(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
6 August 2015 (06.08.2015)

WIPO | PCT

(10) International Publication Number
WO 2015/116002 A1

(51) International Patent Classification:
H02M 7/48 (2007.01) *H02S 40/32* (2014.01)

(21) International Application Number:
PCT/SG2015/000026

(22) International Filing Date:
30 January 2015 (30.01.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
201400853-6 30 January 2014 (30.01.2014) SG

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

(54) Title: A MICRO INVERTER FOR A SOLAR PANEL

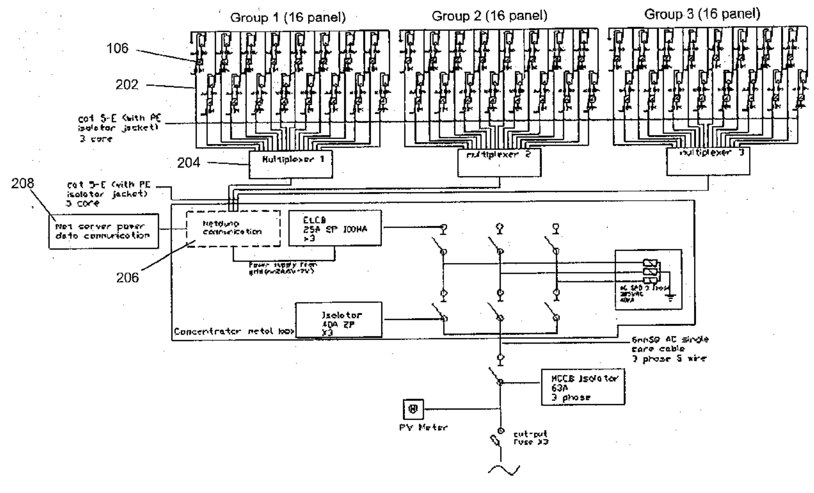

FIG.2

(57) Abstract: A micro inverter (106) for a respective solar panel (102) comprising a communication module configured to connect to a central server (208); a plurality of sensors to collect inverter performance data and/or environmental data; and a controller or processor configured to determine from the data any fault or imminent fault conditions and to communicate the respective condition to relevant party via the central server (208).

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A MICRO INVERTER FOR A SOLAR PANEL

FIELD

The present invention relates to a micro inverter for a solar panel, particularly though not solely to a method of diagnostics.

BACKGROUND

Building integrated solar panels are usually mounted on the roof of a building and may be connected to a battery bank or directly to the grid. Each panel produces a DC output at around 30-50V and a current which varies considerably depending on the level of radiation and/or shading. Such solar panels may also be used in a solar farm.

Connecting the DC output of the panels to the AC network within the installation in a cost effective manner remains a challenge. One method is to connect a number of the panels in series to generate a high DC voltage 300-600V. This can then be chopped directly into AC by a centralized inverter. A second option is a micro inverter which boosts the DC voltage of individual panels above the AC line peak voltage and then converts it to AC.

Central inverters may be cheaper in high power installations but have lower output in some scenarios. If a single panel is shaded it affects the whole string, and the inverter is only able to optimise the load matching for the entire string in some scenarios. Prior art micro inverters may be more expensive in some scenarios but may improve the overall efficiency, as they are able to load match for each individual panel. However in residential installations prior art micro inverters may be cheaper than central inverters. Also micro inverters potentially have a higher maintenance cost, due to the higher number of discrete hardware devices.

SUMMARY

In general terms the invention proposes a micro inverter for a solar panel which regularly runs a self-diagnostic when output is low. This may have the advantage that the high wear components which significantly affect yield can be replaced in a timely manner.

In a first specific expression of the invention there is provided a micro inverter for a respective solar panel comprising

a communications module configured to connect to a central server;

a plurality of sensors to collect inverter performance data and/or environmental data; and a controller or processor configured to determine from the data any fault or imminent fault conditions and to communicate the respective condition to a relevant party via the central server.

The fault or imminent fault conditions may be selected from the group consisting of reduced capacitor capacity, PV panel health, transformer fault, transistor fault.

In some embodiments, the controller is further configured to communicate the inverter performance data and/or environmental data to the central server. The inverter performance data may comprise yield of the panel and inverter, the inverter power supply voltages, the energy produced, the low cut-off voltage, voltage harmonics, the panel position, shading compared to time or season, the ripple of the PV voltage, grid voltage and distortion, and grid load impedance. The environmental data may comprise solar energy, rainfall, humidity, temperature, wind speed, wind direction, pollution level, and seismic activity.

In some embodiments, the controller is configured to determine whether to and/or what value of a DC component to inject into an AC output signal.

The controller may be configured to determine the conversion ability or conversion yield of the inverter or of a portion of the inverter.

The controller may be configured to determine a grid impedance or a grid connection quality.

In a second specific expression of the invention there is provided a central controller comprising

central storage or memory, configured to store inverter performance data and/or environmental data for a plurality of networked inverters according to location, model, date and/or installation characteristics;

a central communications module configured to interrogate respective micro inverters; and

a central controller or processor configured to:

determine an estimated yield for a specific inverter,

determine from the inverter performance data and/or environmental data whether the inverter has any installation defects, fault or imminent fault conditions, and/or

determine whether to initiate and action requests for relevant parties.

The the controller may be further configured to estimate the yield of a potential installation based on a selected installation size, geographic location, and/or installation configuration.

BRIEF DESCRIPTION OF THE DRAWINGS

One or more embodiments will be described, by way of non-limiting example only, with reference to the drawings, in which:

Figure 1 is an electrical diagram of an exemplary system of networked micro inverters;

Figure 2 is a communications diagram of the exemplary system;

Figure 3 is a circuit diagram of a micro inverter of the system of Figures 1 and 2;

Figure 4 are graphs of the AC voltage and current during grid impedance measurement;

Figure 5 is a flow diagram of a method of testing electrolytic capacitors of the micro inverter of Figure 3;

Figure 6 is a graph showing the determination of a faulty capacitor;

Figure 7 is a flow diagram of an exemplary method of diagnostics for main storage capacitors of the micro inverter;

Figure 8 is a flow diagram of a measure subroutine of the method of Figure 7;

Figure 9 is a flow diagram of a main diagnostic process;

Figure 10 is a schematic drawing of a rain sensor; and

Figure 11 is a circuit diagram of a DC to AC H-bridge inverter circuit of the micro inverter of Figure 3.

DETAILED DESCRIPTION

A number of factors can significantly reduce the yield of a solar panel. For example, incorrect positioning or orientation, dirt or dust on the glass, or performance degradation of electronic components such as the storage capacitors can adversely affect yield. The positioning and orientation relies on the skill, experience and knowledge of the installer. However on-going issues such as cleaning and component replacement may only be resolved during scheduled maintenance. As a result the “soft costs” of solar panel ownership are becoming far more significant, as the “hard costs” of the hardware continues to drop.

In the current market, manufacturers are typically striving for even small fractions of a percent increase in efficiency. It may be desirable to reduce, or avoid all together, the need to rely on the installer’s skill, and/or to reduce the maintenance cost.

According to the installation 100 shown in Figure 1, panels 102 are mounted together in an array, each panel 102 being electrically connected with DC connectors 104 to a corresponding micro inverter 106. Each micro inverter 106 is coupled to an AC bus 108, which connects via isolators 110 and leak switches 112 to the grid 114.

As shown in Figure 2 each micro inverter 106 is connected via a data cable 202 or power modem to a multiplexer 204. In a large installation there may be multiple multiplexers. The multiplexers 204 are respectively connected via a modem web client 206, to a central server 208. Each micro inverter 106 and multiplexer 204 includes sensors and/or memory to allow the collection of data. The data may be processed locally and/or communicated to the central server 208.

Diagnostics may be carried out by the micro inverter 106, multiplexer 204 and/or central server 208. As such each of these components has storage, a processor and associated electronics capable of carrying out the diagnostic methods described below. The diagnostics may include checking parameters that could influence the working behaviour of the array 100. The grid voltage and distortion, grid load impedance, the local temperature, the PV condition or wear out (aging), the status or regression of the E-caps or other hardware components are examples of parameters which may be used to assess performance. Typically the measured performance can be compared to historical data or to predetermined operating ranges.

In low light times, when the energy is too low to be harvested, the low output can be safely used for evaluating the status of the main hardware components like transformers, capacitors and transistors. This will allow feedback information of status and/or aging of those vital components. It may allow improvement in the design of further product generations and can be used to initiate a service call for a unit before it fails, or before a more significant fault occurs. This may avoid the damage to the components that might occur if the tests were done using high output power and/or may minimise any reduction in operational efficiency due to diagnostics.

The micro inverter 106 is shown in more detail in Figure 3. The DC input from the panel 102 is buffered on a series of electrolytic capacitors 302. A buck boost converter 304 converts the DC voltage to a higher level, synchronously fluctuating according the AC grid phase voltage, for example at a top value of 400V DC. The high DC voltage is smoothened by a DC filter bank

306. The smooth DC voltage is then converted to an AC voltage by a DC to AC H-bridge inverter circuit 308 and provided to the grid 114.

An example of the DC to AC H-bridge inverter circuit 308 is shown in Figure 11. The micro inverter processor receives signals from the DC voltage and current sensors 312 and the DC voltage and current sensors 310. The microprocessor uses the V&I measurements to generate drive signals for the buck boost converter 304 and the 4 transistors in the inverter circuit 308. The type of modulation of the drive signals and the control strategy can be selected according to the application and/or requirements.

The electrolytic capacitors 302 have a relatively large power capacity, so it may be relatively risky to test them with the panel 102 at full power during daylight hours. Thus sunset or sunrise is a safer time to test, with the additional advantage that the testing does not impact the supply of power.

A method 500 of testing the electrolytic capacitors 302 is shown in Figure 5. First a short circuit transistor is closed to discharge 502 the capacitor. Then the transistor is opened to allow the capacitor to charge 504 from the panel 102. The load curve 600 is then measured 504, as shown in Figure 6. If the time to charge is slow 602 this indicates a good capacitance, whereas a fast time 604 indicates a low capacitance, indicating that replacement of the capacitor is required.

Similarly various tests can be applied to the panel 102. For example the open circuit voltage, and short circuit current can be compared to the panel specifications, and compared to the open circuit voltage and short circuit current of the other panels at the same time. This can be done first statically and then dynamically.

Figure 7 is a flow diagram showing a sequence 700 of diagnostic tests. The panel 102 voltage is measured at open circuit 702. The electrolytic capacitor 302 is tested with burst discharging 704. The left MOSFET is switched on 706 and the measure subroutine 708 is executed. The right MOSFET is also switched on 710 and the measure subroutine 708 is executed again. Then the left MOSFET is switched off 712 and the measure subroutine 708 is executed again. A timer is started and the right MOSFET is switched on 714.

The measure subroutine 708 is shown in Figure 8. The panel 102 short circuit current is measured 802. The panel 102 voltage is measured 804. The data is then stored 806.

The PV DC voltage is measured until it reaches 2/3 of the open circuit value, at which point the timer is stopped and the value stored 716. A lookup table is used to compare the timer value against acceptable values. The sequence 700 can be run at set times of the day, such as sunrise or sunset, or at ad hoc times if the radiation level drops (for example due to cloud), to allow a safe measurement.

The panels are almost ideal current sources. So by measuring the open voltage 702 and the short circuit current 802 it is possible to measure the capacitance of the electrolytic capacitor with very high accuracy. The short circuit is switched off and clock pulses are counted till the voltage is two thirds of the open voltage. While the short circuit is still enabled it is possible to measure the voltage drop and the current at the same time (the rest resistance of the switching transistors). By alternating using the left and the right side of the inverter a quality record of the primary side main components can be generated, this being useful to compare to previously generated quality records and to look for degradation.

If short bursts of high power are sent at a certain beginning of the AC grid cycle it is possible to monitor the conversion ability of the sum or the separate left and right sides. This gives a general diagnosis of all the components, which can be used to determine whether more detailed diagnosis is required on individual components. The conversion ability or conversion yield is measured as the ratio of the voltage across the PV capacitor (which acts as a constant voltage source for this short time) to the peak current.

Figure 9 shows a flow diagram of a diagnostic process. At block 902 the panel 102 open circuit voltage is measured. The complete AC level (the trigger level according to the charge of the capacitors) is set 904. The grid AC voltage is checked to see if it has stabilised 906. A burst (a short sequence of power pulses as shown in Figure 4 at the (AC) grid) is triggered 908. The AC current sensor 310 is sampled 910. Then sequence 906, 908, 910 is repeated 912 for the other channel, for example the left or right channel, or simultaneously for both channels.

If the voltage of the grid is sampled before and just after the pulse, it is possible to evaluate the resistance of the grid, or in other words, to measure the quality of the grid connection.

Consolidated data may be useful for electricity distribution companies to design a model of the consolidated effect of building integrated solar installations for their network simulations.

In an installation with multiple panels that are able to perform intelligent diagnoses, each panel can be allocated a quality coefficient. The coefficient can be compared in real time to indicate the status of each panel. So if a panel is underperforming it will immediately show up as being out of step with the other panels in the installation.

By repeating this exercise, on the equivalent current diagram, the quality of the left assembly to the right assembly of transistor and primary transformer can be compared. This will also provide an indication of the secondary loading health. The panel and connectors are also part of this circuit, and it may also be possible to evaluate the contact quality of the connectors.

It may be useful for remote measurement of the yield of the panel and inverter, the inverter power supply voltages, the power and energy produced the low cut-off voltage, the harmonics generated, and the panel position annex shading in function of daytime or season, the ripple of the PV voltage.

Comparison of the measured data may be done in the multiplexer. Evaluation of the measured data may be done in the web client or at the central server.

This may allow the manufacturer to identifying problems in batches of panels. For example, if it is observed in the measured data that one batch consistently malfunctions when installed where it will encounter over 300W for more than 2 hours, this observation can then be used proactively, for example to avoid installing that batch in super high radiation locations.

Aging of components is very temperature dependent. Cooling is proportional with airstream. Cold humid air has more heat capacitance. The heat capacitance of the micro inverter is very large, such that it takes more than two hours to settle in indoor conditions. Now we are able to throttle the power, even if there is more power available. So if local conditions are so that extreme conditions are encountered only sporadically it could be better to oversize the panel on the inverter. This may give a better yearly performance than trying to match the inverter maximum load to a panel.

In the extreme conditions it is also possible to dynamically throttle the inverter depending on additional factors such as the initial inverter temperature, as this may affect the time period for which it can cope with overload conditions. This can be used to avoid local power over load and over temp inverter core. This may be used in combination with the inverter heat capacitance to start the process before the temperature can overshoot.

If there is a need for a certain option, out of the statistics we are able to evaluate the priority and payback time for this option in view of the amount of times it is really needed. For example the customer could provide the exact geographic location, orientation and layout of the installation. The system can then determine a very accurate yield estimate based on the historical local weather conditions at that exact geographic location, using that orientation and layout. This would allow customers to be more realistic about the payback time and compare different orientations and layouts. Once installed the yield can be compared against expected yield for that location, and if there is any significant deviation, the installer can be given detailed instructions as to what needs correction.

Sometimes micro inverters can introduce a DC current injection into the grid. By controlling individual inverters within an installation to inject an opposite DC current the installation can compensate and present an overall zero DC current injection. The DC current may be measured at regular intervals, such as every minute. It can also be filtered out of the much larger AC component with a saturated steel core transformer with very high hysteresis, for example.

Using the inverter for micro weather logging.

Weather forecasting is a macro science, but there is potential in local micro forecasting. An AC solar module has most of the needed elements available for this performance. It is a fixed stationary solar energy meter, with the needed processing power, and may be connected to the internet. Optionally, sensors can be added for added functionality. For example, a small ceramic disc to monitor rainfall, a humidity sensor and temperature sensor kit that can also measure wind speed and direction, and/or a pollution monitoring sensor can be added. With those extras we can monitor weather, water management and even pre-warning earthquake patterns. After mining this data it could be provided to utility providers, dynamic content aggregators, governmental or environmental organisations.

Figure 10 shows a ceramic disk microphone which can be provided on one of the panels. All the other sensors can be attached to the multiplexer. The noise, frequency and amplitude, of the output of the ceramic sensor are directly proportional to the amount of rainfall. Together with the output energy of the inverter an accurate indication of rainfall can be provided. The software library for these analyses is downloadable at the MPU manufacturer for the controller in the multiplexer.

The term micro inverter used herein is intended to mean a buck and/or boost converter attached to and independently inverting the DC output of a single or side by side PV solar panels into an AC output, and configured in hardware and/or software to operate as per the present invention. The combination of the panel(s) and the micro inverter are referred to herein as an AC solar module. If and where such terms are used in the prior art they are not intended to mean the same thing.

Whilst exemplary embodiments of the invention have been described in detail, many variations are possible within the scope of the invention as claimed as will be clear to a skilled reader.

CLAIMS:

1. A micro inverter for a respective solar panel comprising
a communications module configured to connect to a central server;
a plurality of sensors to collect inverter performance data and/or environmental data; and
a controller or processor configured to determine from the data any fault or imminent fault conditions and to communicate the respective condition to a relevant party via the central server.

2. The inverter in claim 1 wherein the fault or imminent fault conditions is or are selected from the group consisting of: reduced capacitor capacity, PV panel health, transformer fault, and transistor fault.

3. The inverter in claim 1 or 2 wherein the controller is further configured to communicate the inverter performance data and/or environmental data to the central server.

4. The inverter in claim 3 wherein the inverter performance data comprises one or more of: yield of the panel and inverter, the inverter power supply voltages, the energy produced, the low cut-off voltage, voltage harmonics, the panel position, shading compared to time or season, the ripple of the PV voltage, grid voltage and distortion, and grid load impedance.

5. The inverter in claim 3 or 4 wherein the environmental data comprises one or more of: solar energy, rainfall, humidity, temperature, wind speed, wind direction, pollution level, and seismic activity.

6. The inverter in any preceding claim wherein the controller is configured to determine whether to and/or what value of a DC component to inject into an AC output signal.

7. The inverter in any preceding claim wherein the controller is configured to determine the conversion ability or conversion yield of the inverter or of a portion of the inverter.

8. The inverter in any preceding claim wherein the controller is configured to determine a grid impedance or a grid connection quality.

9. A central controller comprising

central storage or memory, configured to store inverter performance data and/or environmental data for a plurality of networked inverters according to location, model, date and/or installation characteristics;

a central communications module configured to interrogate respective micro inverters; and

a central controller or processor configured to:

determine an estimated yield for a specific inverter,

determine from the inverter performance data and/or environmental data whether the inverter has any installation defects, fault or imminent fault conditions, and/or

determine whether to initiate and action requests for relevant parties.

10. The central controller in claim 9 wherein the controller is further configured to estimate the yield of a potential installation based on a selected installation size, geographic location, and/or installation configuration.

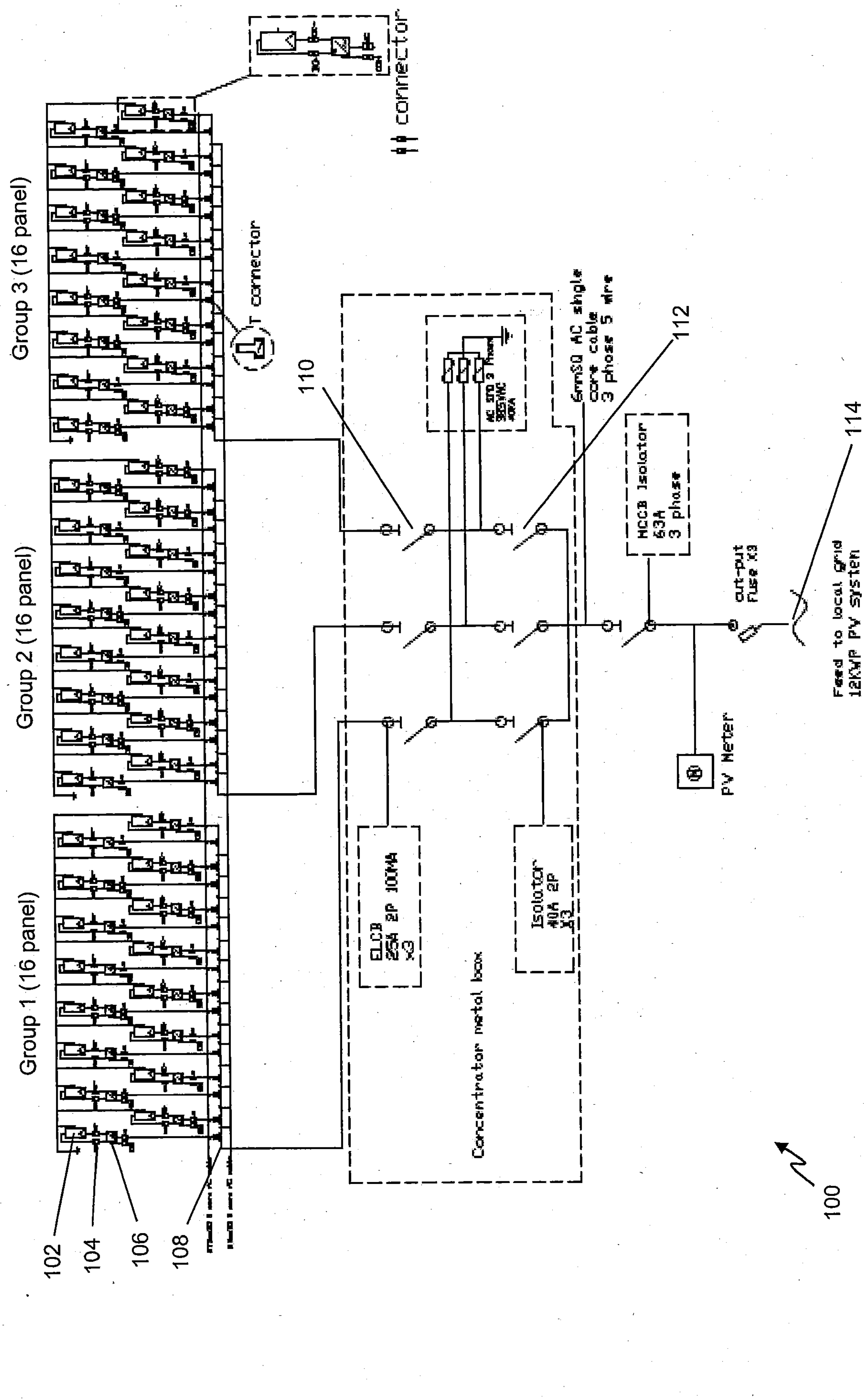

FIG. 1

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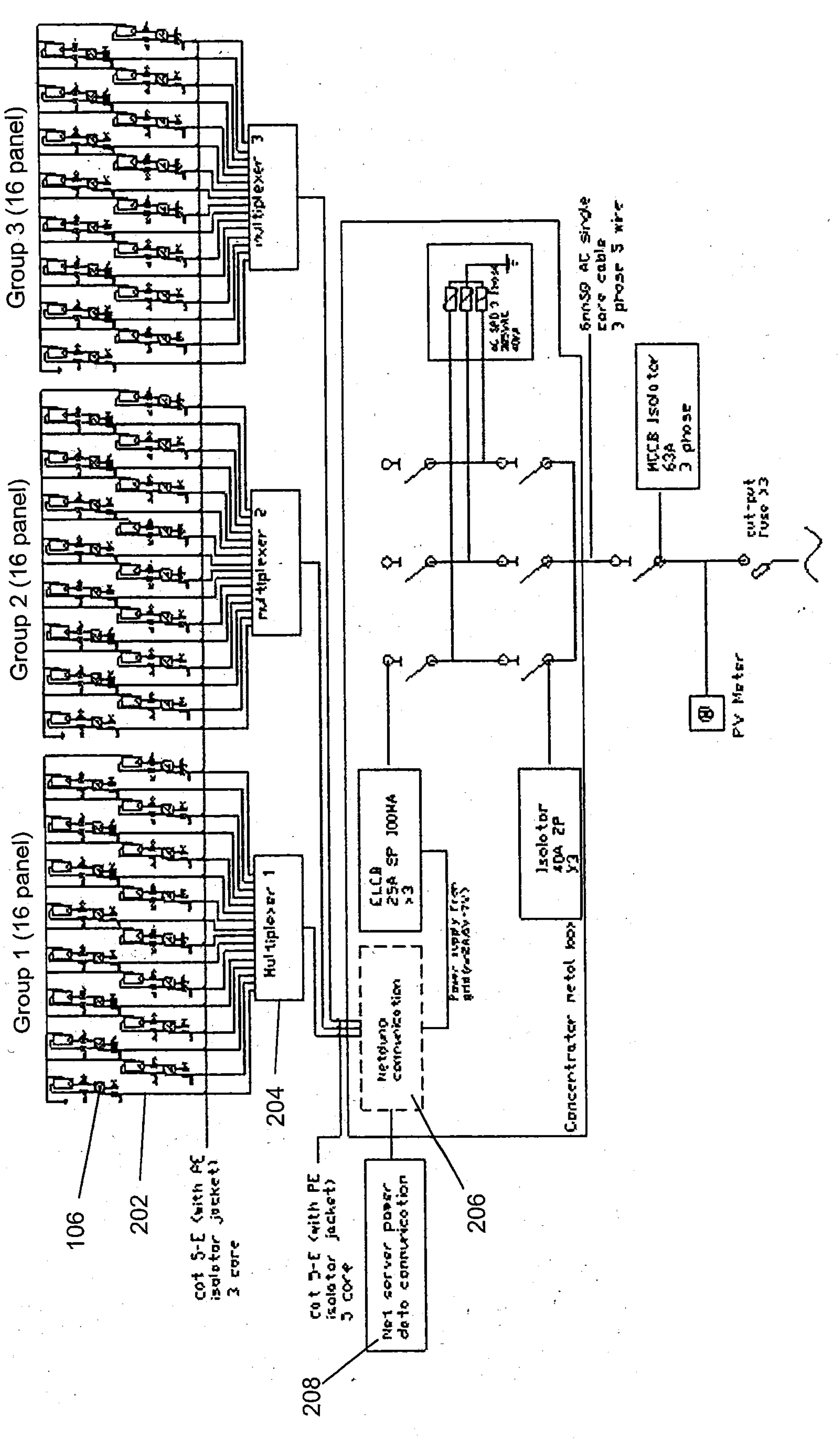
Group 3 (16 panel)
Group 2 (16 panel)
Group 1 (16 panel)
Multiplexer 1
multiplexer 2
multiplexer 3
ELCB 25A SP 100MA X3
Isolator 40A 2P X3
Concentrator metal box
MCCB Isolator 63A 3 phase
PV Meter
106
202
204
206
208
Net server power data communication

FIG. 2

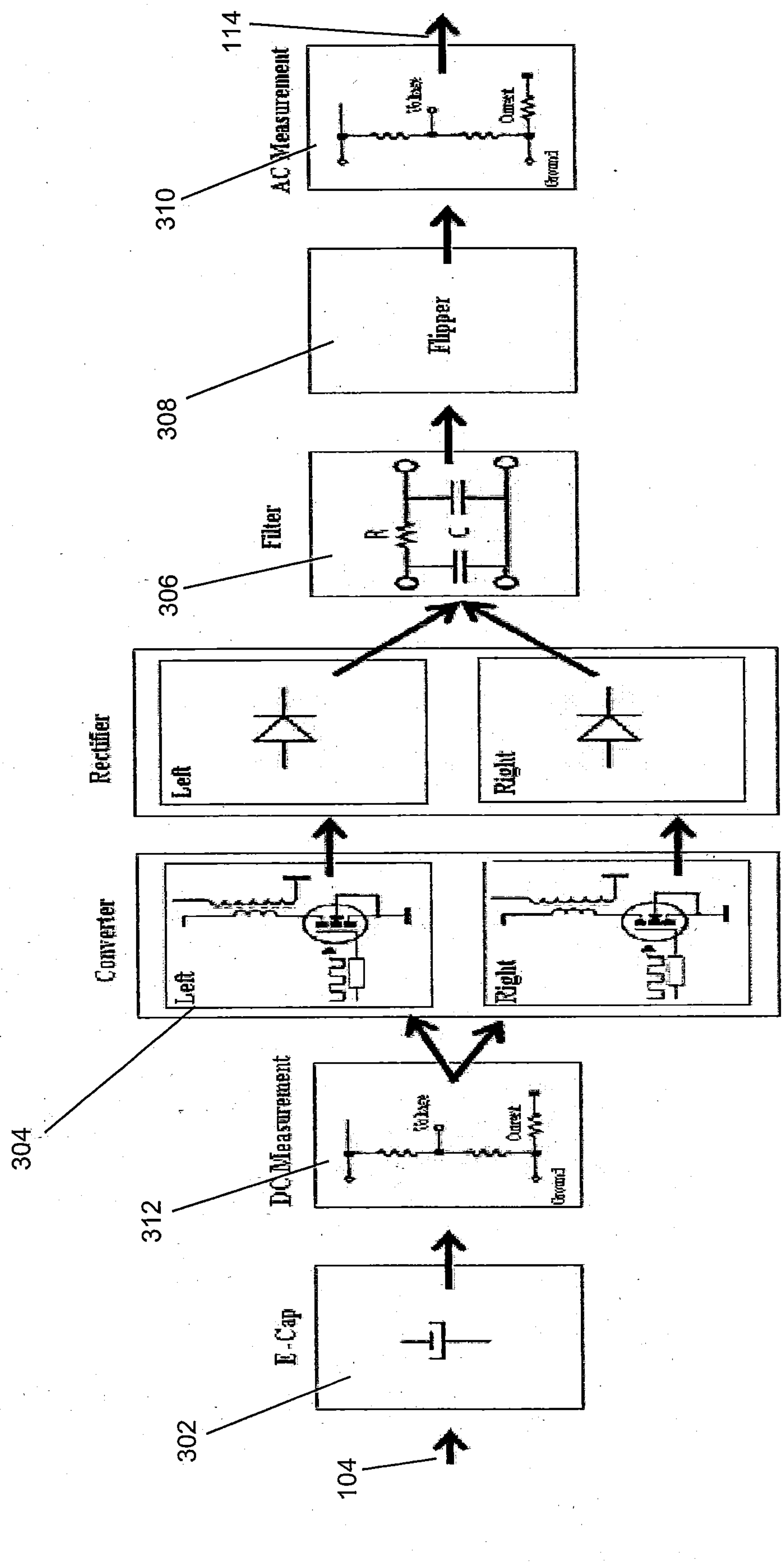
114
310
AC Measurement
Ground
308
Flipper
306
Filter
R
C
Rectifier
Left
Right
Converter
Left
Right
304
312
DC Measurement
Ground
302
E-Cap
104

FIG. 3

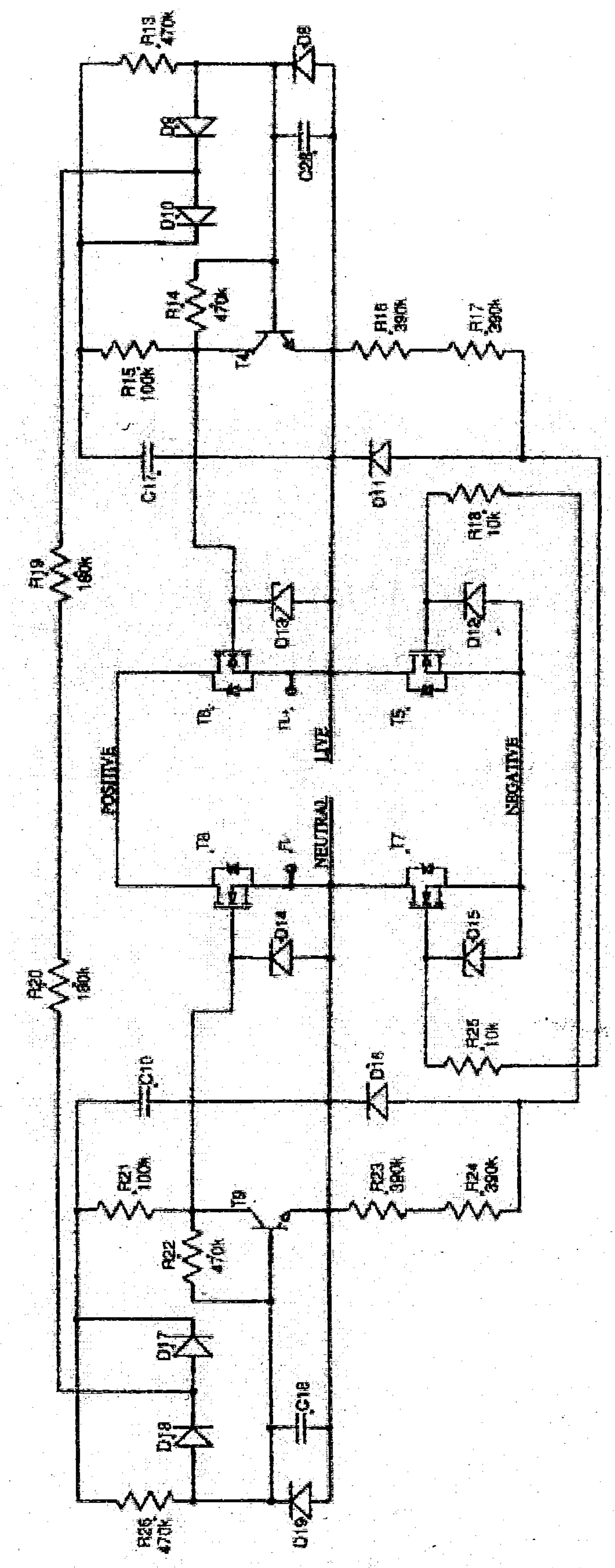

FIG. 11

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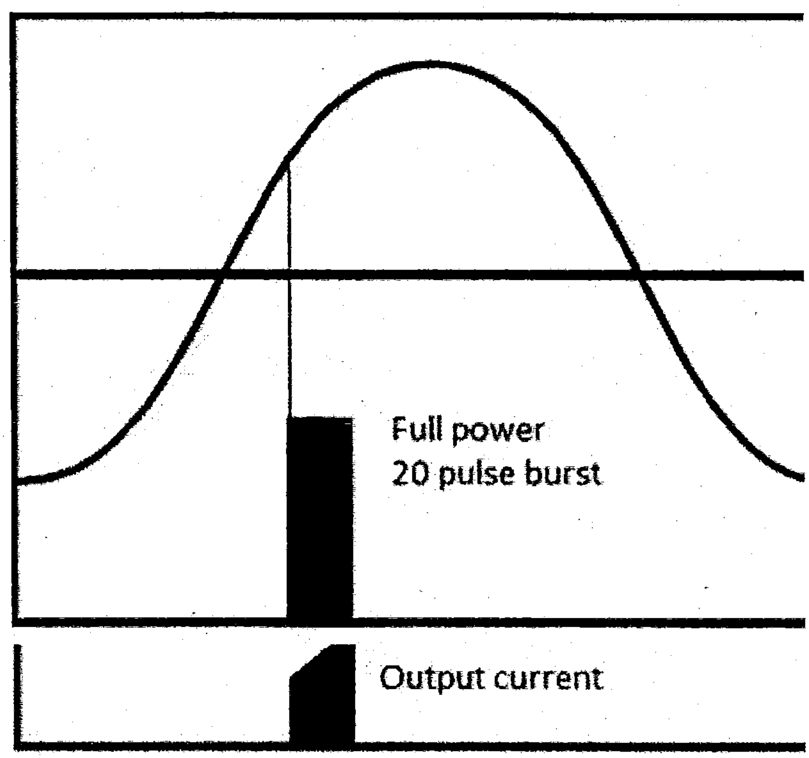

FIG. 4

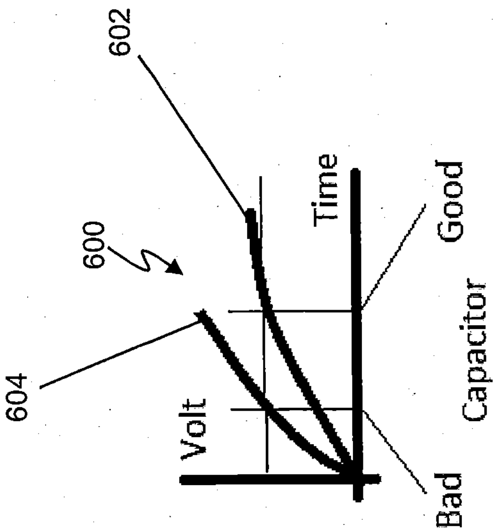

FIG. 6

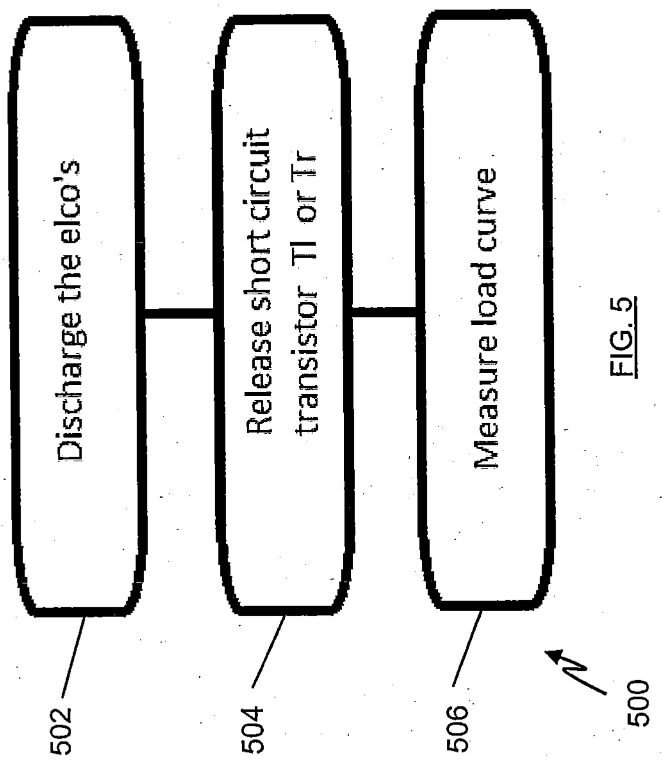

FIG. 5

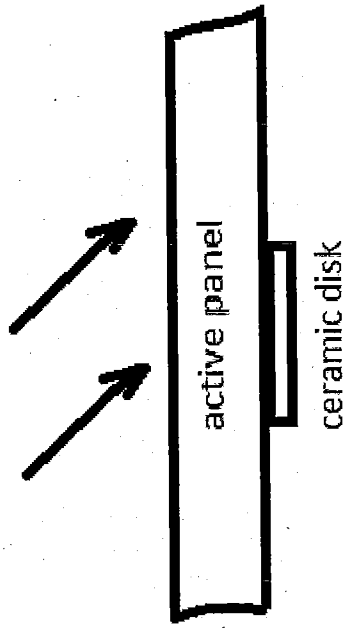

FIG. 10

SUBSTITUTE SHEET (RULE 26)

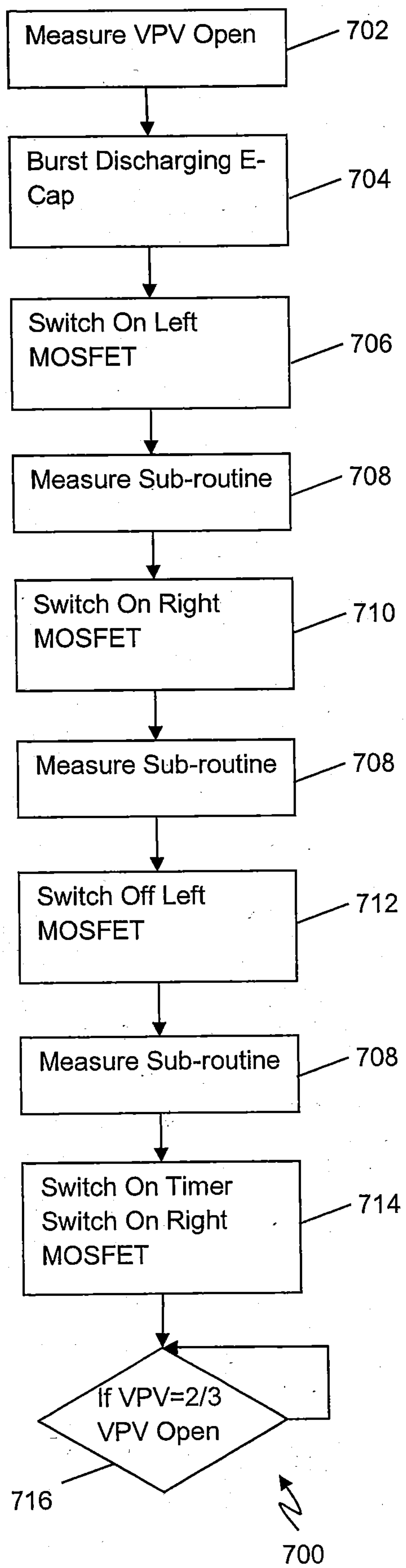
Measure VPV Open
702
Burst Discharging E-Cap
704
Switch On Left MOSFET
706
Measure Sub-routine
708
Switch On Right MOSFET
710
Measure Sub-routine
708
Switch Off Left MOSFET
712
Measure Sub-routine
708
Switch On Timer Switch On Right MOSFET
714
If VPV=2/3 VPV Open
716
700

FIG. 7

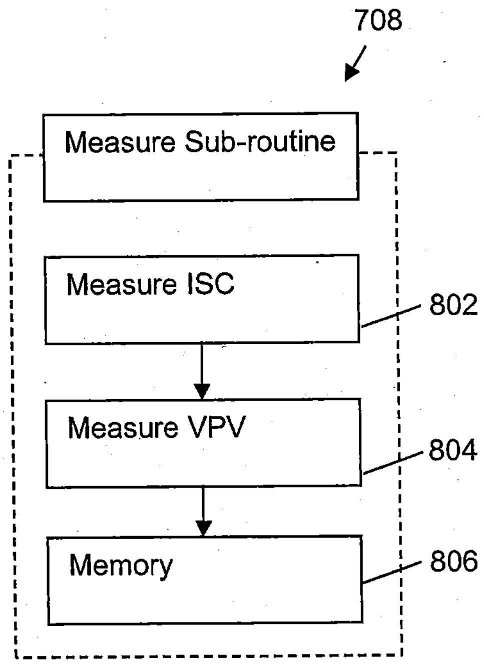
708
Measure Sub-routine
Measure ISC
802
Measure VPV
804
Memory
806

FIG. 8

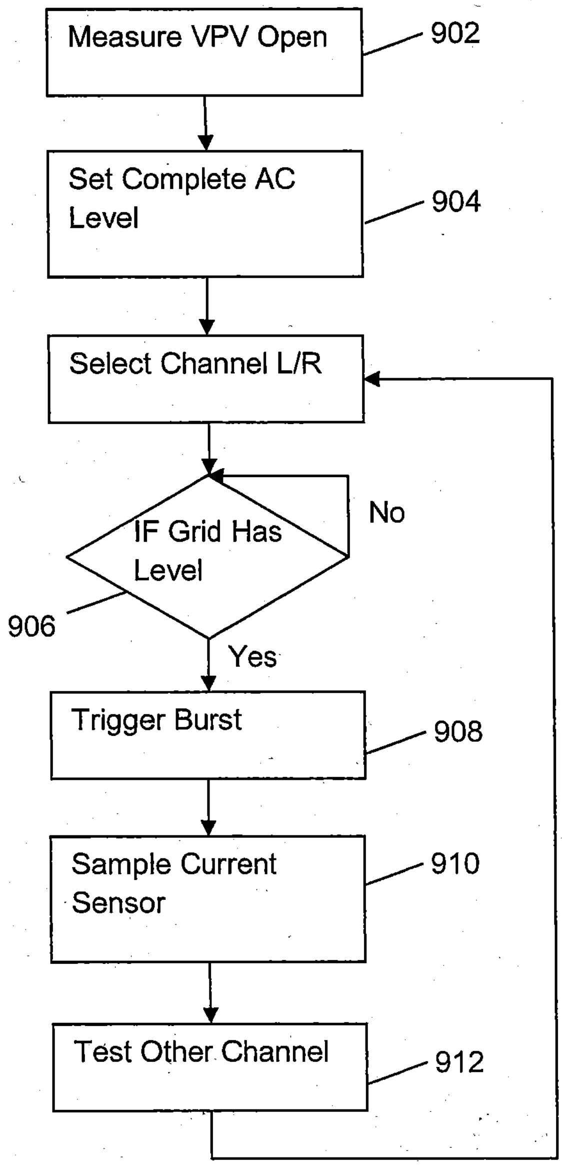
Measure VPV Open
902
Set Complete AC Level
904
Select Channel L/R
IF Grid Has Level
No
906
Yes
Trigger Burst
908
Sample Current Sensor
910
Test Other Channel
912

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SG2015/000026

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. H02M7/48(2007.01)i, H02S40/32(2014.01)i

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)

Int.Cl. H02M7/48, H02S40/32, H02J3/38

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

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2015
Registered utility model specifications of Japan 1996-2015
Published registered utility model applications of Japan 1994-2015

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	US 2009/0066357 A1 (ENPHASE ENERGY, INC.) 2009.03.12, paragraphs [0018]-[0044], Figures 1-2 & JP 2009-65164 A & EP 2034323 A2	1-7,9-10 8
Y	JP 2000-166098 A (DAIWA HOUSE INDUSTRY CO, LTD.) 2000.06.16, paragraphs [0011]-[0012], figures 1-4 (No Family)	8
A	US 2011/0016147 A1 (Martin FORNAGE) 2011.01.20, whole document & JP 2012-533974 A & WO 2011/008701 A2 & CA 2768459 A1 & CN 102474102 A	1-10
A	JP 6-311651 A (CANON INC.) 1994.11.04, whole document (No Family)	1-10

☐ 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
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- "P" document published prior to the international filing date but later than the priority date claimed
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- "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
24.03.2015	07.04.2015

Name and mailing address of the ISA/JP	Authorized officer
Japan Patent Office	Kenichi Matsunaga 3V 2925
3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Telephone No. +81-3-3581-1101 Ext. 3357