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(54) Title: METHOD AND SYSTEM FOR PROVIDING RENEWABLE ENERGY PLANT FREQUENCY RESPONSE

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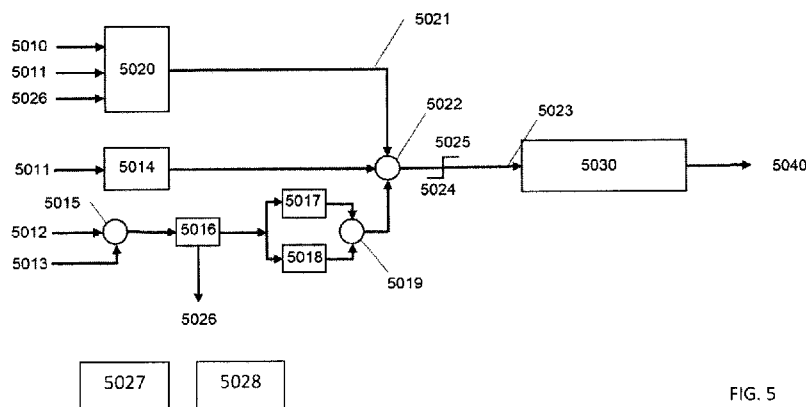


FIG. 5

(57) Abstract: A method for providing frequency response for a plant coupled to an electric power grid, the plant having an intermittent energy source, comprising: measuring frequency of the power output from the plant and determining a first difference between the measured frequency and a frequency reference; measuring power output from the plant and storing the measured power output as a stored value; while the first difference is within a deadband, determining a second difference as a difference between a power reference and the measured power output; while the first difference indicates over-frequency, determining the second difference as a difference between the stored value and the measured power output; while the first difference indicates under-frequency, setting the second difference equal to the power reference; generating an error by limiting a sum of the first and second differences between error limits; generating a control signal; and, applying the control signal to the source.



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**METHOD AND SYSTEM FOR PROVIDING RENEWABLE ENERGY PLANT
FREQUENCY RESPONSE**

[0001] This application claims priority from and the benefit of the filing date of United States Provisional Patent Application No. 62/662,307, filed April 25, 2018, and the entire content of such application is incorporated herein by reference.

FIELD OF THE INVENTION

[0002] This invention relates to the field of control systems, and more specifically, to a method and system for providing renewable energy plant frequency response.

BACKGROUND OF THE INVENTION

[0003] The ability of a power system to maintain its electrical frequency within a safe range is crucial for stability and reliability. Frequency response is a measure of an interconnection's ability to stabilize the frequency immediately following the sudden loss of generation or load. The United States Federal Energy Regulatory Commission ("FERC") recently revisited primary frequency response regulations in Order No. 842 (See "UNITED STATES OF AMERICA FEDERAL ENERGY REGULATORY COMMISSION 18 CFR Part 3500; Order No. 842; Essential Reliability Services and the Evolving Bulk-Power System - Primary Frequency Response"; issued February 15, 2018; <https://www.ferc.gov/whats-new/comm-meet/2018/021518/E-2.pdf>; accessed April 13, 2018; and, incorporated herein by reference). Reliable power system operation depends on system frequency. Frequency deviation from nominal is caused by power imbalance due to abrupt momentous changes in load or generation. Significant frequency excursion can trip generation units and loads. Inertial response, primary frequency response, and secondary frequency response mitigate frequency deviation. Primary frequency response, collectively provided by system generators, is intended to arrest frequency deviation keeping it within an acceptable range.

[0004] In the above mentioned Order, the FERC states that customers "shall ensure that the Large Generating Facility's real power response to sustained frequency deviations outside of the deadband setting is automatically provided and shall begin immediately after frequency deviates

outside of the deadband, and to the extent the Large Generating Facility has operating capability in the direction needed to correct the frequency deviation.” In addition, the FERC notes that the “Large Generating Facility shall sustain the real power response at least until system frequency returns to a value within the deadband setting of the governor or equivalent controls.”

[0005] Renewable energy plants typically include solar photovoltaic (“PV”) and wind intermittent energy sources. Both PV and wind systems are rapidly growing in quantity and size making their frequency response even more important. FIG. 1 is a block diagram illustrating a control system for a renewable energy plant in accordance with the prior art. (See “WECC Solar Plant Dynamic Modeling Guidelines”; <https://www.wecc.biz/Reliability/WECC%20Solar%20Plant%20Dynamic%20Modeling%20Guidelines.pdf>; accessed April 11, 2018; and incorporated herein by reference.) Such control systems typically include the following. First, closed loop voltage regulation at a user-designated bus. The voltage feedback signal has provisions for line drop compensation, voltage droop response, and a user-settable deadband on the voltage error signal. Second, closed loop reactive power regulation on a user-designated branch with a user-settable deadband on the reactive power error signal. Third, a plant-level governor response signal derived from frequency deviation at a user designated bus. The frequency droop response is applied to active power flow on a user-designated branch. Frequency droop control is capable of being activated in both over and under frequency conditions. The frequency deviation applied to the droop gain is typically subject to a user-settable deadband.

[0006] One problem with such existing control systems is that the real power response does not always begin immediately after the frequency deviates outside of the deadband when the plant has operating capability in the direction needed to correct the frequency deviation.

[0007] FIG. 2 is a chart illustrating operations of the control system of FIG. 1 in accordance with the prior art. FIG. 2 illustrates performance of the above-mentioned control during cloud passage over the solar plant. The x -axis is relative test time and the Y -axis is power per unit (p.u.). Line **3010** represents a power reference, which limits plant generation. Line **3030** represents measured plant power generation. Line **3020** represents measured system frequency. Point **3021** on the system frequency line **3020** shows the beginning of an over-frequency deviation outside of the deadband. Required real power response does not occur because power generation is below the

power reference **3010**. However, the plant power is positive and therefore the plant has operating capability in the direction needed to correct the frequency deviation.

[0008] Another problem with such existing control systems is that the plant does not always sustain the real power response until the system frequency returns to a value within the deadband setting of the governor. The automatic generation control (“AGC”) command communicated to the renewable energy plant control system can override the power reference during frequency excursion, effecting plant frequency response.

[0009] A need therefore exists for an improved method and system for providing renewable energy plant frequency response. Accordingly, a solution that addresses, at least in part, the above and other shortcomings is desired.

SUMMARY OF THE INVENTION

[0010] According to one aspect of the invention, there is provided a method for providing frequency response for a renewable energy plant coupled to an electric power grid, the renewable energy plant having an intermittent energy source, the method comprising: using a renewable energy plant control system, measuring frequency of the power output from the renewable energy plant and determining a first difference signal between the measured frequency and a frequency reference; measuring power output from the renewable energy plant and storing the measured power output as a stored measured power output value; while the first difference signal is within a predetermined frequency deviation deadband, determining a second difference signal as a difference between a power reference and the measured power output; while the first difference signal indicates an over-frequency condition, determining the second difference signal as a difference between the stored measured power output value and the measured power output; while the first difference signal indicates an under-frequency condition, setting the second difference signal equal to the power reference; generating an error signal by limiting a sum of the first and second difference signals between predetermined minimum and maximum power error limits; generating a control signal by applying the error signal to a controller; and, applying the control signal to the intermittent energy source to control the power output therefrom.

[0011] In accordance with further aspects of the invention, there is provided an apparatus such as an information system, a control system, a computer system, etc., a method for adapting these, as well as articles of manufacture such as a computer readable medium or product and computer program product or software product (e.g., comprising a non-transitory medium) having program instructions recorded thereon for practicing the method of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Further features and advantages of the embodiments of the present invention will become apparent from the following detailed description, taken in combination with the appended drawings, in which:

[0013] FIG. 1 is a block diagram illustrating a control system for a renewable energy plant in accordance with the prior art;

[0014] FIG. 2 is a chart illustrating operations of the control system of FIG. 1 in accordance with the prior art;

[0015] FIG. 3 is a block diagram illustrating an information system in accordance with an embodiment of the invention;

[0016] FIG. 4 is a block diagram illustrating a renewable energy plant in accordance with an embodiment of the invention;

[0017] FIG. 5 is a block diagram illustrating a control system in accordance with an embodiment of the invention;

[0018] FIG. 6 is a flow chart illustrating operations of the control system of FIG. 5 in accordance with an embodiment of the invention; and,

[0019] FIG. 7 is a flow chart illustrating operations of modules within an information system for providing frequency response for a renewable energy plant coupled to an electric power grid, the renewable energy plant having an intermittent energy source, in accordance with an embodiment of the invention.

[0020] It will be noted that throughout the appended drawings, like features are identified by like reference numerals.

DETAILED DESCRIPTION OF THE EXAMPLE EMBODIMENTS

[0021] In the following description, details are set forth to provide an understanding of the invention. In some instances, certain software, circuits, structures and methods have not been described or shown in detail in order not to obscure the invention. The term “information system” or “system” is used herein to refer to any machine for processing data, including the control systems, controllers, energy management systems, supervisory control and data acquisition (“SCADA”) systems, computer systems, and network arrangements described herein. The present invention may be implemented in any computer programming language provided that the operating system of the data processing system provides the facilities that may support the requirements of the present application. Any limitations presented would be a result of a particular type of operating system or computer programming language and would not be a limitation of the present invention. The present invention may also be implemented in hardware or in a combination of hardware and software.

[0022] According to one embodiment of the invention, there is provided an improved method and system for providing frequency response for a renewable energy plant coupled to an electric power grid, the renewable energy plant having an intermittent energy source. According to another embodiment, there is provided a method for controlling energy sources for a renewable energy plant, wherein the plant is connected to a power grid and the plant has an intermittent energy source whose output is dependent on environmental variables.

[0023] FIG. 3 is a block diagram illustrating an information system **1000** in accordance with an embodiment of the invention. The information system **1000** is suitable for performing as a control system (e.g., **2800**), supervisory control and data acquisition (“SCADA”) system, energy management system (“EMS”), or the like. The information system **1000** may be implemented as a virtual machine. The information system **1000** may be a client and/or a server in a client-server configuration. As an example, the information system **1000** may be a server and/or a personal computer. The information system **1000** may be a distributed system deployed on multiple

processors or hosts.

[0024] The information system **1000** includes a display **1100**, a processor or CPU **1200**, an input device **1300**, memory **1400**, and an interface device **1600**. The display **1100** may include a computer screen or a television screen. The CPU **1200** is coupled to a memory **1400** that stores an operating system **1420** to manage the information system **1000**. The CPU **1200** is operatively coupled to an input device **1300** for receiving user commands and to the display **1100** for displaying the results of these commands to a user. These commands may also be received over a network **1700** via the interface device **1600**. The CPU **1200** may operate in association with dedicated co-processors, memory devices, or other hardware modules **1500**. The input device **1300** may include a keyboard, mouse, touchpad, or the like. The memory **1400** may include a plurality of storage devices including an internal memory and an external storage device. For example, memory **1400** may include databases, random access memory, read-only memory, flash drives, and/or hard disk devices. The information system **1000** may include a database management system and a database **1410** that may be stored in the memory **1400** of the information system **1000**. The interface device **1600** may include one or more network connections. The information system **1000** may be adapted to communicate with other information systems over a network **1700** (e.g., control system **2800**, master SCADA/EMS **2900**) via the interface device **1600**. For example, the interface device **1600** may include an interface to a network **1700** such as the Internet and/or a wireless network. Thus, the interface **1600** may include suitable transmitters, receivers, connectors, and the like. The information system **1000** may be associated with other information systems (e.g., **2800**, **2900**) over the network **1700**. Of course, the information system **1000** may include additional software and hardware, the description of which is not necessary for understanding the invention.

[0025] The information system **1000** includes programmed computer-executable instructions to implement embodiments of the present invention. The instructions may be embodied in one or more hardware modules **1500** or program (software) modules (e.g., **1420**) resident in the memory **1400** of the information system **1000**. Alternatively, programmed instructions may be embodied on a machine-readable medium or product such as one or more DVDs, CDs, etc.

[0026] A user may interact with the information system **1000** using a user interface (“UI”) **1120**

such as a graphical user interface. The UI **1120** may be used for monitoring, managing, and accessing the information system **1000**. Typically, a UI is used to display information to and receive commands from users and includes a variety of controls including icons, drop-down menus, toolbars, text, buttons, and the like. A user interacts with the UI **1120** presented on a display **1100** by using an input device **1300** to position a pointer or cursor **1122** over a graphical object, for example, an icon, menu, etc. **1121** and by selecting the object **1121**. Typically, UI elements are presented in at least one window **1110**, that is, a rectangular area within the display **1100**. A window **1110** may be open, closed, displayed full screen, reduced in size, or moved to different areas of the display **1100**.

[0027] FIG. 4 is a block diagram illustrating a renewable energy plant **2000** in accordance with an embodiment of the invention. The renewable energy plant **2000** may be a photovoltaic plant. The photovoltaic plant **2000** may include a photovoltaic system **2020** which includes photovoltaic arrays **2021**, inverters **2022**, and transformers. An electrical collector subsystem, which includes feeders **2100** and a medium voltage bus **2200**, connects the PV system **2020** to a generator step-up transformer **2300**. The generator step-up transformer **2300** may be equipped with an on-load tap changer. The control system **2800** (e.g., information system **1000**) controls the properties of the PV system **2020** at a point of common coupling **2600**. The control system **2800** receives setpoints from a master SCADA/EMS **2900** (e.g., information system **1000**) over a communications network **2110** (e.g., network **1700**). The control system **2800** receives measurements such as power flow and frequency from a power meter **2700** located at a point of metering **2500**. The plant **2000** may also include: a battery energy storage system (“BESS”) **2030**, an electric load **2040**, shunt capacitors and reactor banks **2010**, or combinations of these. Finally, a circuit breaker **2400** connects the plant **2000** to the electrical grid **2610**.

[0028] FIG. 5 is a block diagram illustrating a control system **2800** in accordance with an embodiment of the invention. And, FIG. 6 is a flow chart illustrating operations **5000** of the control system **2800** of FIG. 5 in accordance with an embodiment of the invention.

[0029] Referring to FIGS. 5 and 6, a power reference **5010** is processed through a logic block **5020**. Measured at the point of metering (e.g., **2500** in FIG. 4), power flow for plant regulation **5011** is processed through a filter **5014** and subtracted from the output **5021** of the logic block

5020 in a summation block **5022** to form or generate an error signal **5023**. The frequency droop response applied **5022** to the power reference **5010** processed through the logic block **5020**, acts during frequency events **5026**. Frequency deviation (or frequency) **5012** is subtracted in block **5015** from a frequency deviation (or frequency) reference **5013**. The droop is defined by an over- and under-frequency dead bandblock **5016**. Down and up regulation droop is defined by blocks **5017** and **5018** and summation block **5019**. The error signal **5023** is limited between minimum **5024** and maximum **5025** power error limits. The error signal **5023** is handled by a controller **5030** which may be a proportional-integral (“PI”) controller or any other type of controller. The controller output **5040** is sent to the inverters **2022** to control the active power output of the inverters **2022** (i.e., of the photovoltaic system **2020**).

[0030] Referring again to FIGS. 5 and 6, when system frequency **5012** deviates outside of the deadband (e.g., a predetermined frequency deviation deadband) **5016**, updated reference values can be disregarded thereby preventing undesirable frequency response impact.

[0031] Referring again to FIGS. 5 and 6, when a cloud (for example) covers the PV arrays **2021** causing a decrease in power flow **5011** below the power reference **5010** and when system frequency increases above over-frequency deadband in block **5016**, a signal **5026** is sent to the logic block **5020** causing the power flow value **5011** to be stored in the logic block **5020** and forming the block’s output signal **5021** which in turn sustains frequency response until system frequency decreases below the over-frequency deadband. In this case, frequency droop response is applied to the power flow **5011** to decrease the power flow proportionally with respect to the frequency deviation outside of the deadband.

[0032] Referring again to FIGS. 5 and 6, when the system frequency returns to within the deadband, the logic block **5020** ramps output **5021** from the power flow current value **5011** to the power reference value **5010** providing a gradual power flow transition to the power reference level **5010**.

[0033] According to one embodiment, as illustrated in the FIG. 5, frequency control may be embedded in an inverter (or inverters) **2022**. In this case, frequency and power measurements may be performed at the terminals of the inverter(s) **2022**.

[0034] Referring again to FIGS. 5 and 6, according to one embodiment, there is provided a method for providing renewable energy plant frequency response, the plant **2000** having an intermittent energy source **2020**, the method comprising: using a control system **2800**, maintaining power flow to and from a power grid **2610** coupled to the renewable energy plant **2000** by: measuring active power flow **5011** for plant regulation and subtracting **5022** its value from a power reference **5010** to form an error signal **5023**; applying a frequency droop response to the power reference **5010** during frequency events; the frequency droop being characterized by a deadband **5016** and regulation droop **5017, 5018, 5019**; handling the error signal **5023** by a controller **5030** to control the intermittent energy source **2020**; when the power flow **5011** is below the power reference **5010** and the frequency increases above the deadband, the power flow value is stored **5020**, and the frequency droop response **5017, 5018, 5019** is applied to the power flow stored value until frequency returns to within the deadband. In the above method, the updated power reference values may be disregarded while frequency deviates outside of the deadband. The power flow may be gradually transitioned from its current value **5011** to the power reference **5010** when the system frequency returns to within the deadband. The intermittent energy source **2020** may include a wind turbine. The intermittent energy source **2020** may be one or more intermittent energy sources. The renewable energy plant **2000** may have an energy load **2040** coupled thereto. And, the energy load **2040** may be one or more energy loads.

[0035] Also in the above method, the power flow may be gradually transitioned from its current value to the power reference **5010** when the system frequency returns to within the deadband. The power flow transition may be controlled by a ramp limiting block **5027** with a configurable ramp rate, or ramp-up and ramp-down rates. And, a configurable timer **5028** may be used to delay the power flow transition after the system frequency returns to within the deadband.

[0036] According to another embodiment, there is provided a method for providing renewable energy plant frequency response, the plant **2000** having an intermittent energy source **2020**, the method comprising: using a control system **2800**, maintaining power flow to and from a power grid **2610** coupled to the renewable energy plant **2000** by: measuring active power flow **5011** for plant regulation and subtracting **5022** its value from a power reference **5010** to form an error signal **5023**; applying a frequency droop response **5017, 5018, 5019** to the power reference **5010** during

frequency events; handling the error signal **5023** with a controller **5030**; communicating the controller's output **5040** to control the intermittent energy source **5040**; and, when the power flow is below the power reference **5010** and the frequency increases above the over-frequency deadband, the frequency droop response is applied to the power flow. In the above method, after the system frequency returns to within the deadband, the power flow is gradually transitioned from its current value to the power reference **5010**.

[0037] The embodiments described herein may contribute to an improved method and system for renewable energy plant frequency response and may provide one or more advantages. First, the system **2800** ensures automatic sustained frequency response that begins immediately after the power system frequency deviates outside of the deadband until the frequency returns to a value within the deadband. Second, the system **2800** provides an unabrpt transition after the power system frequency returns to a value within the deadband, smoothly ramping power generation to the value set by the power reference. Third, the system **2800** provides frequency response for generating assets under automatic generation control ("AGC") that is compliant with grid interconnection requirements. For reference, AGC is an advanced power system application typically controlling power plants in an ISO/RTO/utility service area. AGC reacts upon power system frequency deviations by adjusting a plant's power reference in a direction opposite to the frequency droop direction. This is done so that the AGC doesn't override the plant frequency response. However, AGC operates asynchronously with respect to power plant control. In addition, AGC has a significantly longer cycle time (typically 1 to 5 seconds) compared to the power plant control cycle time (typically below 1 second). Furthermore, AGC may have a significant delay in data communications and a significant execution time. Consequently, AGC acting on "old" power and frequency data may override the plant frequency response. To prevent this from happening, the system **2800** of the present invention disregards AGC updated commands while responding to a frequency event.

[0038] Aspects of the methods and systems described herein may be illustrated with the aid of a flowchart.

[0039] FIG. 7 is a flow chart illustrating operations **700** of modules (e.g., **1420**, **1500**) within an information system (e.g., **1000**, **2800**) for providing frequency response for a renewable energy

plant **2000** coupled to an electric power grid **2610**, the renewable energy plant **2000** having an intermittent energy source (e.g., **2020**), in accordance with an embodiment of the invention.

[0040] At step **701**, the operations **700** start.

[0041] At step **702**, using a renewable energy plant control system (e.g., **2800**), frequency (or frequency deviation) of the power output from the renewable energy plant **2000** is measured and a first difference signal between the measured frequency (or measured frequency deviation) **5012** and a frequency reference (or frequency deviation reference) **5013** is determined **5015**.

[0042] At step **703**, power output from the renewable energy plant **2000** is measured and the measured power output **5011** is stored as a stored measured power output value (e.g., in a logic block **5020** in the memory **1400** of the control system **2800**).

[0043] At step **704**, while the first difference signal is within a predetermined frequency deviation deadband **5016**, a second difference signal is determined **5022** as a difference between a power reference **5010** and the measured power output **5011**.

[0044] At step **705**, while the first difference signal indicates an over-frequency condition **5026**, the second difference signal is determined **5022** as a difference between the stored measured power output value and the measured power output **5011**.

[0045] At step **706**, while the first difference signal indicates an under-frequency condition **5026**, the second difference signal is set equal to the power reference **5010**.

[0046] At step **707**, an error signal **5023** is generated by limiting a sum **5022** of the first and second difference signals between predetermined minimum and maximum power error limits **5024**, **5025**.

[0047] At step **708**, a control signal **5040** is generated by applying the error signal **5023** to a controller (or loop) **5030**.

[0048] At step **709**, the control signal **5040** is applied to the intermittent energy source **2020** to control the power output therefrom.

[0049] At step **710**, the operations **700** end.

[0050] In the above method, the power reference **5010** may be disregarded while the first difference signal is outside of the predetermined frequency deviation deadband **5016**. The control signal **5040** may control the power output to gradually transition to the power reference when the first difference signal is within or returns to within the predetermined frequency deviation deadband **5016**. The transition may be controlled by a configurable timer **2028** which delays the transition. The power reference **5010** may have associated therewith at least one of a ramp-up rate limit value and a ramp-down rate limit value (e.g., stored in a ramp limiting block **5027**). At least one of the ramp-up rate limit value and the ramp-down rate limit value may be user configurable. The frequency (or frequency deviation) and power output may be measured at the intermittent energy source **2020**. The power output from the renewable energy plant **2000** may be an active power output, the power reference **5010** may be an active power reference, the minimum and maximum power error limits **5024**, **5025** may be minimum and maximum active power error limits, and the power output from the intermittent energy source **2020** may be an active power output. The intermittent energy source may include a photovoltaic energy source **2020**. The intermittent energy source may include a wind turbine. The intermittent energy source **2020** may be one or more intermittent energy sources. The renewable energy plant **2000** may have at least one energy load **2040** coupled thereto. The renewable energy plant **2000** may have at least one controllable load **2040** coupled thereto. The renewable energy plant **2000** may have at least one energy storage **2030** coupled thereto. The controller **5030** may be a proportional-integral (“PI”) controller or loop. And, the control signal **5040** may be applied to the intermittent energy source **2020** to control the power output therefrom and to maintain power flow to and from the electric power grid **2610** coupled to the renewable energy plant **2000**.

[0051] According to one embodiment, each of the above steps **701-710** may be implemented by a respective software module **1420**. According to another embodiment, each of the above steps **701-710** may be implemented by a respective hardware module **1500** (e.g., application-specific hardware **1500**). According to another embodiment, each of the above steps **701-710** may be implemented by a combination of software **1420** and hardware modules **1500**. For example, FIG. 7 may represent a block diagram illustrating the interconnection of specific hardware modules **701-710** (collectively **1500**) within the information system or systems **1000**, each hardware module **701-710** adapted or configured to implement a respective step of the method of the application.

[0052] According to one embodiment, one or more of the software **1420** and hardware modules **1500** (or to components referred to as a "module" herein) may be implemented by one or more information systems **1000** or components thereof.

[0053] According to one embodiment, certain implementations of the functionality of the present application are sufficiently mathematically, computationally, or technically complex that application-specific hardware (e.g., **1500**) or one or more physical computing devices (e.g., **1000**, **1200**, **2800**) (using appropriate executable instructions (e.g., **1420**)) may be necessary or essential to perform that functionality, for example, due to the volume or complexity of the calculations involved and/or to provide results substantially in real-time.

[0054] While this application is primarily discussed as a method, a person of ordinary skill in the art will understand that the apparatus discussed above with reference to an information system **1000** may be programmed to enable the practice of the method of the invention. Moreover, an article of manufacture for use with an information system **1000**, such as a pre-recorded storage device or other similar computer readable medium or computer program product including program instructions recorded thereon, may direct the information system **1000** to facilitate the practice of the method of the invention. It is understood that such apparatus, products, and articles of manufacture also come within the scope of the invention.

[0055] In particular, the sequences of instructions which when executed cause the method described herein to be performed by the information system **1000** may be contained in a data carrier product according to one embodiment of the invention. This data carrier product may be loaded into and run by the information system **1000**. In addition, the sequences of instructions which when executed cause the method described herein to be performed by the information system **1000** may be contained in a computer software product or computer program product (e.g., comprising a non-transitory medium) according to one embodiment of the invention. This computer software product or computer program product may be loaded into and run by the information system **1000**. Moreover, the sequences of instructions which when executed cause the method described herein to be performed by the information system **1000** may be contained in an integrated circuit product (e.g., a hardware module or modules **1420**, **1500**) which may include a coprocessor or memory according to one embodiment of the invention. This integrated circuit product may be installed in

the information system **1000**.

[0056] The embodiments of the application described above are intended to be examples only. Those skilled in the art will understand that various modifications of detail may be made to these embodiments, all of which come within the scope of the invention.

WHAT IS CLAIMED IS:

1. A method for providing frequency response for a renewable energy plant coupled to an electric power grid, the renewable energy plant having an intermittent energy source, the method comprising:

using a renewable energy plant control system, measuring frequency of the power output from the renewable energy plant and determining a first difference signal between the measured frequency and a frequency reference;

measuring power output from the renewable energy plant and storing the measured power output as a stored measured power output value;

while the first difference signal is within a predetermined frequency deviation deadband, determining a second difference signal as a difference between a power reference and the measured power output;

while the first difference signal indicates an over-frequency condition, determining the second difference signal as a difference between the stored measured power output value and the measured power output;

while the first difference signal indicates an under-frequency condition, setting the second difference signal equal to the power reference;

generating an error signal by limiting a sum of the first and second difference signals between predetermined minimum and maximum power error limits;

generating a control signal by applying the error signal to a controller; and,

applying the control signal to the intermittent energy source to control the power output therefrom.

2. The method of claim 1, wherein the power reference is disregarded while the first difference signal is outside of the predetermined frequency deviation deadband.

3. The method of claim 1, wherein the control signal controls the power output to gradually transition to the power reference when the first difference signal is within or returns to within the predetermined frequency deviation deadband.

4. The method of claim 3, wherein the transition is controlled by a configurable timer which delays the transition.
5. The method of claim 3, wherein the power reference has associated therewith at least one of a ramp-up rate limit value and a ramp-down rate limit value.
6. The method of claim 5, wherein at least one of the ramp-up rate limit value and the ramp-down rate limit value is user configurable.
7. The method of claim 1, wherein the frequency deviation and power output are measured at the intermittent energy source.
8. The method of claim 1, wherein the power output from the renewable energy plant is an active power output, wherein the power reference is an active power reference, wherein the minimum and maximum power error limits are minimum and maximum active power error limits, and wherein the power output from the intermittent energy source is an active power output.
9. The method of claim 1, wherein the intermittent energy source includes a photovoltaic energy source.
10. The method of claim 1, wherein the intermittent energy source includes a wind turbine.
11. The method of claim 1, wherein the intermittent energy source is one or more intermittent energy sources.
12. The method of claim 1, wherein the renewable energy plant has at least one energy load coupled thereto.
13. The method of claim 1, wherein the renewable energy plant has at least one controllable load coupled thereto.

14. The method of claim 1, wherein the renewable energy plant has at least one energy storage coupled thereto.
15. The method of claim 1, wherein the controller is a proportional-integral (“PI”) controller or loop.
16. The method of claim 1, wherein the control signal is applied to the intermittent energy source to control the power output therefrom and to maintain power flow to and from the electric power grid coupled to the renewable energy plant.
17. A control system for providing frequency response for a renewable energy plant coupled to an electric power grid, the renewable energy plant having an intermittent energy source, the control system comprising:
 - a processor coupled to memory; and,
 - at least one of hardware and software modules within the memory and controlled or executed by the processor, the modules including computer readable instructions executable by the processor for causing the control system to implement the method of any one of claims 1 to 16.

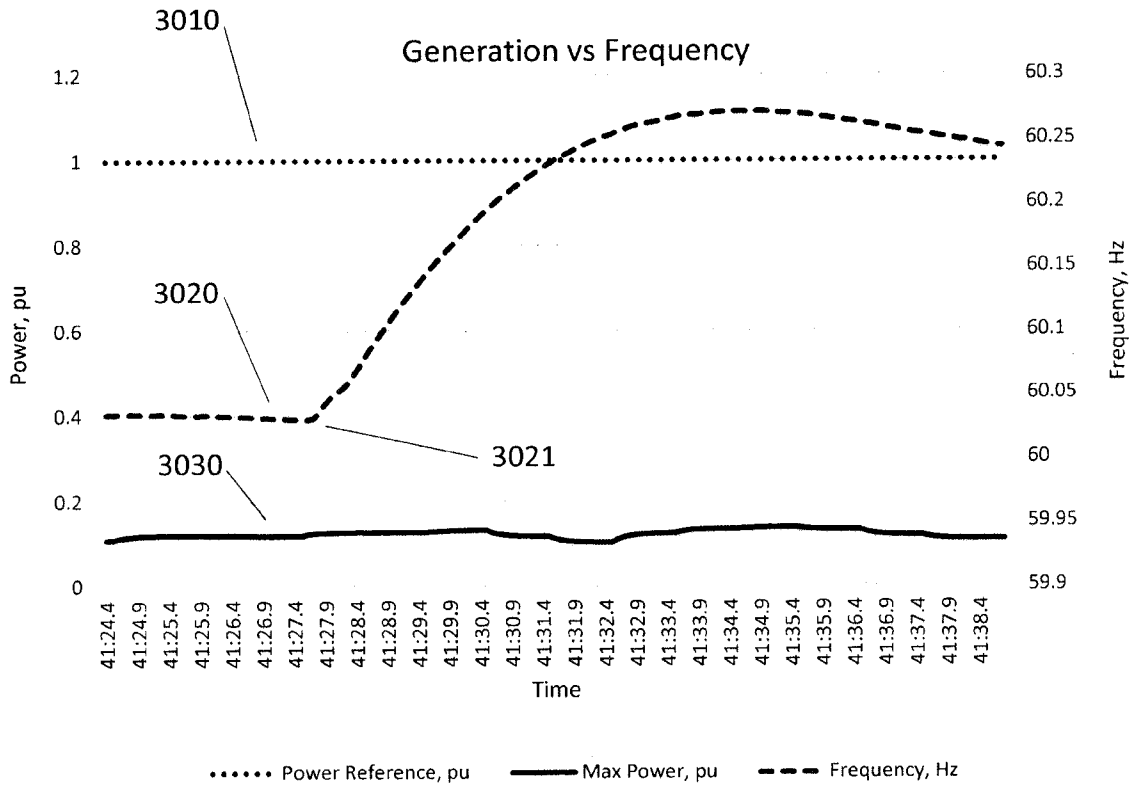


FIG. 2
PRIOR ART

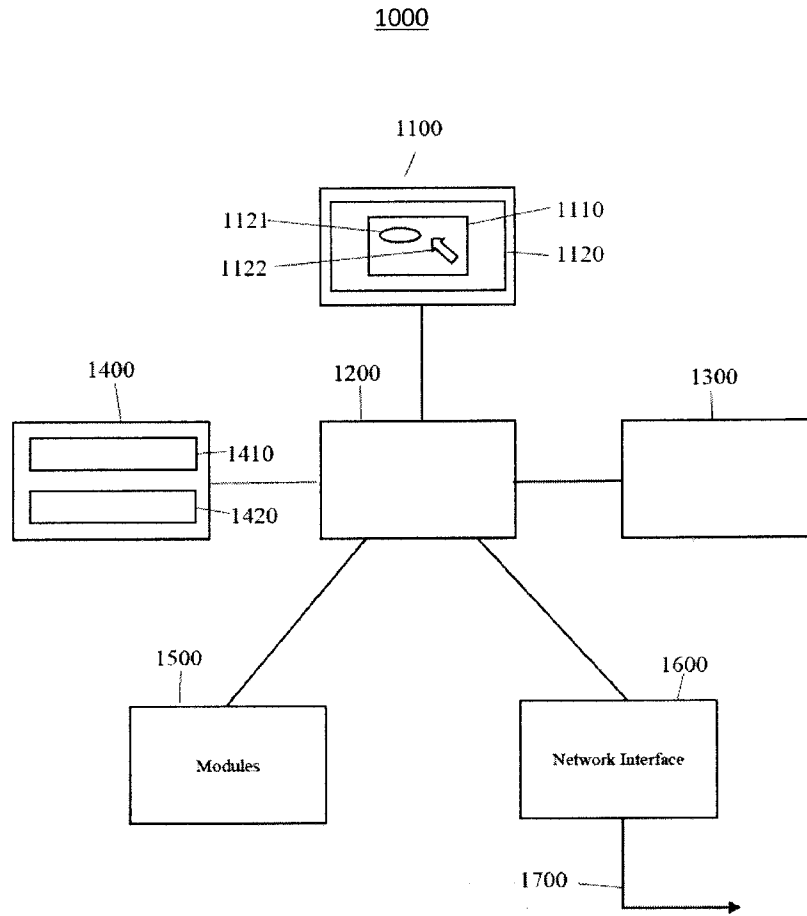


FIG. 3

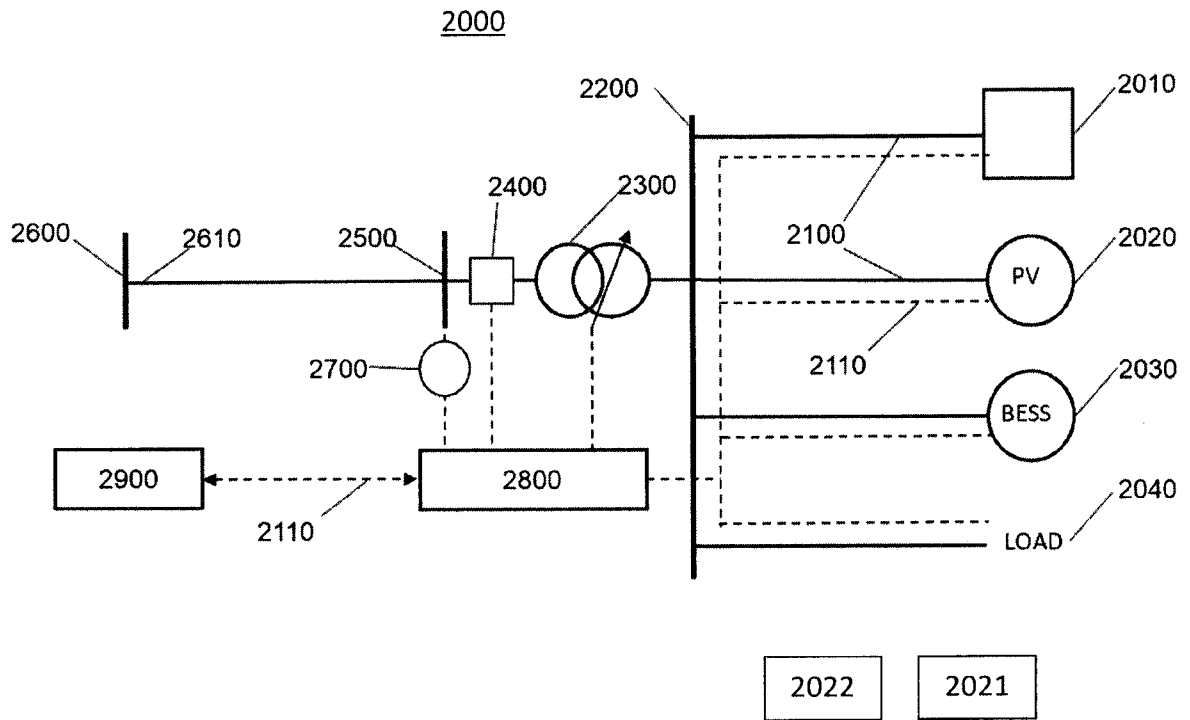


FIG. 4

2800

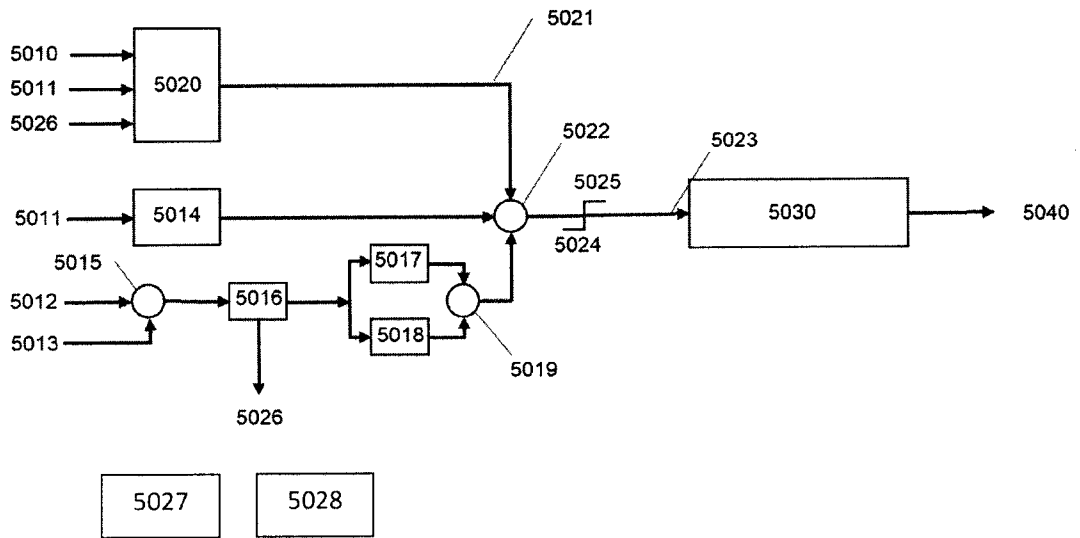


FIG. 5

5000

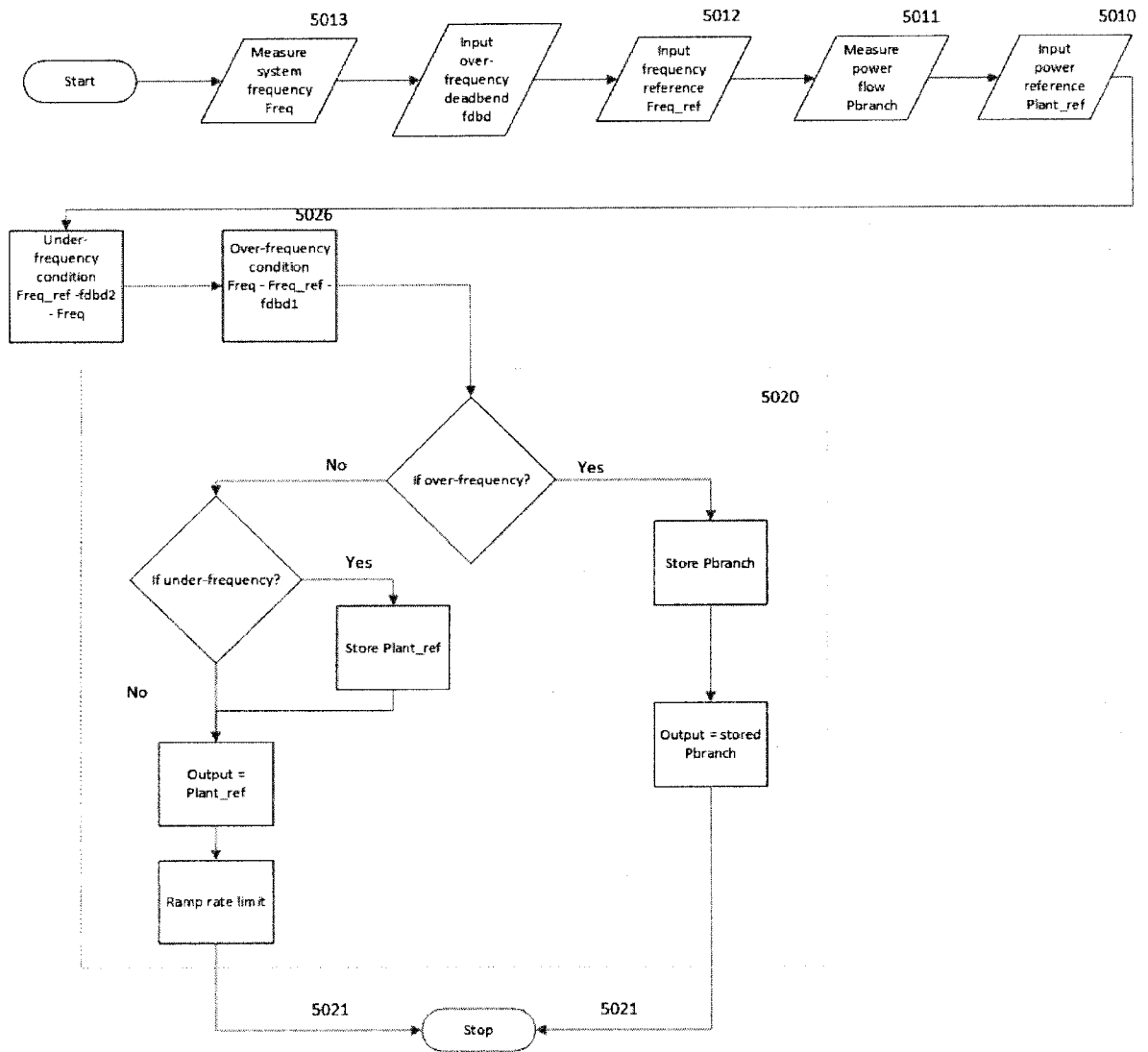


FIG. 6

700

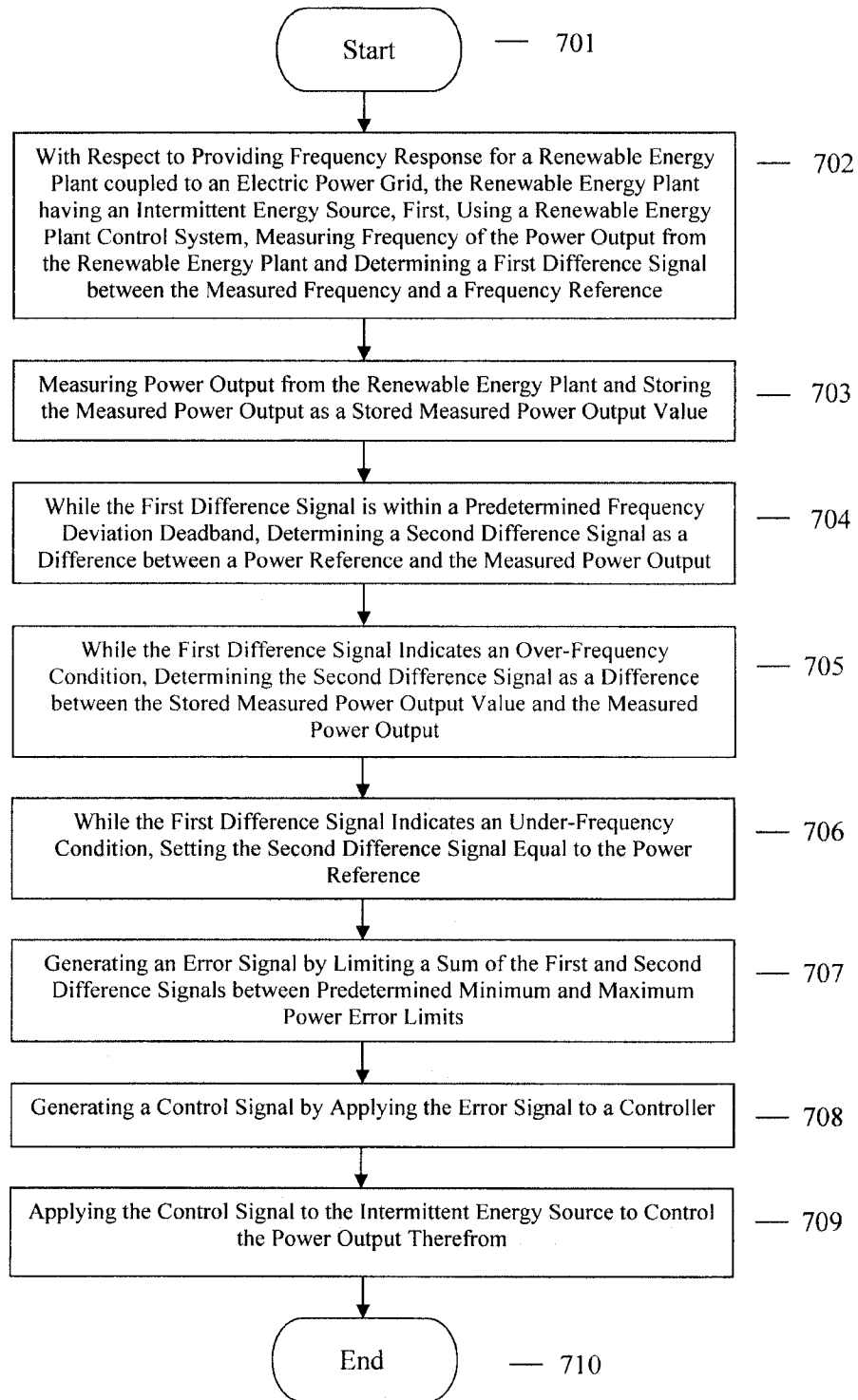


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 19/28489

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - H02P 9/02, 9/04, 9/48 (2019.01)

CPC - Y02E 40/10; F02C 9/28; H02P 9/00, 9/02, 9/04, 9/42, 9/48, 2101/10, 2101/15; H02J 3/01

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History Document

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

See Search History Document

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

See Search History Document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2010/0066086 A1 (KO et al.) 18 March 2010 (18.03.2010), entire document; especially para [0011], para [0073]-[0076]	1-17
A	US 2014/0152009 A1 (UNITED) 05 June 2014 (05.06.2014), entire document; especially para [0018]	1-17
A	US 2015/0137519 A1 (VESTAS) 21 May 2015 (21.05.2015), entire document; especially para [0020]	1-17
A	US 2011/0001318 A1 (NELSON) 06 January 2011 (06.01.2011), entire document; especially para [0024]-[0027]	1-17
A	US 2016/0329713 A1 (SCHNEIDER) 10 November 2016 (10.11.2016), entire document, especially para [0039], [0086]	17

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

* Special categories of cited documents:

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"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

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"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

09 July 2019

Date of mailing of the international search report

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