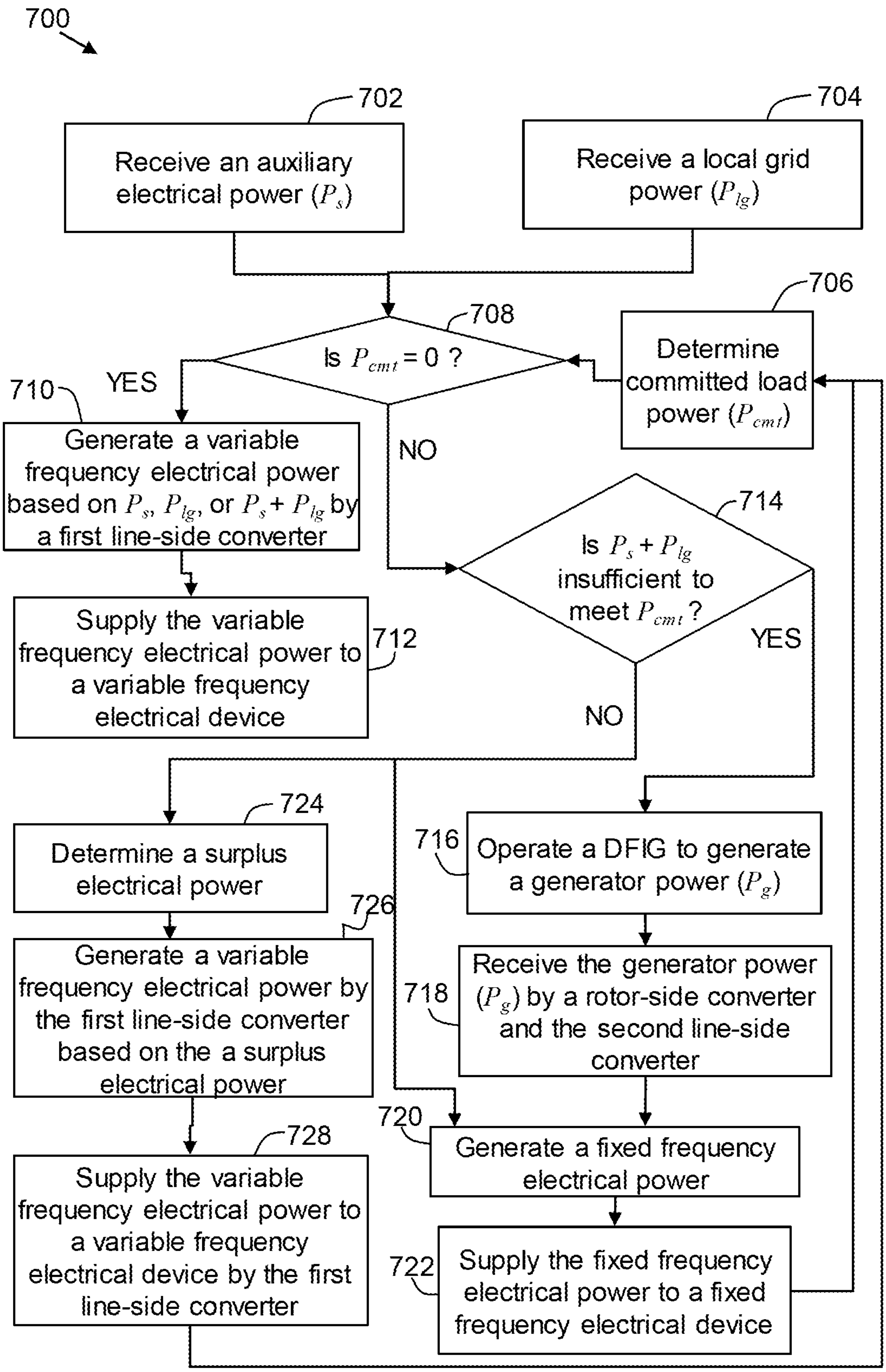
700
702
Receive an auxiliary electrical power (P_s)
704
Receive a local grid power (P_{lg})
706
Determine committed load power (P_{cmt})
708
Is P_{cmt} = 0 ?
YES
NO
710
Generate a variable frequency electrical power based on P_s, P_{lg}, or $P_s + P_{lg}$ by a first line-side converter
712
Supply the variable frequency electrical power to a variable frequency electrical device
714
Is $P_s + P_{lg}$ insufficient to meet P_{cmt} ?
YES
NO
724
Determine a surplus electrical power
726
Generate a variable frequency electrical power by the first line-side converter based on the a surplus electrical power
728
Supply the variable frequency electrical power to a variable frequency electrical device by the first line-side converter
716
Operate a DFIG to generate a generator power (P_g)
718
Receive the generator power (P_g) by a rotor-side converter and the second line-side converter
720
Generate a fixed frequency electrical power
722
Supply the fixed frequency electrical power to a fixed frequency electrical device

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2017/046691

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02J1/14 H02J3/14 H02J3/38
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F25B H02J

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2013/263613 A1 (BITTNER JOHN D [US] ET AL) 10 October 2013 (2013-10-10) paragraphs [0005], [0006], [0016]; figure 2b	1,10,11, 17
X	US 2013/043724 A1 (BOSCH GMBH ROBERT) 21 February 2013 (2013-02-21) paragraphs [0022] - [0024], [0044], [0059] - [0061]; figure 1	1-5,11, 17
X	US 2012/187764 A1 (ROCKENFELLER UWE [US] ET AL) 26 July 2012 (2012-07-26) paragraphs [0017], [0018], [0030]; figures 6, 7	1,11,17
A	US 2013/187464 A1 (SMITH MARK BERRY [US] ET AL) 25 July 2013 (2013-07-25) the whole document	6,12,18

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
14 November 2017	21/11/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Colombo, Alessandro

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2017/046691

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			US	2013043723	A1	21-02-2013
			US	2016149414	A1	26-05-2016
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			CN	102624077	A	01-08-2012
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US 2013187464	A1	25-07-2013	US	2013186450	A1	25-07-2013
			US	2013187464	A1	25-07-2013