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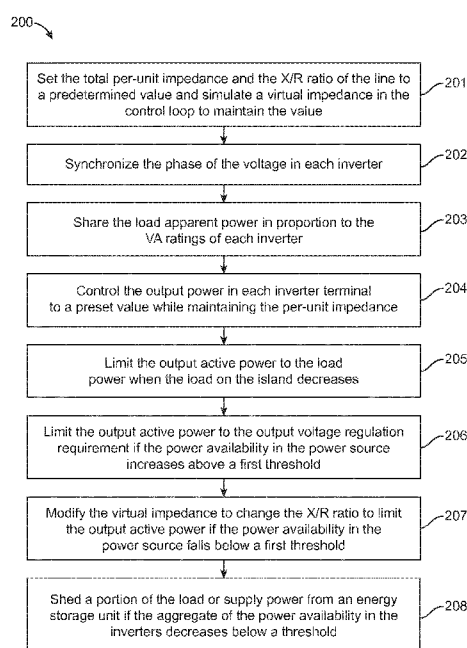


FIG. 2

(57) Abstract: The invention proposes a method of load sharing between two or more inverters having different volt ampere (VA) ratings connected in a micro-grid. The method includes setting a total per-unit impedance of a line joining the inverter terminal to its point of common coupling (PCC) and an X/R ratio of the line to predetermined values. A virtual impedance simulated in a control loop of each inverter is modified to maintain the set value. The output at the terminals is controlled to preset values while maintaining the per-unit impedance at the initial value. Also, a fuzzy logic controller that may be incorporated in the control logic of the microgrid system to maintain load sharing is disclosed. The inverter voltages may be synchronized using GPS signals. Also, the application of virtual impedance for the purpose of load sharing does not require communication between the inverters.

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**GRID-CONNECTED P-V INVERTER SYSTEM AND METHOD OF LOAD
SHARING THEREOF**

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] None.

FIELD OF THE INVENTION

[0002] The disclosure relates generally to power sharing and in particular to a method of load sharing in a distributed system that has two or more inverters having different VA ratings.

DESCRIPTION OF THE RELATED ART

[0003] Grid-connected inverters are usually designed to operate in synchronism with the grid for active power injection, typically at UPF. A number of discrete power generating units such as photovoltaic (PV) panels or wind turbines may be connected to these inverters, which is generally referred to as a microgrid. Whenever the grid power fails, for example line tripping due to faults or load shedding, the inverters are designed to detect the failure and switch off. Several algorithms are used to detect this event denoted as islanding event. There is a need for continued operation of photovoltaic inverters (PVI) in the island. This is especially required if the islanding happens for extended hours, where in spite of having a power source PV, it may not be utilized. While operating under such islanded situations, there are several important aspects to be considered. Firstly, inverters connected in the island may have varying capacities. Secondly, inverters may be distributed over a large area and the feasibility and/or desirability of communication between them would need to be considered. Thirdly, in such islanded operations, with the load being distributed over the island, load sensing may not be feasible.

[0004] Prior work involves droop control technique for operation of such islanded inverters. Droop technique involves increasing or decreasing the active or reactive power flow based on the system parameter whichever is chosen to droop based on the load demand. One common droop practice is P-f and Q-V droop. As the load active power demand increases the frequency droops and the PVIs inject more active power to restore the frequency. A similar action is done with respect to reactive power and voltage. Droop control obviates the need for sharing of control status information among inverters.

[0005] Sharing of loads among inverters is performed while having communication between them. Load sharing in such cases is expediently controlled through control loop, Master/Slave operation. Nevertheless, there may be inaccuracies in sharing of load due to the practice of droop technique with mismatched feeder impedances.

[0006] “Control System Design, Analysis, and Simulation of a Photovoltaic Inverter for Unbalanced Load Compensation in a Microgrid,” Elizabeth K. Tomaszewsk (2015) presents a control scheme for a single-stage three-phase Photovoltaic (PV) converter with negative sequence load current compensation. A Chinese application CN106300324A discloses a graded adaptive coordination control method for a DC microgrid energy storage system. “Droop Control of Parallel Inverters with LCL Filter and Virtual Output Impedance”, Anuroop et al. (2013), discloses a simple and effective droop control strategy for two three-phase inverters to operate in stand-alone manner. CN102623993A discloses a method for islanding microgrid control and optimization based on rotating coordinate virtual impedance. Systems and methods for power sharing in a direct current (DC) network is disclosed in US published application US 20170180006A1. The present disclosure describes systems and method for load sharing between two or more inverters connected in a microgrid.

SUMMARY OF THE INVENTION

[0007] In various embodiments a method of load sharing between two or more inverters having equal or different volt-ampere (VA) ratings and operating in parallel in a microgrid, in particular an islanded microgrid, is disclosed. Each inverter includes a power source and a voltage control loop that has a control logic, a voltage source inverter, a phase angle generating system, a GPS receiver, and a filter, in particular an LCL filter, to maintain voltage at a terminal. Each inverter terminal is connected to their respective points of common coupling (PCC) by a suitable line thereof and connected to a load distributed in the microgrid. The method includes setting the total per-unit impedance between the inverter terminal and its PCC to a predetermined value with a predetermined ratio of reactance to resistance (X/R) of the impedance of the line which interfaces the inverter to its own PCC and simulating a virtual impedance in the control loop configured to maintain the predetermined value. The phase of the voltage in each of the inverters is synchronized. In various embodiments, the method includes sharing the load apparent power among the two or more inverters in proportion to the VA ratings. The output voltages generated by the inverters are controlled at a preset value while the per-unit impedance is maintained at an initial value at the two or more inverter units.

[0008] In some embodiments when the load on the island decreases the output active power is limited to the load power by reducing the power injected into the PCC so as to maintain constant voltage at the terminal. In one embodiment when the power availability in the power source increases above a first threshold, the output active power at an inverter is limited to the output voltage regulation requirement in an inverter.

[0009] In another embodiment the power availability in the power source falls below the first threshold, the output active power is limited to the maximum active power availability in an inverter. The virtual impedance simulated in the control loop is modified to change the X/R ratio of the impedance of the inverter to reduce the output

active power. In some embodiments, a portion of the load in proportion to the power non-availability or power is supplied from an energy storage unit to the portion of the load, when the aggregate of the power availability in the inverters falls below a threshold.

[0010] In various embodiments, the power source is selected from a wind energy source, a solar power array, a fuel cell, a biomass reactor driven generator or a combination thereof. In various embodiments, the voltages behind the virtual impedances of respective inverters are synchronized by deriving their phase angles from a GPS receiver attached to each inverter.

[0011] The invention in various embodiments includes a fuzzy logic controller to maintain power sharing between two or more inverters connected in a microgrid. The fuzzy logic controller includes a fuzzifier, a fuzzy logic inference engine and a defuzzifier. The fuzzifier receives one or more crisp input values and converts the crisp input values to one or more linguistic variables using membership functions stored in a fuzzy knowledge base. In some embodiments, the input values include an error signal that is a ratio of the actual voltage in an inverter to the maximum possible voltage that can be delivered by the inverter. The fuzzy logic inference engine processes the linguistic variables and generates a fuzzy output. The defuzzifier that converts the fuzzy output to crisp output values includes the values of X/R ratio that increase or decrease the active power delivered while maintaining the per-unit impedance.

[0012] In some embodiments, the controller computes the virtual impedance values (R,X) and the virtual drop in the direct and quadrature axis voltages making use of the measured instantaneous inverter output currents.

[0013] In various embodiments, the microgrid control system incorporating the fuzzy logic controller is disclosed. The fuzzy logic controller simulates the virtual impedance to modify the X/R ratio and stabilizes the microgrid.

[0014] An electrical system for grid power injection is disclosed. The system includes an electrical grid providing ac power to a load, a microgrid having one or more inverter units comprising equal or different VA ratings operating in parallel in a microgrid, and one or more nodes connecting the electrical grid, the microgrid comprising one or more inverter units and a load distributed in the microgrid. Each inverter unit comprises a control logic, a voltage source inverter, a phase angle generating system, a GPS receiver, a filter, in particular an LCL filter, to maintain voltage at the terminal connected to a point of common coupling (PCC) by a suitable line thereof. In some embodiments, the total impedance between the inverter terminals and the PCC are initially set to a predetermined value with a predetermined X/R ratio. In various embodiments, the system shares the load apparent power among the two or more inverters in proportion to their VA ratings and seamlessly transits to the islanded mode of operation. In various embodiments, the output active power of each inverter is controlled by changing the X/R ratio of impedance to balance the reactive power and maintain the apparent power in each of the inverters in proportion to the VA ratings thereof while maintaining a per unit impedance at the two or more inverter units at an initial value thereof.

[0015] In various embodiments the power source is selected from a wind energy source, a solar power array, a fuel cell, a biomass reactor driven generator or a combination thereof. In some embodiments, the control logic comprises a fuzzy logic controller or any other suitable controller to maintain power sharing between two or more inverters connected in the system.

[0016] In some embodiments when the load on the island decreases the voltage control loop reduces the output active power injected into the network so as to maintain constant voltage at the terminal. In some embodiments, the output active power is limited to the load requirements.

[0017] In one embodiment when the power availability in the power source increases above a first threshold the voltage in the DC bus connecting the power source and the inverter is allowed to vary, to limit the output active power of the inverter. The output active power is limited to the output voltage regulation requirement in the inverter.

[0018] In another embodiment when the power availability in the power source panel falls below a first threshold, the virtual impedance is modified to change the X/R ratio of the line of the inverter to reduce the output active power. The output active power is limited to the maximum active power availability in the inverter.

[0019] In some embodiments when the power availability in the power source falls below a second threshold thereby limiting the power availability from the power source, suitable load is shed or power in proportion to the power non-availability is drawn from an energy storage unit. In various embodiments, the inverters are synchronized using GPS signals obtained from a GPS receiver attached to each inverter.

[0020] This and other aspects are disclosed herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] The invention has other advantages and features which will be more readily apparent from the following detailed description of the invention and the appended claims, when taken in conjunction with the accompanying drawings, in which:

[0022] FIG. 1 illustrates an electrical system that performs load sharing in proportion to the VA rating of inverters in a microgrid system.

[0023] FIG. 2 illustrates a method of load sharing in proportion to the VA rating of inverters in a microgrid system.

[0024] FIG. 3A illustrates a fuzzy logic controller.

[0025] FIG. 3B illustrates a flowchart of the operation of a fuzzy logic controller used in load sharing in a microgrid.

[0026] FIG. 4A illustrates a per-phase equivalent circuit for two PV-inverter with LCL filters.

[0027] FIG. 4B illustrates the virtual impedance pertaining to the inverters

[0028] FIG. 4C illustrates virtual impedance implementation with fuzzy logic controller for parallel operation of PV inverters in islanded micro-grid.

[0029] FIG. 4D shows control block diagram for operation of PV-inverter with LCL filter.

[0030] Referring to the drawings, like numbers indicate like parts throughout the views.

DETAILED DESCRIPTION

[0031] While the invention has been disclosed with reference to certain embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted without departing from the scope of the invention. In addition, many modifications may be made to adapt to a particular situation or material to the teachings of the invention without departing from its scope.

[0032] Throughout the specification and claims, the following terms take the meanings explicitly associated herein unless the context clearly dictates otherwise. The meaning of "a", "an", and "the" include plural references. The meaning of "in" includes "in" and "on." Referring to the drawings, like numbers indicate like parts throughout the views. Additionally, a reference to the singular includes a reference to the plural unless otherwise stated or inconsistent with the disclosure herein.

[0033] The invention in its various embodiments proposes a method and a system of load sharing between two or more inverters connected in a microgrid. The system is simple, reliable and includes two or more inverters in a microgrid without centralized communication and intercommunication among the inverters. The method uses the concept of virtual impedance for load sharing between two or more inverters.

[0034] In various embodiments, an electrical system **100** for grid power injection is disclosed. The system as shown in FIG. 1 includes an electrical grid that supplies ac power **140** to loads **131, 132, 133**, a microgrid containing one or more inverter units **110, 120** of equal or different volt-ampere (VA) ratings connecting to their respective distributed load **131, 132, 133** and one or more nodes **151, 152, 153** that connect the grid **140**, the microgrid having one or more inverters units **110, 120** and the load at a point of common coupling (PCC). Each inverter unit **110** and **120** in the microgrid includes a power source **117, 127** that supplies power to the respective inverter unit as illustrated in FIG. 1. Each inverter unit **110, 120** further includes a control logic **111, 121** a voltage

source inverter (VSI) **113, 123**, a phase angle generating system, a GPS receiver and a respective LCL filter **115, 125**. Each inverter is connected to the respective distributed load **131, 132, 133** at nodes **151, 152, 153**. The control logic **111**, the voltage source inverter (VSI) **113, 123**, the phase angle generating system, the GPS receiver and the LCL filter **115, 125** together form a control loop that maintains voltage at the terminals. Each inverter terminal is connected to its point of common coupling (PCC) via a suitable line **112, 122**. In some embodiments the total per-unit impedance of the line **112, 122** connecting the inverter terminals and the PCC are set to a predetermined value with a predetermined ratio of reactance to resistance (X/R) of the impedance of the line, which interfaces the inverter to its own PCC. A virtual impedance simulated at the control loop maintains the per-unit impedance of the line **112, 122** and the X/R ratio. The virtual impedance is simulated as virtual voltage drop, that acts as an input to modify the voltage reference. In various embodiments, in islanded mode of operation the system shares the required load apparent power among the two or more inverters in proportion to the VA ratings of each inverter. The apparent power shared among the inverters is maintained in each inverter. In various embodiments, to maintain the apparent power sharing in each inverter the output active power at each inverter terminal is controlled by changing the X/R ratio of impedance that connects the inverter terminal to the PCC. The reactive power automatically changes to maintain the apparent power while maintaining the per unit value of total impedance at the two or more inverter units connected in the microgrid.

[0035] In various embodiments, the power source may include any intermittent source of power such as a PV module, a wind energy source, a fuel cell, a biomass reactor driven generator or a combination of any of these sources. In various embodiments the control logic may include a distributed control methodology comprising a controller for a PV based AC microgrid system. The controller is responsible for a desirable trajectory of the states of the microgrid. The controller may include a fuzzy logic controller or any

other suitable controller that improves the performance of the system. The fuzzy logic controller in various embodiments maintains power sharing between the two or more inverters included in the distributed system.

[0036] In some embodiments, when the load on the island decreases, the voltage control loop reduces the power injected into the network to maintain constant voltage at the terminal. Hence the dc voltage at the output of the power source connected to the inverter automatically reaches a value corresponding to the power output. In some embodiments the output active power is limited to the load requirements.

[0037] In one embodiment, as the power availability in the power source increases above a first threshold, the voltage in the DC bus **119, 129** connecting the power source **117, 127** and the inverter unit **110, 120** is allowed to vary so as to limit the output active power available at the inverter. The output active power is limited to the output voltage regulation requirement in an inverter.

[0038] In another embodiment, as the power availability in the power source decreases below a first threshold, the virtual impedance simulated in the control loop is modified to change the X/R ratio of impedance of the line while maintaining the total per unit impedance of the line. As the ratio of X/R is increased, the active power delivered is limited to the desired value and the inverter maintains the apparent power delivered constantly by increasing the reactive power flow. The output active power is limited to the maximum active power availability in an inverter. The remaining load is shared by the other inverters in the system while keeping the apparent power shared still in proportion to their VA ratings.

[0039] In yet another embodiment, when the when the aggregate of the power availability in the inverters fall below a threshold the system may not be able to maintain the apparent power requirement at the load. Hence suitable load that is in proportion to the power non-availability is shed to reduce the apparent power requirement or the

required power may be fed from an energy storage unit. In various embodiments, the inverter voltages are synchronized using GPS signals obtained from a GPS receiver attached to each inverter.

[0040] In some embodiments, the power availability in the source power depends on the level of solar irradiation in the solar panel, in solar power systems. In wind energy systems the power drawn by the wind turbine depends on the speed of the wind or the pitch angle of the blades of the turbine.

[0041] In various embodiments of the invention, a method **200** of load sharing between two or more inverters that have different VA ratings is disclosed. The inverters operate in parallel in an islanded microgrid and are connected to their respective loads by a suitable line at a point of common coupling (PCC). Each inverter includes a power source and voltage control loop that includes a control logic, a voltage source inverter, a phase angle generating system, a GPS receiver, and an LCL filter to maintain a constant terminal voltage.

[0042] In various embodiments, the method **200** of load sharing between two or more inverters as shown in FIG. 2 includes the following steps. In step **201** the total per-unit impedance of the line joining the inverter terminal to the PCC and the X/R ratio of the line are set to a predetermined value. A virtual impedance simulated in the control loop maintains the value of the per-unit impedance and the X/R ratio. The terminal voltages in the inverters are synchronized in step **202** using GPS signal received from the GPS receiver attached to each inverter. In step **203**, apparent power required by the load is shared in proportion to the VA ratings of each inverter. Active and reactive powers are also shared such that the per unit values are the same across all inverter units as long as power available from the respective power sources is more than their share of active power. Hence each inverter delivers a fixed apparent power to meet the load apparent power requirements. In step **204**, the output active power delivered by each inverter is

controlled by changing the X/R ratio of impedance that connects the inverter terminal to the PCC. In some embodiments a controller in the control loop of the inverter modifies the X/R ratio while the per-unit impedance at the two or more inverter units is maintained constant. In step **205**, the output active power is limited to the load power when the load on the island decreases. The voltage control loop reduces the power injected into the network to maintain constant voltage at the terminal. In step **206**, when the power availability at the source increases above a first threshold the voltage in the DC bus connecting the source and the inverter is allowed to vary to limit the output active power from the inverter to the output voltage regulation requirements. When the power availability at the source decreases below the first threshold, the output active power is limited to the maximum active power availability in an inverter in step **207**. In step **207** to reduce the output active power the virtual impedance simulated in the control loop is modified to change the X/R ratio of the impedance of the line connecting the inverter terminal to the PCC while maintaining the per-unit impedance value. In step **208**, when the aggregate of the power availability in the inverters decrease below a threshold suitable load is shed. The amount of load shed is in proportion to the power non-availability in the inverter. As an alternative, power in proportion to the power non-availability is drawn from an energy storage unit.

[0043] In various embodiments, the phase angles of the voltage generated by the inverters are derived from a GPS receiver attached to each inverter. The voltages generated for simulating the virtual impedance of each inverter in various embodiments are thus synchronized by deriving their phase angles using the GPS receivers attached to the respective inverters. The method applies virtual impedance for the purpose of load sharing among the inverters in the microgrid. The load is shared without centralized communication and inter-communication between the inverters. Hence the system does not include expensive and non-reliable communication infra-structure. The system can

operate in its optimal capacity even in the event of power being limited due to practical constraints such as occlusion of a solar array for any reason.

[0044] In various embodiments, a fuzzy logic controller (FLC) **300** that forms part of the control logic is disclosed. The FLC **300** maintains power sharing between the various inverters connected in the microgrid. The fuzzy logic controller **300** includes as shown in FIG. 3A a fuzzifier **321** that receives one or more crisp input values comprising an error signal of the modulation index and converts the error signal to linguistic variables using membership functions stored in a fuzzy knowledge base. Further, a fuzzy logic inference engine system **323** that includes Rule base **329** and inference engine **327** processes the linguistic variables and generates a fuzzy output. A defuzzifier **325** then converts the fuzzy output to crisp output values that includes the values of X/R ratio. The X/R ratio increases or decreases the active power delivered by each inverter and maintains the per-unit impedances set in each line connecting the inverter and its PCC.

[0045] In various embodiments the operation of the FLC as illustrated in FIG. 3B includes the following steps. The FLC in step **402** fetches the modulation to compute the modulation index vector that is a ratio of actual voltage delivered to the maximum possible voltage that can be delivered by the inverter. The error signal Δm , that is the difference between the actual modulation index m_{act} and reference modulation index m_{ref} is computed in step **403**. If the error signal, Δm is positive in step **404** the FLC does not act and if the error signal is negative then the FLC acts on Δm , then the corresponding $\Delta\theta$ is generated in step **405** as output from the FLC. The crisp output values are obtained. In step **406** the difference in reactance, ΔX and the difference in resistance, ΔR is computed from input in step **406**. The direct axis voltage V_d and the quadrature axis voltage V_q are computed in step **407** and in step **408** is given as input to the control algorithm that generates the modulation index m_{abc} from the output V_d^* and V_q^* of the control algorithm in step **409**. Pulse width modulated (PWM) pulses are generated in from the modulation index m_{abc} in step **410**.

[0046] The controller **300** in various embodiments computes the virtual impedance values (R,X) from the output delivered from the defuzzifier **325**. In some embodiments, the instantaneous load current is also measured and the controller computes the virtual drop in the direct V_d and quadrature V_q axis voltages.

[0047] In various embodiments, the fuzzy logic controller **300** is incorporated in a microgrid control system. The fuzzy logic controller **300** incorporated in the control logic simulates the virtual impedance that may modify the X/R ratio and maintains the power sharing among the inverters in the microgrid. When the power availability increases, the DC bus voltage increases. The inverter maintains the terminal voltage constant and the power drawn depends on the load. The DC bus voltage as a result is allowed to vary to limit the power output to just meet the load requirement. Hence the modulation index falls and there is no trigger to change X/R ratio during falling modulation index. In some embodiments the modulation index raises either for a decrease in the power availability for a given load, or for an increases in the load for a given power availability level.

[0048] While the above is a complete description of the embodiments of the invention, various alternatives, modifications, and equivalents may be used. It will be understood by those skilled in the art that various changes may be made and equivalents may be substituted without departing from the scope of the invention as described above. In addition, many modifications may be made to adapt to a particular situation or material the teachings of the invention without departing from its scope. Therefore, the above description and the examples to follow should not be taken as limiting the scope of the invention, which is defined by the appended claims.

EXAMPLES

Example 1: Method of load sharing in multi inverter systems operating in islanded mode

[0049] Two three-phase 1.2kVA Inverters with LCL filters were connected to the PCC to supply a common load. The inverters were fed from PV sources. The system is as shown in FIG. 4A. In this system, the virtual impedance was simulated to restrict the active power flow when solar irradiation dropped. This was manifested by Fuzzy Logic Controller as represented in FIG. 4B. The Fuzzy Logic Controller as shown in FIG. 4C takes modulation index error as input. The input was processed by the fuzzy logic inference engine and was de-fuzzified to give crisp output which was inferred as X/R ratio. The X/R ratio was further converted as R and X respectively. With instantaneously computed load current, the virtual drop in the d-q axis was also computed. The virtual drop was further added in the existing control schematic as depicted in FIG. 4D. Virtual impedance 'X/R' ratio was varied such that impedance 'Z' remained constant. Hence, active and reactive power delivered by the PV-inverter changed but not the apparent power. All the PV-inverters shared the load according to their VA ratings, since their per-unit impedances were the same. As the X/R ratio was increased, the active power delivered was limited to the desired value and the inverter maintained the apparent power delivered constantly by increasing the reactive power flow. Even in the event of limited solar power availability because of practical constraints such as partial shading or temporary shading of the solar array, the PV-inverter operated in its full capacity by supplying the load demands in terms of reactive power. Thus the PV-inverters operated in their optimal capacity at any point of operation. In a microgrid all the PV-inverters were installed with this concept embedded along with their control algorithm. Since the PV-inverters in the microgrid were of different capacity the change in the ratio of 'X/R' was facilitated such that the ratio varied slowly in PV-inverter with larger capacity while in PV-inverter with smaller capacity the ratio varied relatively faster. This is to ensure that there were no power fluctuations which may cause stability issues.

WE CLAIM:

1. A method of load sharing between two or more inverters (110, 120) of equal or different volt-ampere (VA) ratings and operating in parallel in a microgrid, each inverter (110, 120) comprising a power source (117, 127) and a voltage control loop comprising a control logic (111, 121), a voltage source inverter (113, 123), a phase angle generating system, a GPS receiver, and a filter (115, 125) to maintain voltage at a terminal connected to a point of common coupling (PCC) by a suitable line (112, 122) thereof and connected to a load distributed in the microgrid, the method comprising:
 - i. setting (201) a total per-unit impedance of the line (112, 122) connecting the inverter terminal and its PCC to a predetermined value with a predetermined ratio of reactance to resistance (X/R ratio) and simulating a virtual impedance in the control loop configured to maintain the predetermined value;
 - ii. synchronizing (202) respective phases of the voltage in each of the inverters;
 - iii. sharing (203) a load apparent power among the two or more inverters in proportion to the VA ratings thereof; and
 - iv. controlling (204) an output at the terminal to a preset value to limit an output active power, while maintaining the per-unit impedance at the two or more inverter units at an initial value.
2. The method of claim 1, wherein the controlling limits the output active power
 - a. to a load power when the load on the island decreases, by reducing the power injected into the PCC so as to maintain constant voltage at the terminal; and/or
 - b. to the output voltage regulation at an inverter when the power availability in the power source increases above a first threshold; and/or

- c. to the maximum active power availability in an inverter, when the power availability in the power source falls below the first threshold by modifying (207) the virtual impedance to change the X/R ratio.
3. The method of claim 1, further comprising shedding (208) a portion of the load in proportion to the power non-availability or supplying power from an energy storage unit to the portion of the load, when the aggregate of the power availability in the inverters falls below a threshold.
 4. The method of claim 1, wherein the power source is selected from a wind energy source, a solar power array, a fuel cell, a biomass reactor driven generator or a combination thereof.
 5. The method of claim 1, wherein the voltages behind the virtual impedances of respective inverters are synchronized by deriving their phase angles from a GPS receiver attached to each inverter.
 6. An electrical system (100) for grid power injection comprising
an electrical grid (140) providing ac power to a load (131, 132, 133);
a microgrid comprising one or more inverter units (110, 120) comprising equal or different VA ratings, each inverter unit (110, 120) comprising a power source (117, 127) interfaced with a control loop comprising a control logic (111, 121), a voltage source inverter (113, 123), a phase angle generating system, a GPS receiver, and a filter (115, 125) to maintain voltage at a terminal connected to a point of common coupling (PCC) by a suitable line thereof wherein the total per-unit impedance between the inverter terminal and its PCC are set to a predetermined value

with a predetermined X/R ratio and a virtual impedance in the control loop is configured to maintain the per-unit impedance thereof;

one or more nodes (151, 152, 153) connecting the electrical grid(140), the microgrid comprising one or more inverter units (110, 120) and a load distributed (131, 132, 133) in the microgrid; wherein

the system (100) is configured to share the load apparent power among the two or more inverters (110, 120) in proportion to the VA ratings of each inverter.

7. The system of claim 6, wherein the power source is selected from a wind energy source, a solar power array, a fuel cell, a biomass reactor driven generator or a combination thereof.
8. The system of claim 6, wherein the control logic comprises a fuzzy logic controller or any other suitable controller to maintain power sharing between two or more inverters connected in the system.
9. The system of claim 6, wherein when the load on the island decreases the voltage control loop reduces the output active power injected into the network so as to maintain constant voltage at an inverter terminal.
10. The system of claim 9, wherein the output active power is limited to the load requirements.
11. The system of claim 6, wherein when the power availability in the power source increases above a first threshold, the voltage in the DC bus connecting the power source and an inverter changes to limit the output active power of the inverter.

12. The system of claim 11, wherein the output active power is limited to the output voltage regulation requirement in the inverter.
13. The system of claim 6, wherein when the power availability in the power source falls below a first threshold, the virtual impedance in the control loop is configured to modify the X/R ratio of the line of an inverter to limit the output active power, while maintaining the per unit impedance of the line.
14. The system of claim 13, wherein the output active power is limited to the maximum active power availability in the inverter.
15. The system of claim 6, wherein when the aggregate of the power availability in the sources fall below a threshold, suitable load is shed or power in proportion to the power non-availability is drawn from an energy storage unit.
16. The system of claim 6, wherein the inverters are synchronized using GPS signals obtained from a GPS receiver attached to each inverter.
17. The system of claim 8, the fuzzy logic controller comprising:
 - a fuzzifier for receiving one or more crisp input values and converting the crisp input values to one or more linguistic variables using membership functions stored in a fuzzy knowledge base, wherein the input values comprise an error signal that is a ratio of a voltage delivered by an inverter and a maximum voltage delivered by the inverter;
 - a defuzzifier that converts a fuzzy output to a crisp output value comprising a value of X/R ratio that increase or decrease a delivered active power while maintaining a per-unit impedance.

18. The system of claim 17, wherein the controller computes the virtual impedance values (R,X) to compute the virtual drop in the direct and quadrature axis voltages.
19. The system of claim 17, wherein the fuzzy logic controller is configured to simulate the virtual impedance to modify the X/R ratio and to maintain power sharing between two or more inverters connected in the microgrid.

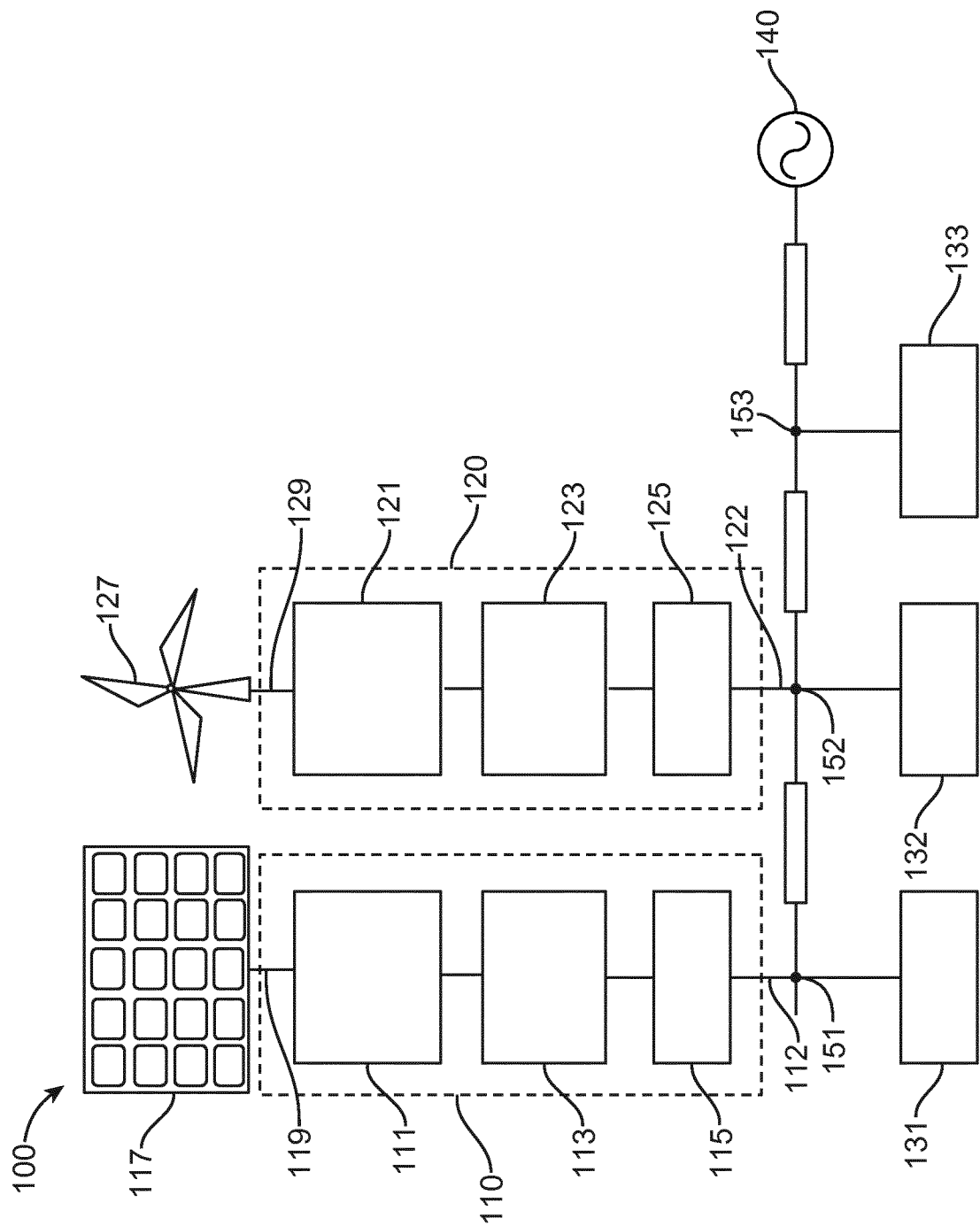


FIG. 1

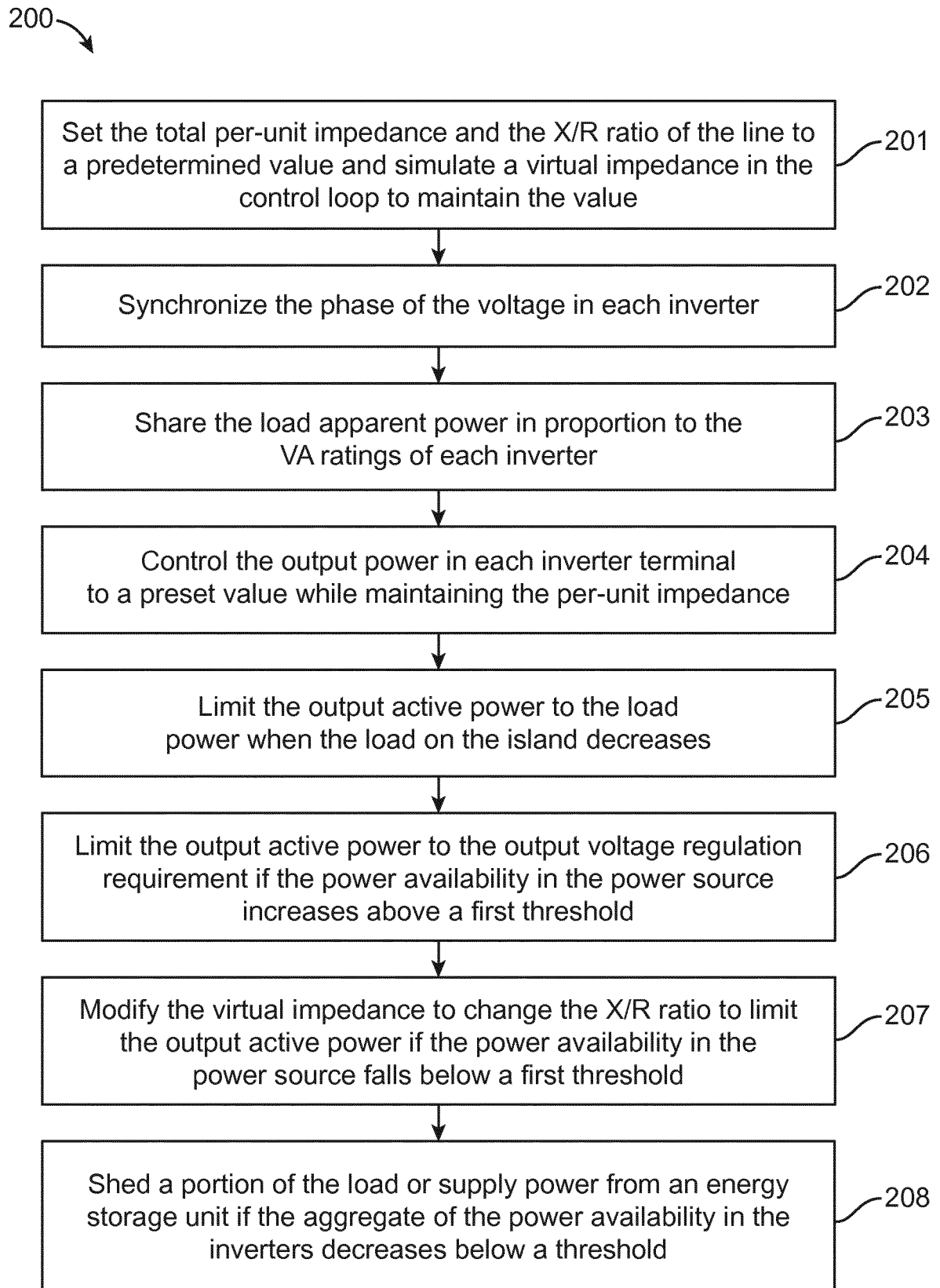


FIG. 2

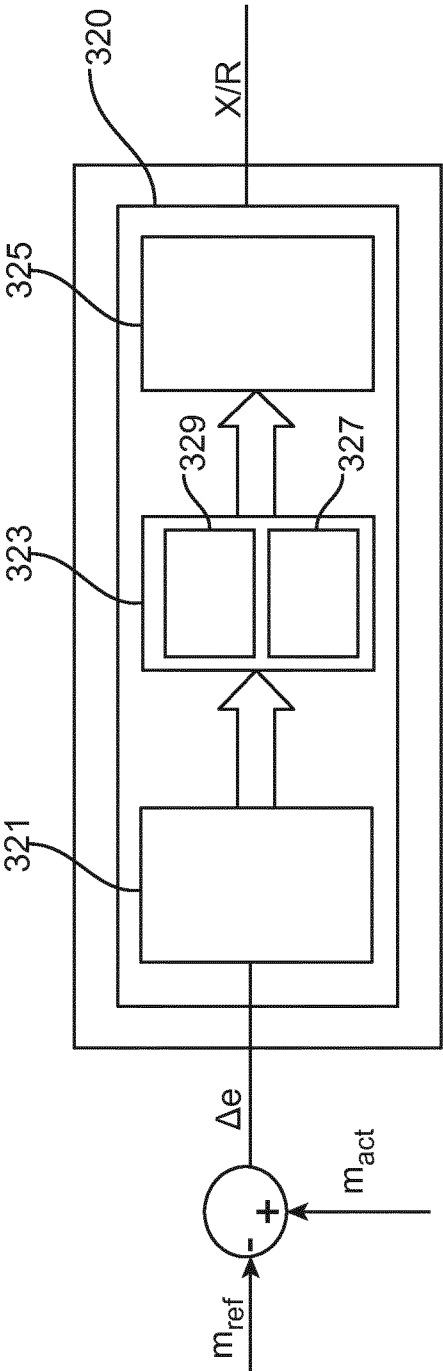


FIG. 3A

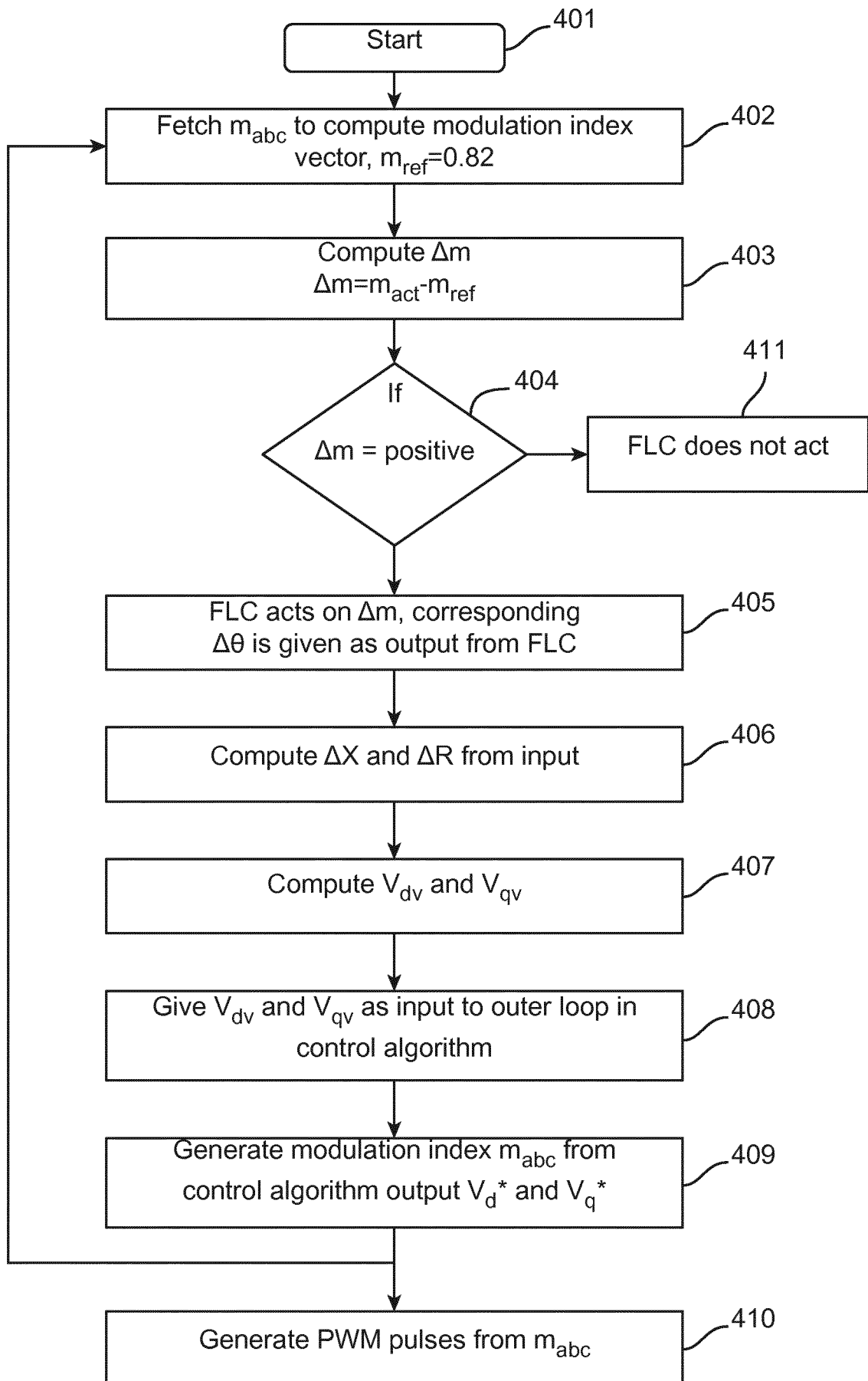


FIG. 3B

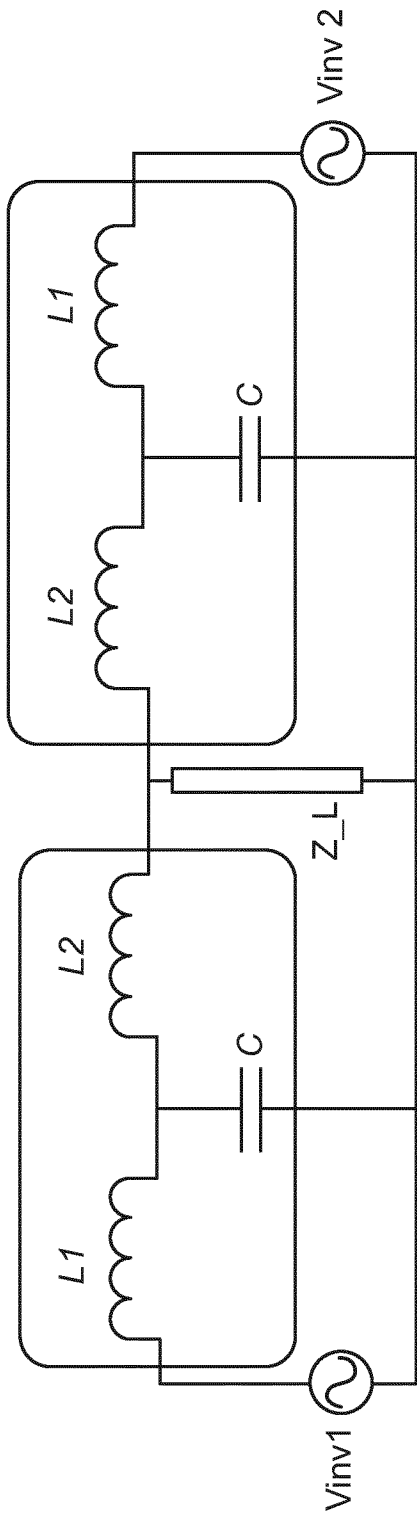


FIG. 4A

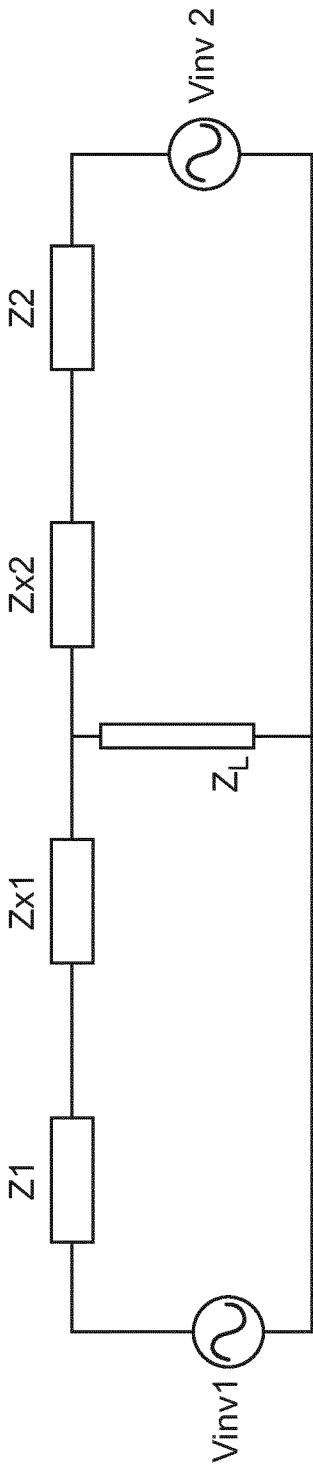


FIG. 4B

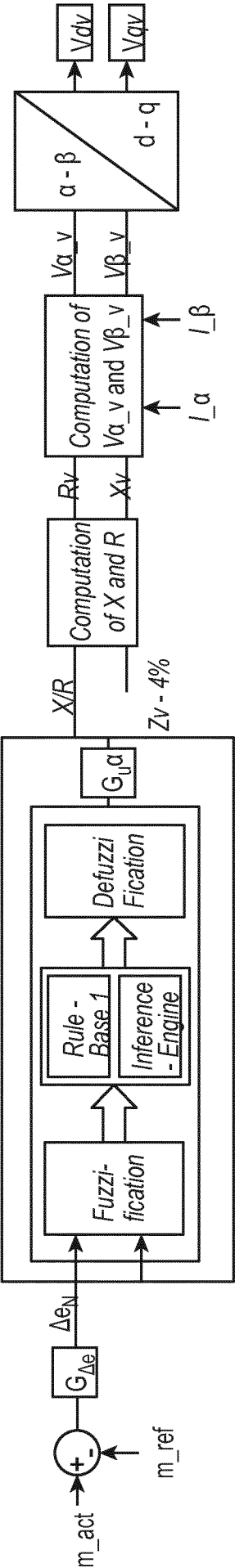


FIG. 4C

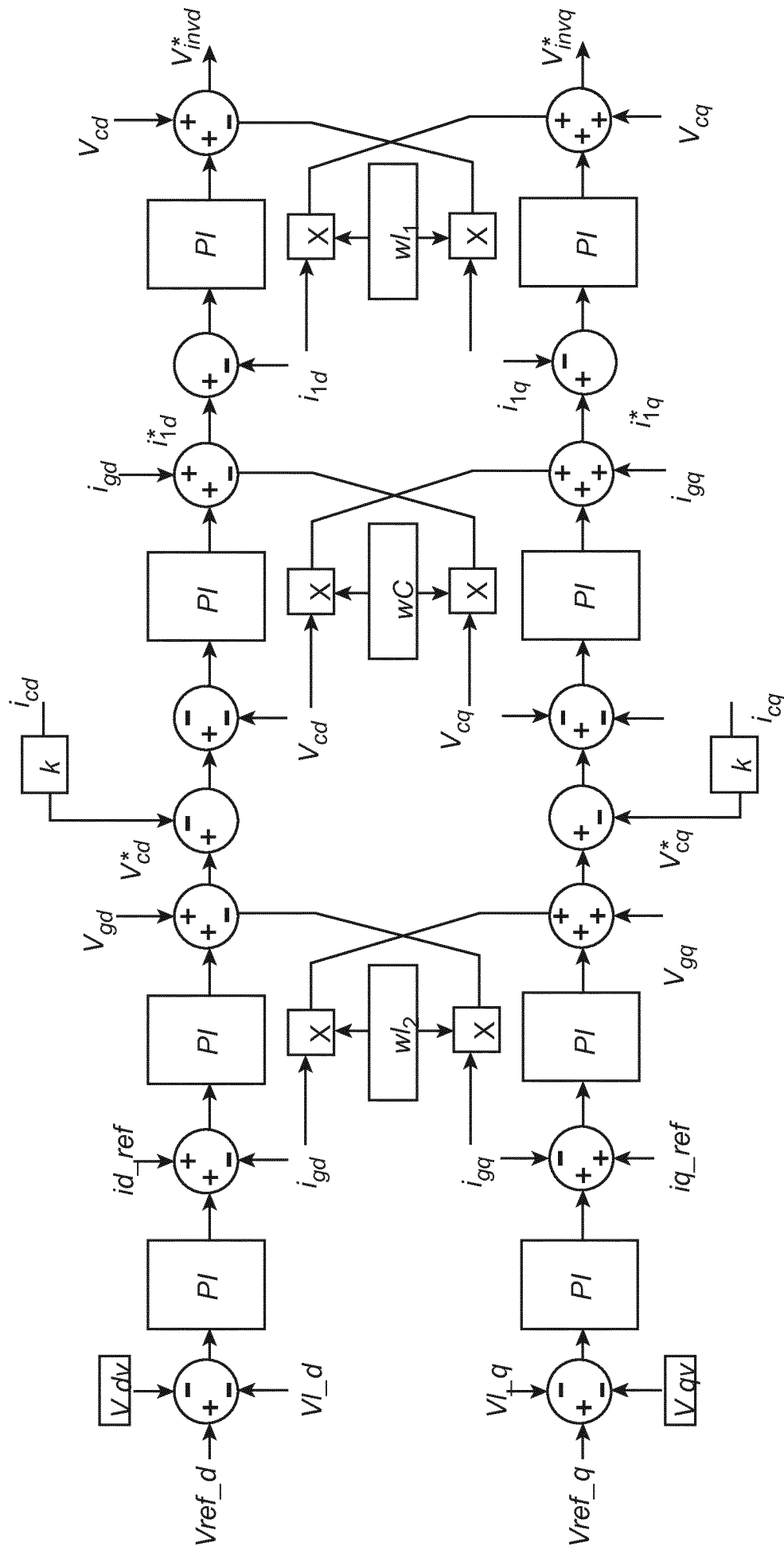


FIG. 4D

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2019/071172

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02J3/46
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)
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.
Y	WO 2017/044922 A1 (ENPHASE ENERGY INC [US]) 16 March 2017 (2017-03-16) paragraphs [0002], [0005], [0008], [0014] - [0048]; figures 1-3 -----	1-19
Y	WO 2016/134319 A1 (ENPHASE ENERGY INC [US]) 25 August 2016 (2016-08-25) paragraphs [0003], [0020] - [0050]; figures 1-5 -----	1-19
Y	CN 103 956 778 A (GUANGZHOU INST ENERGY CONV CAS) 30 July 2014 (2014-07-30) paragraph [0005]; figures 1-5 -----	1-19
A	WO 2013/087085 A1 (FACHHOCHSCHULE SUEDEWESTFALEN; ORTJOHANN EGON [DE] ET AL.) 20 June 2013 (2013-06-20) paragraphs [0009] - [0013]; figures 2-24 ----- -/-	1-19



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

23 October 2019

Date of mailing of the international search report

31/10/2019

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Authorized officer

Krasser, Bernhard

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2019/071172

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2018/033721 A1 (UNIV SWANSEA [GB]) 22 February 2018 (2018-02-22) pages 1-10; figures 1-16 -----	1-19

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2019/071172

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2017044922 A1	16-03-2017	EP 3347960 A1	18-07-2018
		US 2017077707 A1	16-03-2017
		WO 2017044922 A1	16-03-2017

WO 2016134319 A1	25-08-2016	US 2016248253 A1	25-08-2016
		US 2018301904 A1	18-10-2018
		WO 2016134319 A1	25-08-2016

CN 103956778 A	30-07-2014	NONE	

WO 2013087085 A1	20-06-2013	CN 104011959 A	27-08-2014
		EP 2792042 A1	22-10-2014
		US 2014316604 A1	23-10-2014
		WO 2013087085 A1	20-06-2013

WO 2018033721 A1	22-02-2018	EP 3497771 A1	19-06-2019
		US 2019207391 A1	04-07-2019
		WO 2018033721 A1	22-02-2018
