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(54) Benævnelse: **Fotovoltaisk omformer med maksimal strømbegrænsning i diskontinuerlig ledningsstrømtilstand**

(56) Fremdragne publikationer:
**US-A- 4 580 090**
**US-A- 6 057 665**
**US-A1- 2005 110 474**
**GWON-JONG YU ET AL: "Maximum power point tracking with temperature compensation of photovoltaic for air conditioning system with fuzzy controller", 19960513; 19960513 - 19960517, 13 May 1996 (1996-05-13), pages 1429-1432, XP010208423,**

# DESCRIPTION

## FIELD OF THE INVENTION

**[0001]** The present invention is a discontinuous conduction current mode maximum power limitation photovoltaic converter.

## BACKGROUND OF THE INVENTION

**[0002]** With reference to Figs. 1 to 3, a photovoltaic system converter can convert electromagnetic energy into electrical energy by photoelectric effect in a temperature, is known as a solar cell and has a conversion efficiency, illumination (S), an output voltage ($V_{PV}$), an output current ($I_{PV}$), a loading power, a maximum power, an output power ($P_{PV}$), a floating charge voltage ($V_F$) and a different maximum power point at different illuminations (S).

**[0003]** The temperature is comprises a first temperature (T1) and a second temperature (T2). T1 is 298 Kelvin (K). T2 is 338 K. The conversion efficiency is 6% to 30%. The illumination (S) has a unit that is abbreviated as $W/m^2$. The output voltage ($V_{PV}$) is represented by a graph of voltage and current (V-I) with the output current ($I_{PV}$) for different illuminations. The maximum power point is represented by four black points in Fig. 3 and is affected by illumination (S) and temperature. The floating charge voltage divides the graph of voltage and current (V-I) into a current source zone and a voltage source zone.

**[0004]** The voltage zone is a general operational zone of the solar cell and makes the solar cell stable.

**[0005]** If the loading power increases, $I_{PV}$ increases at the same illumination. When the loading power is greater than the maximum power, $V_{PV}$ will decrease suddenly and make the solar cell operate in the current source zone.

**[0006]** Conduction current mode divides a continuous conduction mode (CCM) and a discontinuous conduction mode (DCM) by directing an inductance current. The continuous conduction mode is when minimal inductance current is greater than 0 amperes. The discontinuous conduction mode is when minimal inductance current equal to 0 amperes.

**[0007]** A maximum power point tracker (MPPT) is a logic circuit for keeping the solar cell from operating at a maximum power point, so a state of a solar cell can be observed and PPV can be adjusted near maximum power.

**[0008]** U.S. Patent No.US 5,327,071 discloses a method and an apparatus for efficiently controlling the power output of a solar cell array string or multiple solar cell array strings to achieve a maximum output power from the strings under varying conditions of use. Maximum power output from a solar array string is achieved through control of a pulse width modulated DC/DC buck converter that transfers power from a solar array to a load or battery bus. The input voltage from the solar array to the converter is controlled by a pulse width modulation duty cycle that in turn is controlled by a differential signal comparing the array voltage with a control voltage from a controller. By periodically adjusting the control voltage up or down by a small amount and comparing the power on the load or bus with that generated at different voltage values causes a maximum power output voltage to be obtained. The apparatus is totally modular and additional solar array strings may be added to the apparatus simply be adding converter boards to the apparatus and changing some constants in the controller's control routines.

**[0009]** However, the foregoing maximum power point tracker is designed by a digital circuit that needs an analog to digital converter, a digital to analog converter and Hall device, decreases efficiency and makes the loading power greater than the maximum power.

**[0010]** Document US 6057665 A discloses an apparatus for extracting maximum power from a variable voltage; energy source. The apparatus determines the maximum operating point of the energy source, and circuits and circuit topologies are presented for extracting the energy. The apparatus eliminates the problem of finding local maximum points, and problems attendant variations of the absolute maximum power point as a function of temperature, insolation, array construction, and photo voltaic panel manufacturing tolerances. The energy source suppliers tower in the form of a voltage and charges the batteries with a controllable current source.

**[0011]** Accordingly, a new photovoltaic converter needs to have an analog maximum power point tracker designed with a maximum power limiter.

## SUMMARY OF THE INVENTION

**[0012]** The primary objective of the present invention is to design an analog maximum power point tracker with maximum power limitation.

**[0013]** A discontinuous conduction current mode maximum power limitation photovoltaic converter on in accordance with the present invention connects to a ground and a solar cell. The solar cell has a temperature compensation signal and an output power and is solarized. The discontinuous conduction current mode maximum power limitation photovoltaic converter comprises a direct current/direct current voltage converter and a maximum power control circuit.

**[0014]** The direct current/direct current voltage converter connects to the solar cell, comprises an input terminal and an output terminal, offers a stable voltage and has an output voltage signal and an inner current.

**[0015]** The maximum power control circuit connects to the direct current/direct current voltage converter and the solar cell, controls the direct current/direct current voltage converter to limit the output power of the solar cell is maximum and comprises a temperature compensation feedback circuit, an output voltage feedback circuit, a current detection circuit and a main control circuit.

**[0016]** The temperature compensation feedback circuit connects to the input terminal of the direct current/direct current voltage converter and transmits the temperature compensation signal of the solar cell.

**[0017]** The output voltage feedback circuit connects to the output terminal of the direct current/direct current voltage converter and transmits the output voltage signal of the direct current/direct current voltage converter.

**[0018]** The current detection circuit connects to the direct current/direct current voltage converter and detects the inner current of the direct current/direct current voltage converter.

**[0019]** The main control circuit comprises an output and connects to the solar cell and outputs a control signal to limit the output power of the solar cell to a maximum according to the temperature compensation signal, the output voltage signal and the inner current.

**BRIEF DESCRIPTION OF THE DRAWINGS**

**[0020]**

Fig. 1 is a graph of voltage and current (V-I) in accordance with a solar cell;

Fig. 2 is a graph of voltage and power (V-P) in accordance with a solar cell;

Fig. 3 is a graph of voltage and current (V-I) in different temperature in accordance with a solar cell;

Fig. 4 is a block diagram of a first embodiment of a discontinuous conduction current mode maximum power limitation photovoltaic converter in accordance with the present invention;

Fig. 5 is a circuit diagram of a direct current/direct current voltage converter in accordance with the present invention;

Fig. 6 is a block diagram of a second embodiment of a discontinuous conduction current mode maximum power limitation photovoltaic converter in accordance with the present invention;

Fig. 7 is a circuit diagram of a temperature compensation feedback circuit in accordance with the present invention;

Fig. 8 is a circuit diagram of an output voltage feedback circuit in accordance with the present invention;

Fig. 9 is a circuit diagram of a current detection circuit in accordance with the present invention;

Fig. 10 is a circuit diagram of a main control circuit in accordance with the present invention; and

Fig. 11 is a circuit diagram of a first embodiment of a discontinuous conduction current mode maximum power limitation photovoltaic converter in Fig. 3.

**DETAILED DESCRIPTION OF THE PRESENT INVENTION**

**[0021]** With reference to Figs. 4 to 11, a discontinuous conduction current mode maximum power limitation photovoltaic converter (1) in accordance with the present invention connects to a ground and a solar cell (0). The solar cell (0) has a temperature compensation signal and an output power and is solarized. The discontinuous conduction current mode maximum power limitation photovoltaic converter comprises a direct current/direct current voltage converter (10) and a maximum power

**[0022]** The direct current/direct current voltage converter (10) connects to the solar cell (0), comprises an input terminal (101), an output terminal (102), an optional main inductor (103), an optional rectifier (104), an optional main capacitor (105) and an optional switch circuit (106), offers a stable voltage and has an output voltage signal and an inner current.

**[0023]** The main inductor (103) comprises a first end (1031) and a second end (1032). The first end (1031) of the main inductor (103) connects to the input terminal (101) of the direct current/direct current voltage converter (10).

**[0024]** The rectifier (104) comprises an anode (1041) and a cathode (1042). The anode (1041) of the rectifier (104) connects to the second end (1032) of the main inductor (103).

**[0025]** The main capacitor (105) comprises a first end (1051) and a second end (1052). The first end (1051) of the main capacitor (105) connects to the cathode of the rectifier (104). The second end (1052) of the main capacitor (105) connects to the ground.

**[0026]** The switch circuit (106) comprises a first terminal (1061), a second terminal (1062), a third terminal (1063), a fourth terminal (1064), an optional main switch (1065) and an optional first resistor (1066). The first terminal (1061) connects to the anode (1041) of the rectifier (104). The second terminal (1062) connects to the ground. The main switch (1065) is an enhanced N type metal-oxide-semiconductor field effect transistor (NMOSFET) and comprises a drain (D), a gate (G) and a source (S). The drain (D) of the main switch (1065) connects to the anode (1041) of the rectifier (104). The first resistor (1066) comprises a first end (10661) and a second end (10662). The first end (10661) of the first resistor (1066) connects to the source (S) of the main switch (1065). The second end (10662) of the first resistor (1066) connects to the ground.

**[0027]** The maximum power control circuit (11) connects to the direct current/direct current voltage converter (10) and the solar cell (0), controls the direct current/direct current voltage converter (10) to limit the output power of the solar cell (0) to maximum and comprises a temperature compensation feedback circuit (111), an output voltage feedback circuit (112), a current detection circuit (113) and a main control circuit (114).

**[0028]** The temperature compensation feedback circuit (111) connects to the input terminal (101) of the direct current/direct current voltage converter (10), transmits the temperature compensation signal of the solar cell (0) and comprises at least one optional temperature sensor (1111), an optional main temperature compensation circuit (1112), an optional first voltage divider (1113), an optional first subtractor (1114) and an optional second subtractor (1115).

**[0029]** The temperature sensor (1111) senses the temperature of the solar cell (0).

**[0030]** The main temperature compensation circuit (1112) comprises an input (11121) and an output (11122). The input (11121) of the main temperature compensation circuit (1112) connects to the temperature sensor (1111).

**[0031]** The first voltage divider (1113) comprises an input (11131), an output (11132), a third resistor and a fourth resistor.

**[0032]** The input (11131) of the first voltage divider (1113) connects to the input terminal (101) of the direct current/direct current voltage converter (10).

**[0033]** The third resistor of the first voltage divider (1113) comprises a first end and a second end. The first end of the third resistor connects to the input (11131) of the first voltage divider (1113).

**[0034]** The fourth resistor of the first voltage divider (1113) comprises a first end and a second end. The first end of the fourth resistor connects to the second end of the third resistor. The second end of the fourth resistor connects to the ground.

**[0035]** The first subtractor (1114) comprises an anode (11141), a cathode (11142) and an output (11143). The anode (11141) of the first subtractor (1114) connects to a first reference voltage ($V_{REF1}$). The cathode (11142) of the first subtractor (1114) connects to the output (11122) of the main temperature compensation circuit (1112) and generates an input voltage. The output (11143) of the first subtractor (1114) outputs an output voltage that is the first reference voltage ($V_{REF1}$) subtracts the input voltage of the cathode (11142) of the first subtractor (1114).

**[0036]** The second subtractor (1115) comprises an anode, a cathode and an output. The anode of the second subtractor (1115) connects to the output (11132) of the first voltage divider (1113) and generates an input voltage. The cathode of the second subtractor (1115) connects to the output (11143) of the first subtractor (1114) and generates an input voltage. The output of the second subtractor (1115) outputs an output voltage that the input voltage of the anode of the second subtractor (1115) subtracts the input voltage of the cathode of the second subtractor (1115).

**[0037]** The output voltage feedback circuit (112) connects to the output terminal (102) of the direct current/direct current voltage converter (10), transmits the output voltage signal of the direct current/direct current voltage converter (10) and comprises a second voltage divider (1121) and an integrator (1122).

**[0038]** The second voltage divider (1121) comprises an input (11211) and an output (11212). The input (11211) of the second voltage divider (1121) connects to the output terminal (102) of the direct current/direct current voltage converter (10).

**[0039]** The integrator (1122) comprises a first input (11221), a second input (11222), an output (11223), a second resistor (11224), a capacitor (11225) and an operational amplifier (11226).

**[0040]** The first input (11221) of the integrator (1122) connects to the output (11212) of the second voltage divider (1121).

**[0041]** The second input (11222) of the integrator (1122) connects to a second reference voltage ($V_{REF2}$).

**[0042]** The output (11223) of the integrator (1122) outputs a voltage variance between the first input (11221) and second input (11222) of the integrator (1122) is amplified and time-integrated.

**[0043]** The second resistor (11224) comprises a first end (112241) and a second end (112242). The first end (112241) of the second resistor (11224) connects to the output (11212) of the second voltage divider (1121).

**[0044]** The capacitor (11225) connects to the second end (112242) of the second resistor (11224).

**[0045]** The operational amplifier (11226) comprises a positive input (112261) and a negative input (112262). The positive input (112261) of the operational amplifier (11226) connects to the second reference voltage ($V_{REF2}$). The negative input (112262) of the operational amplifier

(11226) connects to the second end (112242) of the second resistor (11224).

**[0046]** The current detection circuit (113) connects to the direct current/direct current voltage converter (10), the third terminal (1063) of the switch circuit (106) and the source (S) of the main switch (1065), detects the inner current of the direct current/direct current voltage converter (10) and comprises a first end (1131), a second end (1132), a third end (1133), a fourth end (1134) and a coupling inductance (1135). The second end (1132) of the current detection circuit (113) connects to the ground. The fourth end (1134) of the current detection circuit (113) connects to the third end (1133) of the current detection circuit (113). The coupling inductance (1135) of the current detection circuit (113) inductive couples with the main inductor (103) of the direct current/direct current voltage converter (10) and comprises a first end (11351) and a second end (11352).

**[0047]** The main control circuit (114) connects to the fourth terminal (1064) of the switch circuit (106) and comprises an output, an optional multiplier (1141), an optional comparator (1142), an optional zero-current detection circuit (1143) and an pulse width modulation generator (1144), connects to the solar cell (0) and outputs a control signal to limit the output power of the solar cell (0) to maximum according to the temperature compensation signal, the output voltage signal and the inner current.

**[0048]** The multiplier (1141) comprises a first input (11411), a second input (11412) and an output (11413). The first input (11411) of the multiplier (1141) connects to the temperature compensation feedback circuit (111) and produces a first input voltage signal. The second input (11412) of the multiplier (1141) connects to the output voltage feedback circuit (112) and produces a second input voltage signal. The output (11413) of the multiplier (1141) outputs a multiplication of the first input voltage signal and the second input voltage signal.

**[0049]** The comparator (1142) comprises a positive input (11421), a negative input (11422) and an output (11423). The positive input (11421) of the comparator (1142) connects to the current detection circuit (113). The negative input (11422) of the comparator (1142) connects to the output (11413) of the multiplier (1141).

**[0050]** The zero-current detection circuit (1143) comprises at least one input (11431) and an output (11432). The input (11431) of the zero-current detection circuit (1143) connects to the current detection circuit (113).

**[0051]** The pulse width modulation generator (1144) connects to the gate (G) of the main switch (1065), generates a pulse width modulation signal to control the direct current/direct current voltage converter (10) and comprises a first input (11441), a second input (11442) and an output (11443). The first input (11441) of the pulse width modulation generator (1144) connects to the output (11423) of the comparator (1142). The second input (11442) of the pulse width modulation generator (1144) connects to the output (11432) of the zero-current detection circuit (1143). The output (11443) of the pulse width modulation generator (1144) connects to the direct current/direct current voltage converter (10).

# REFERENCES CITED IN THE DESCRIPTION



**Patent documents cited in the description**


- US5327071A **[0008]**
- US6057665A **[0010]**

**Patentkrav**

**1.** Fotovoltaisk omformer med maksimal strømbegrænsning i diskontinuerlig ledningsstrømtilstand (1), der kan forbindes til en jord og en solcelle (0), og hvor den fotovoltaiske omformer med maksimal strømbegrænsning i diskontinuerlig ledningsstrømtilstand (1) omfatter:

en jævnstrøm-jævnstrømsspændingsomformer (DC-til-DC-omformer) (10), der kan forbindes til solcellen, omfattende en inputterminal (101) og en outputterminal (102), der giver en stabil spænding og har et outputspændingssignal og en indre strøm; og

et maksimumeffekt-styrekredsløb (11) forbundet til jævnstrøm-jævnstrømsspændingsomformeren (10) og kan forbindes til solcellen (0), hvilket maksimumeffekt-styrekredsløb styrer jævnstrøm-jævnstrømsspændingsomformeren (10) for at begrænse solcellens (0) outputeffekt maksimalt, og omfattende:

et temperaturkompensation-feedbackkredsløb (111), der er forbundet til jævnstrøm-jævnstrømsspændingsomformerens (10) inputterminal (101) og sender solcellens (0) temperaturkompensationssignal;

en outputspænding-feedbackkredsløb (112), der er forbundet til jævnstrøm-jævnstrømsspændingsomformerens (10) outputterminal (102) og sender jævnstrøm-jævnstrømsspændingsomformerens (10) outputspændingssignal;

et strømdetektionskredsløb (113), der er forbundet til jævnstrøm-jævnstrømsspændingsomformeren (10) og detekterer jævnstrøm-jævnstrømsspændingsomformerens (10) indre strøm; og

et hovedstyrekredsløb (114), der omfatter et output og kan forbindes til solcellen (0) og outputter et styresignal for at begrænse solcellens (0) outputeffekt maksimalt i henhold til temperaturkompensationssignalet, outputspændingssignalet og den indre strøm, hvor hovedstyrekredsløbet (114) yderligere omfatter

en multiplikator (1141) omfattende

et første input (11411), der er forbundet til temperaturkompensation-feedbackkredsløbet (111) og producerer et første inputspændingssignal;

et andet input (11412), der er forbundet til outputspænding-feedbackkredsløbet (112) og producerer et andet inputspændingssignal; og

et output (11413), der outputter en multiplikation af det første inputspændingssignal og det andet inputspændingssignal;

en komparator (1142) omfattende

et positivt input (11421), der er forbundet til strømdetektionskredsløbet;

et negativt input (11422), der er forbundet til multiplikatorens (1141) output; og

et output (11423);

et nulstrømdetektionskredsløb (1143) omfattende

mindst et input, der er forbundet til strømdetektionskredsløbet (113); og

et output (11432); og

en impulsbreddemodulationsgenerator (1144), der genererer et impulsbreddemodulationssignal til at styre jævnstrøm-jævnstrømsspændingsomformeren (10), og omfatter:

et første input (11441), der er forbundet til komparatorens (1142) output (11423);

et andet input (11442), der er forbundet til nulstrømdetektionskredsløbets (1143) output (11432); og

et output (11443), der er forbundet til jævnstrøm-jævnstrømsspændingsomformeren (10).

**2.** Den fotovoltaiske omformer med maksimal strømbegrænsning i diskontinuerlig ledningsstrømtilstand (1) ifølge krav 1, hvor temperaturkompensation-feedbackkredsløbet (111) yderligere omfatter:

mindst en temperatursensor (1111) konfigureret til at detektere solcellens (0) temperatur;

et hovedtemperatur-kompensationskredsløb (1112) omfattende:

et input (11121), der er forbundet til temperatursensoren (1111); og

et output (11122);

en første spændingsdeler (1113) omfattende:

et input (11131), der er forbundet til jævnstrøm-jævnstrømsspændingsomformerens (10) inputterminal (101); og

et output (11132);

en første subtraktor (1114) omfattende:

en anode (11141), der er forbundet til en første referencespænding;

en katode (11142), der er forbundet til hovedtemperatur-kompensationskredsløbets (1112) output (11122) og genererer en inputspænding; og

et output (11143), der outputter en outputspænding, der er den første referencespænding subtraherer inputspændingen af den første subtraktors (1114) katode (11142); og

en anden subtraktor (1115) omfattende

en anode, der er forbundet til den første spændingsdelers (1113) output (11132) og genererer en inputspænding; og

en katode, der er forbundet til den første subtraktors (1114) output (11143) og genererer en inputspænding; og

et output, der outputter en outputspænding, som inputspændingen af den anden subtraktors (1115) anode subtraherer inputspændingen af den anden subtraktors (1115) katode.

**3.** Den fotovoltaiske omformer med maksimal strømbegrænsning i diskontinuerlig ledningsstrømtilstand (1) ifølge krav 2, hvor den første spændingsdeler (1113) yderligere omfatter en tredje modstand omfattende

en første ende, der er forbundet til den første spændingsdelers (1113) input; og

en anden ende;

en fjerde modstand omfattende

en første ende, der er forbundet til den anden ende af den tredje modstand; og

en anden ende, der er forbundet til jorden.

**4.** Den fotovoltaiske omformer med maksimal strømbegrænsning i diskontinuerlig ledningsstrømtilstand ifølge krav 1, hvor outputspænding-feedbackkredsløbet yderligere omfatter:

en anden spændingsdeler omfattende:

et input, der er forbundet til jævnstrøm-jævnstrømsspændingsomformerens outputterminal; og

et output; og

en integrator omfattende:

et første input, der er forbundet til den anden spændingsdelers output;

et andet input, der er forbundet til en anden referencespænding; og

et output, der outputter en spændingsvarians mellem det første input og det andet input af integratoren, der forstærkes og tidsintegreres.

**5.** Den fotovoltaiske omformer med maksimal strømbegrænsning i diskontinuerlig ledningsstrømtilstand (1) ifølge krav 4, hvor den første spændingsdeler (1113) yderligere omfatter en tredje modstand omfattende en første ende, der er forbundet til den anden spændingsdelers input; og en anden ende; og en fjerde modstand omfattende en første ende, der er forbundet til den anden ende af den tredje modstand; og en anden ende, der er forbundet til jorden.

**6.** Den fotovoltaiske omformer med maksimal strømbegrænsning i diskontinuerlig ledningsstrømtilstand ifølge krav 4, hvor integratoren yderligere omfatter:

en anden modstand omfattende:

en første ende, der er forbundet til den anden spændingsdelers output; og

en anden ende;

en kondensator, der er forbundet til den anden ende af den anden modstand; og

en driftsforstærker omfattende:

et positivt input, der er forbundet til den anden referencespænding ($V_{REF2}$); og

et negativt input, der er forbundet til den anden ende af den anden modstand.

**7.** Den fotovoltaiske omformer med maksimal strømbegrænsning i diskontinuerlig ledningsstrømtilstand ifølge krav 1, hvor jævnstrøm-jævnstrømsspændingsomformeren yderligere omfatter:

en hovedinduktor omfattende:

en første ende, der er forbundet til jævnstrøm-jævnstrømsspændingsomformerens inputterminal; og

en anden ende;

en ensretter omfattende:

en anode, der er forbundet til den anden ende af hovedinduktoren; og

en katode;

en hovedkondensator omfattende:

en første ende, der er forbundet til ensretterens katode; og

en anden ende, der er forbundet til jorden; og

et omskifterkredsløb omfattende:

en første terminal, der er forbundet til hovedstyrekredsløbets output;

en anden terminal, der er forbundet til ensretterens anode;

en tredje terminal, der er forbundet til strømdetektionskredsløbet; og

en fjerde terminal, der er forbundet til jorden.

**8.** Den fotovoltaiske omformer med maksimal strømbegrænsning i diskontinuerlig ledningsstrømtilstand ifølge krav 7, hvor omskifterkredsløbet yderligere omfatter:

en hovedomskifter, der er en forbedret N-type metal-oxid-halvleder-felteffekttransistor (NMOSFET) og omfatter:

et drain, der er forbundet til ensretterens anode;

en gate, der er forbundet til impulsbreddemodulationsgeneratorens output; og

en kilde, der er forbundet til strømdetektionskredsløbet; og

en første modstand omfattende:

en første ende, der er forbundet til hovedomskifterens kilde; og

en anden ende, der er forbundet til jorden.

**9.** Den fotovoltaiske omformer med maksimal strømbegrænsning i diskontinuerlig ledningsstrømtilstand ifølge krav 7, hvor strømdetektionskredsløbet yderligere omfatter:

en første ende;

en anden ende, der er forbundet til jorden;

en tredje ende;

en fjerde ende, der er forbundet til den tredje ende af strømdetektionskredsløbet; og

en koblingsinduktans, der induktivt kobler med jævnstrøm-jævnstrømsspændingsomformerens hovedinduktor og omfatter en første ende og en anden ende.

# DRAWINGS

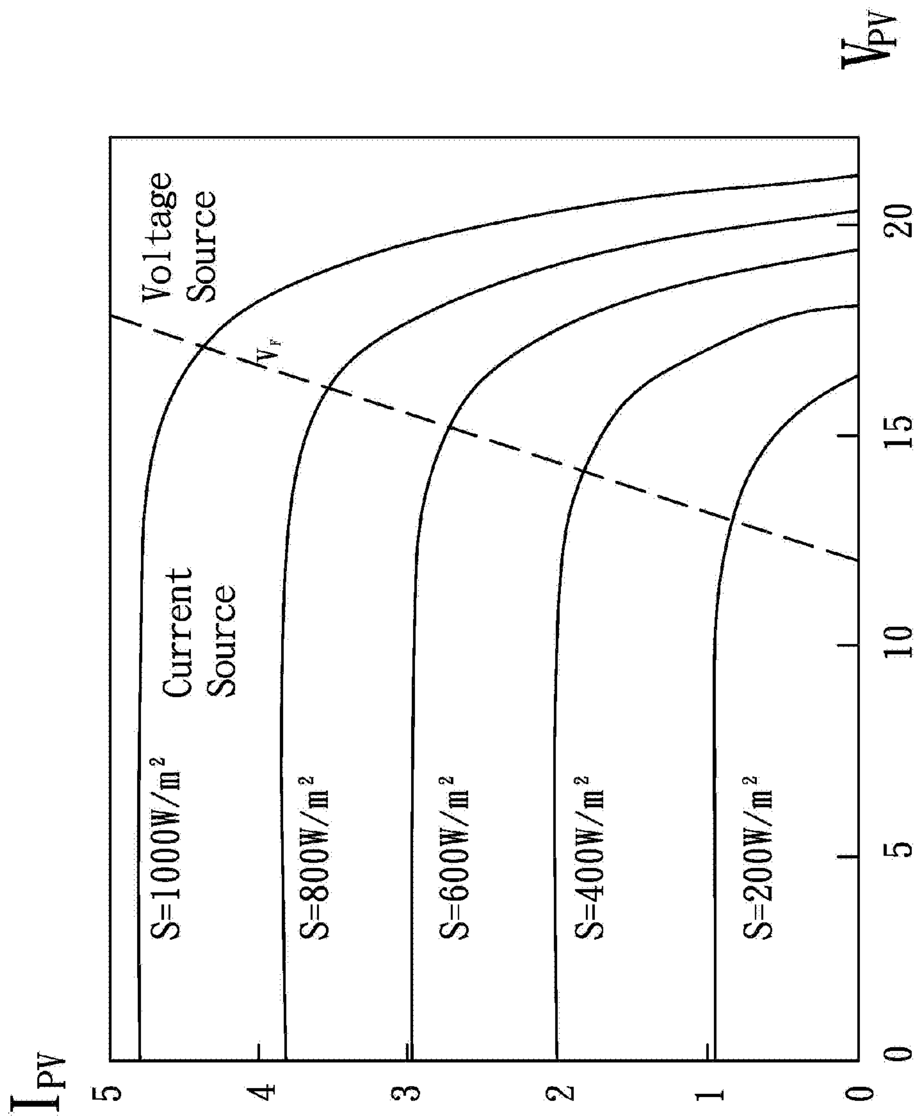
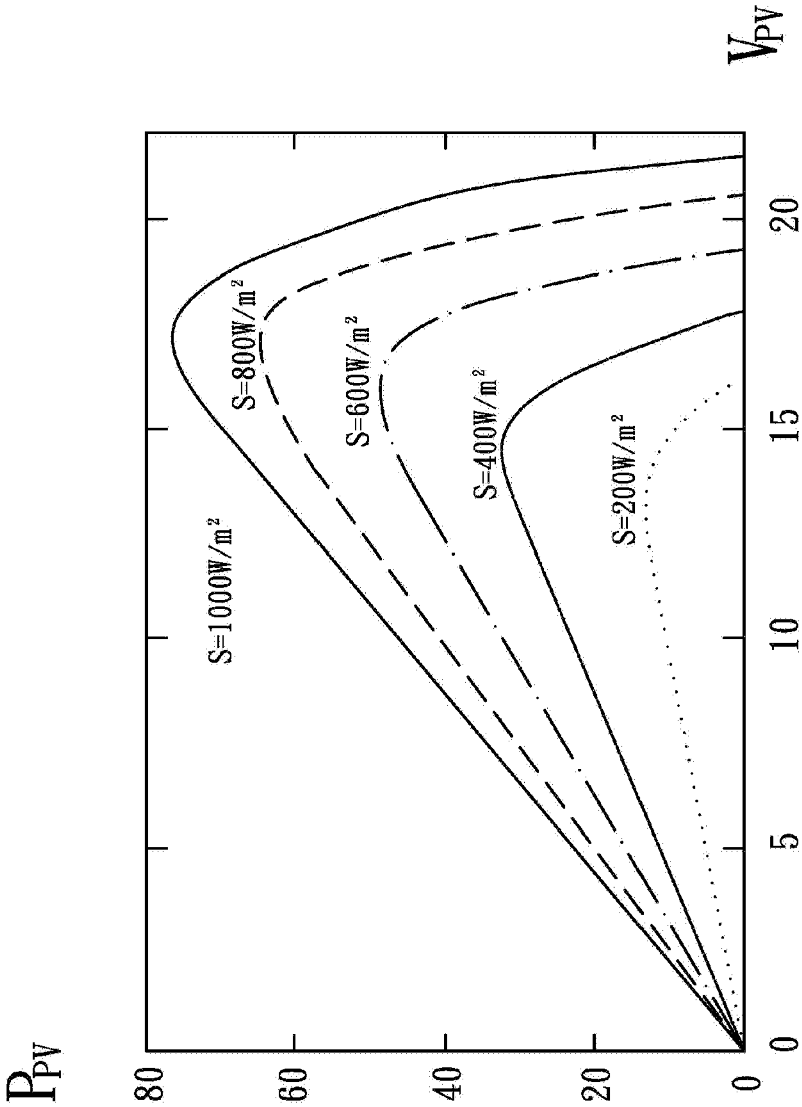



Fig. 1



P_PV
V_PV
0
20
40
60
80
0
5
10
15
20
S=1000W/m²
S=800W/m²
S=600W/m²
S=400W/m²
S=200W/m²


Fig. 2

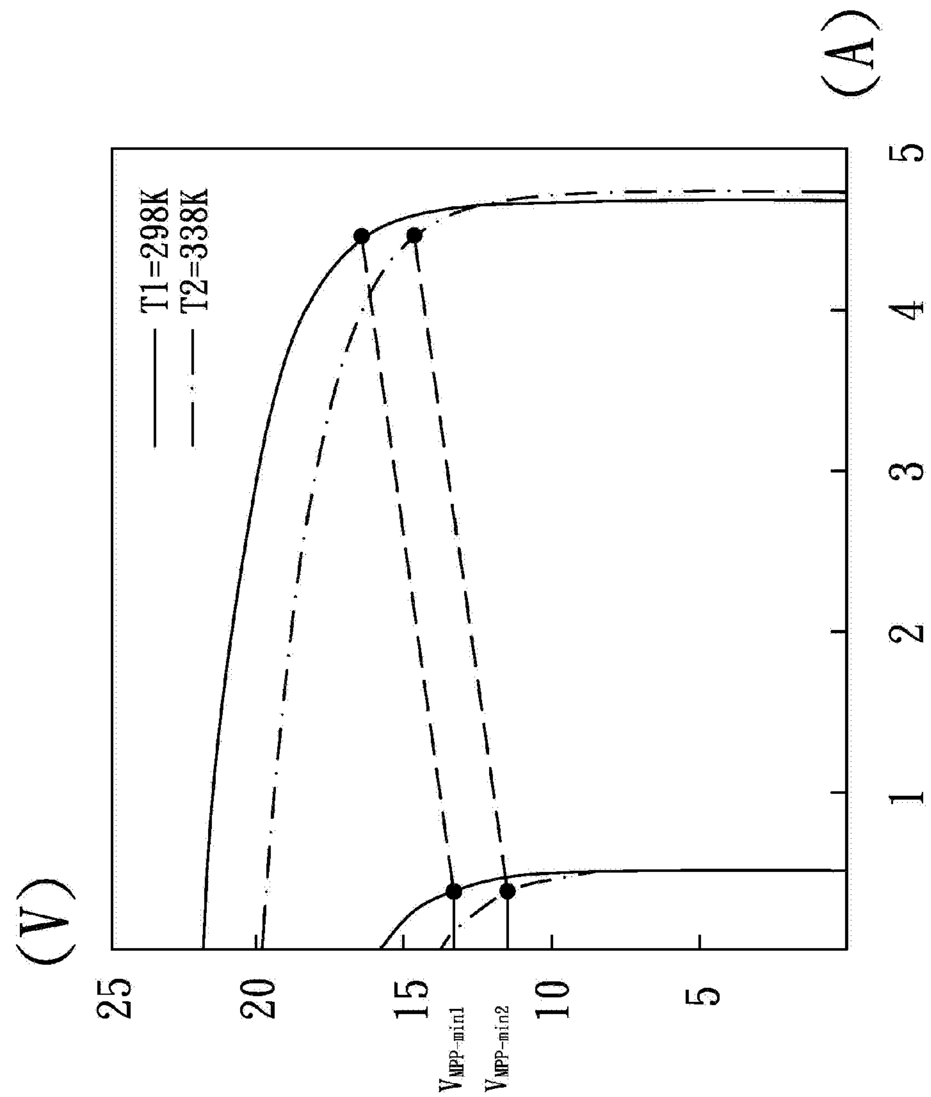



Fig. 3

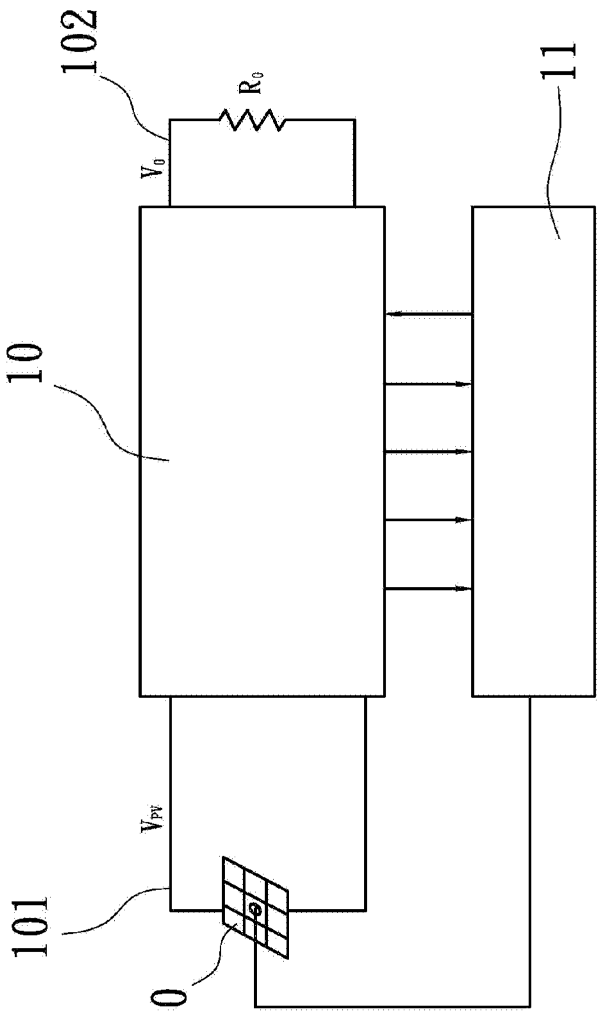



Fig. 4

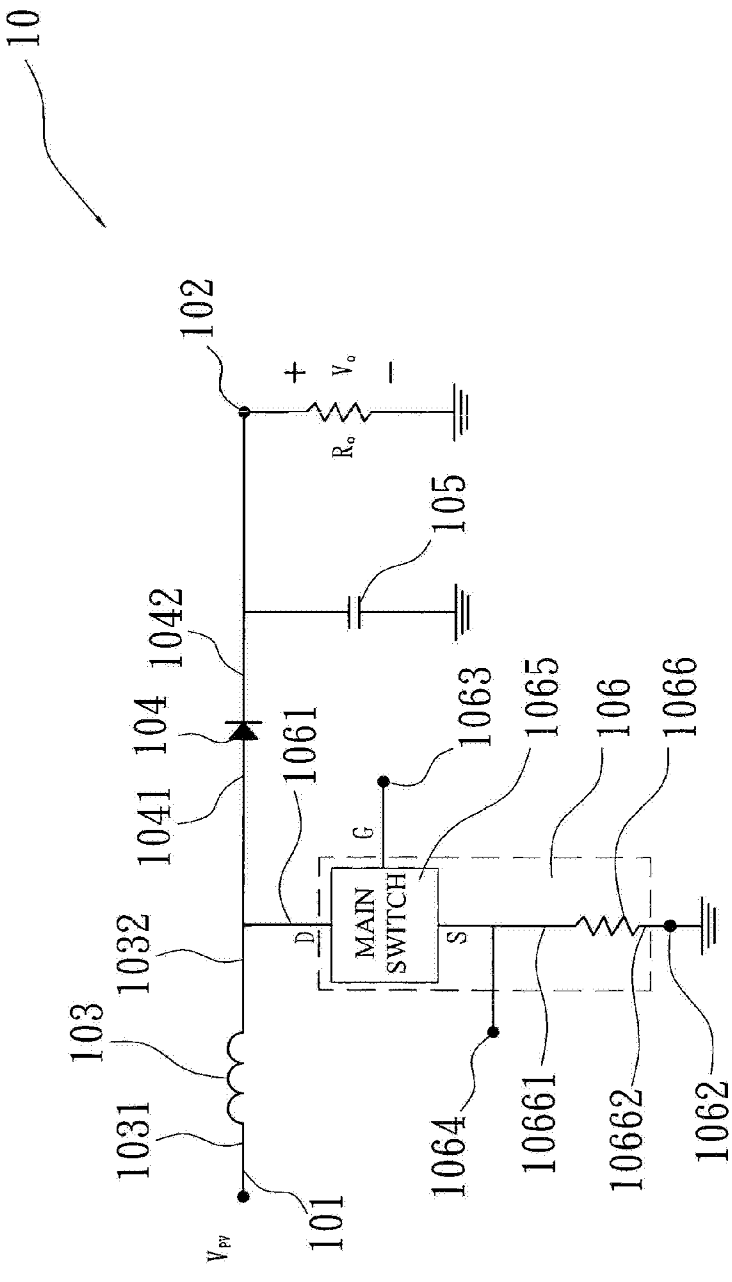

10
101
1031
103
1032
1041
104
1042
105
102
1061
1063
1065
106
1066
1064
10661
10662
1062
MAIN SWITCH
D
G
S
+
−

Fig. 5

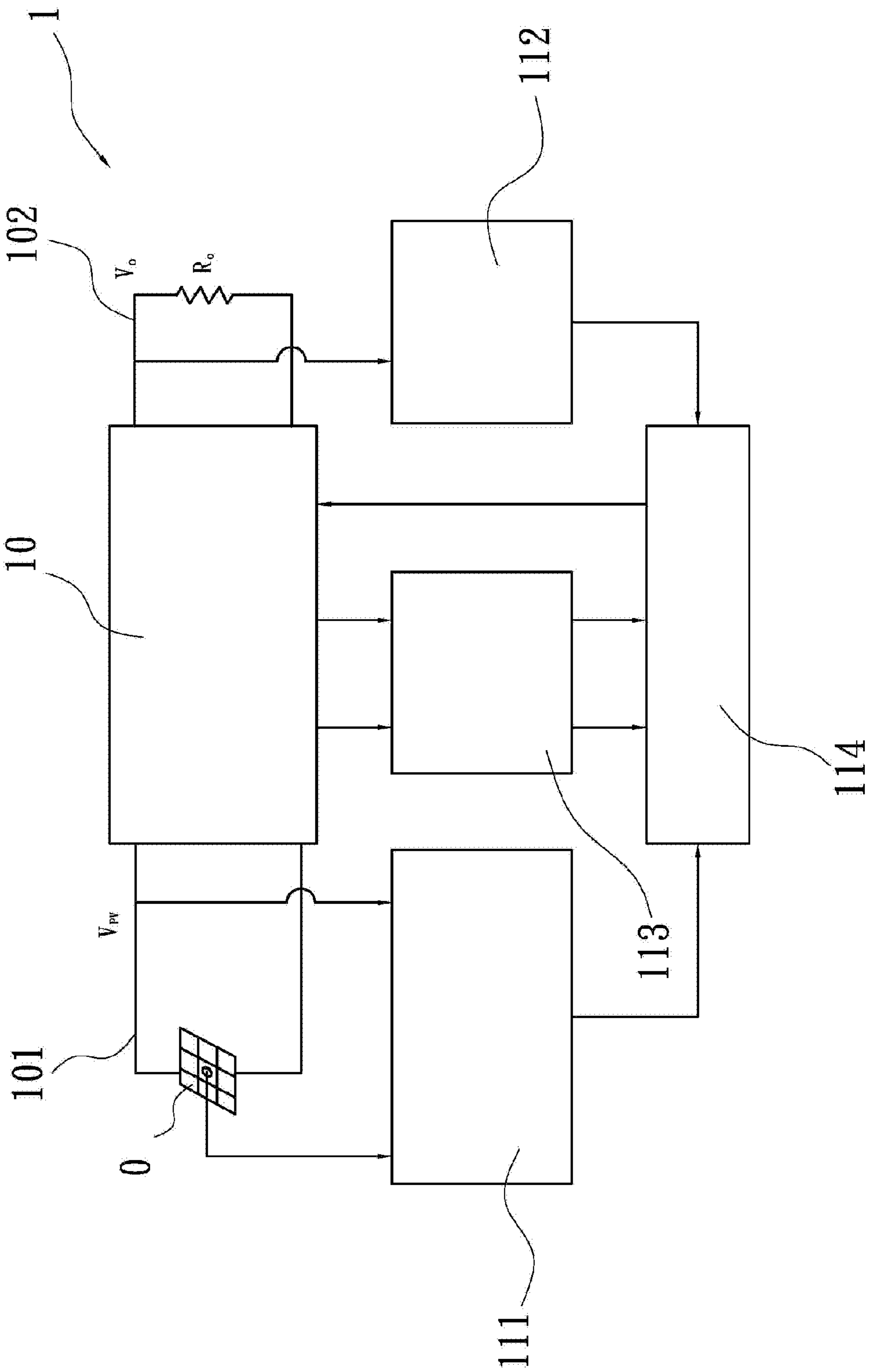



Fig. 6

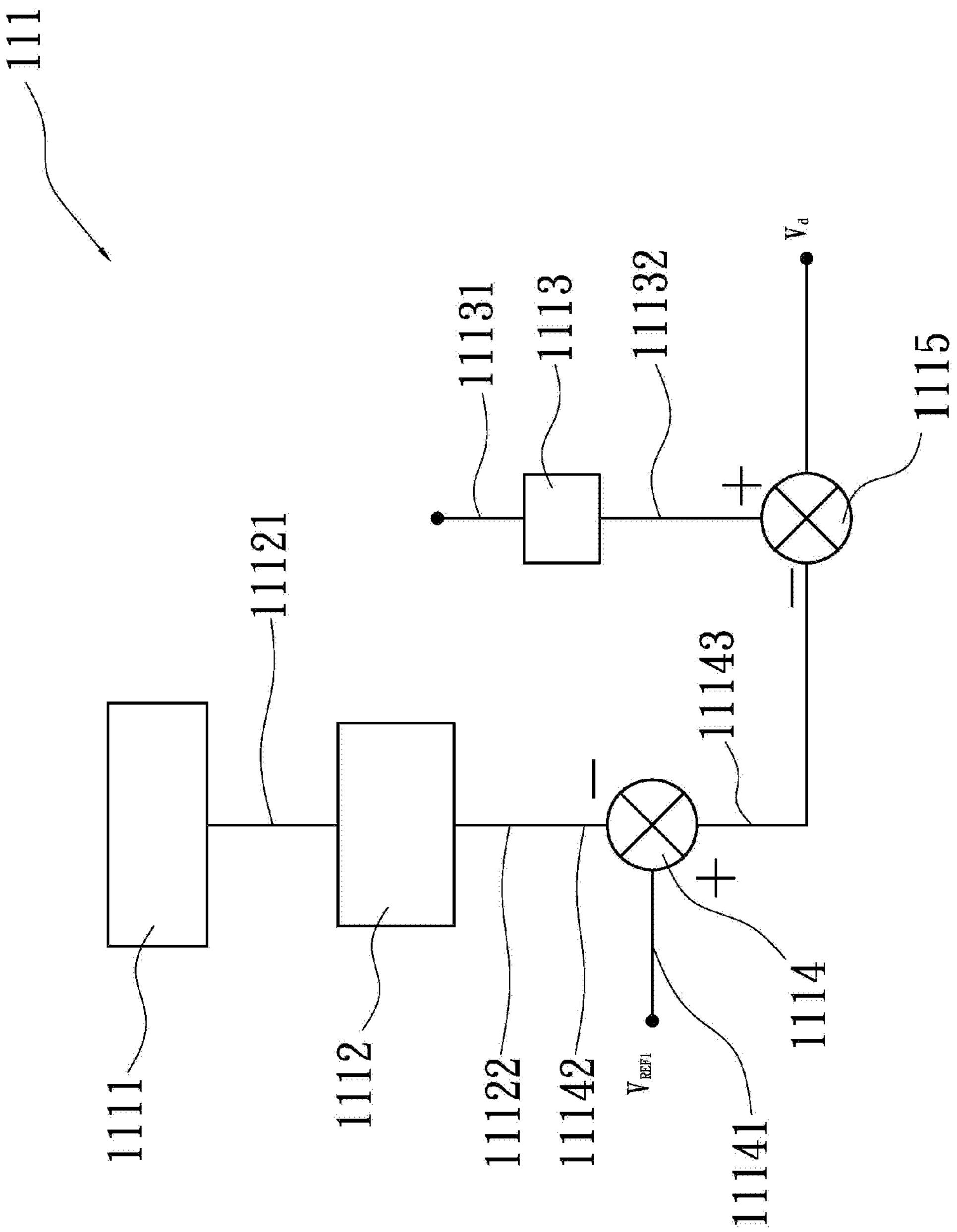

111
1111
1112
11121
11122
11142
11141
1114
11143
11131
1113
11132
1115
VREF1
Vd

Fig. 7

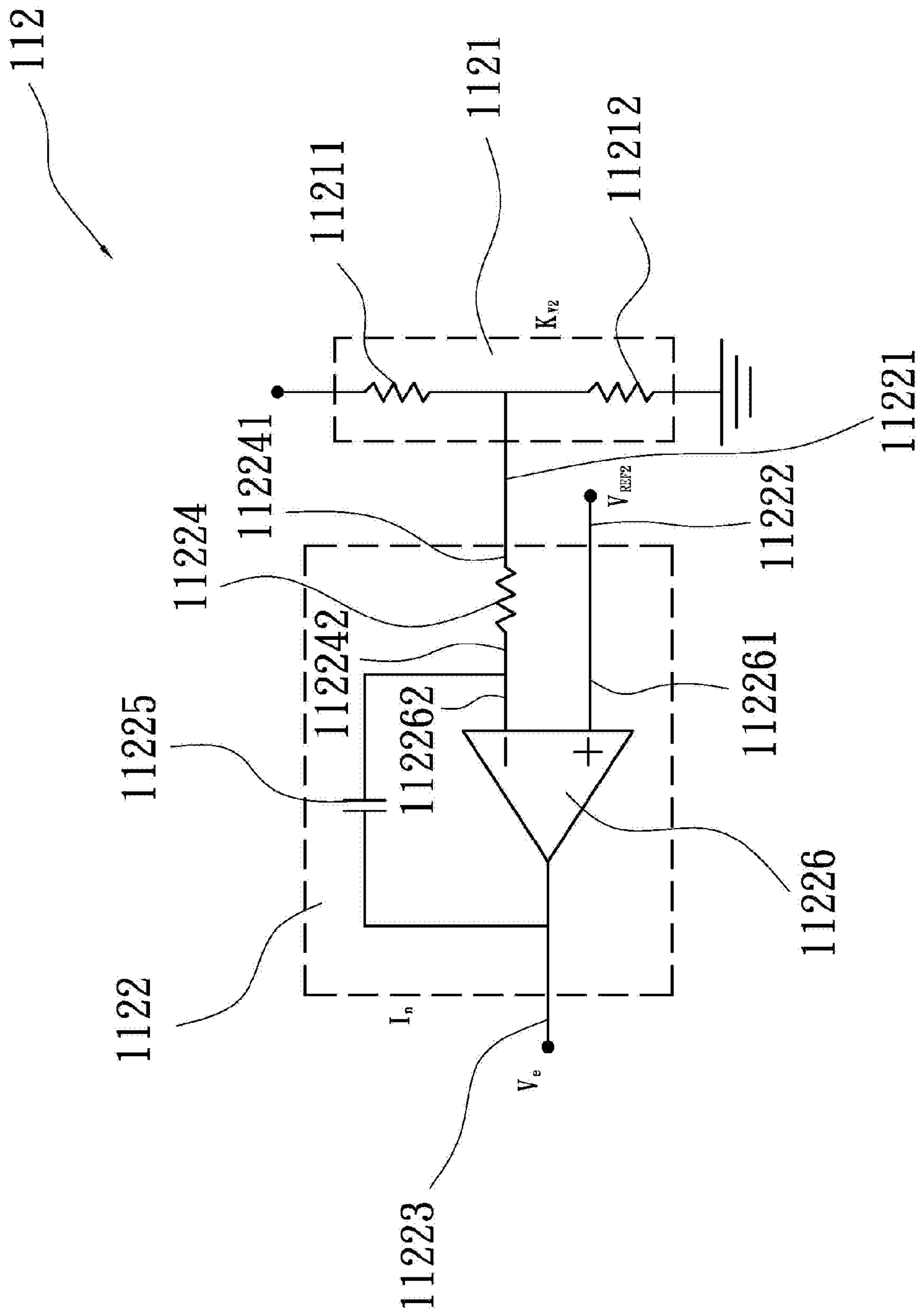

112
1121
11211
11212
11221
11222
1122241
11224
112242
112262
11225
112261
11226
1122
11223
K_V2
V_REF2
I_n
V_e

Fig. 8

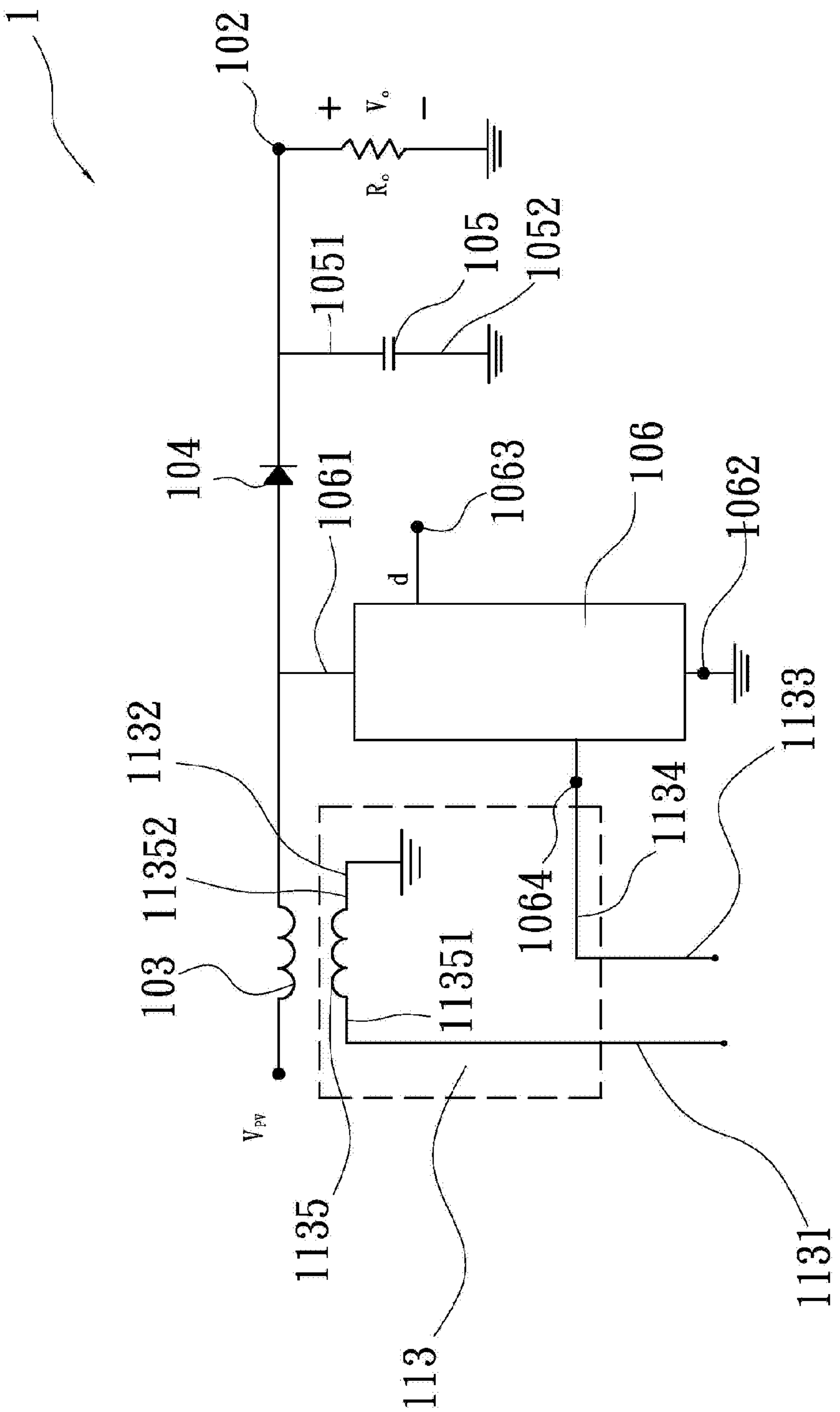

1
102
+
V_o
−
R_o
1051
105
1052
104
1061
1063
d
106
1062
1132
11352
103
11351
1064
1134
1133
V_PV
1135
113
1131

Fig. 9

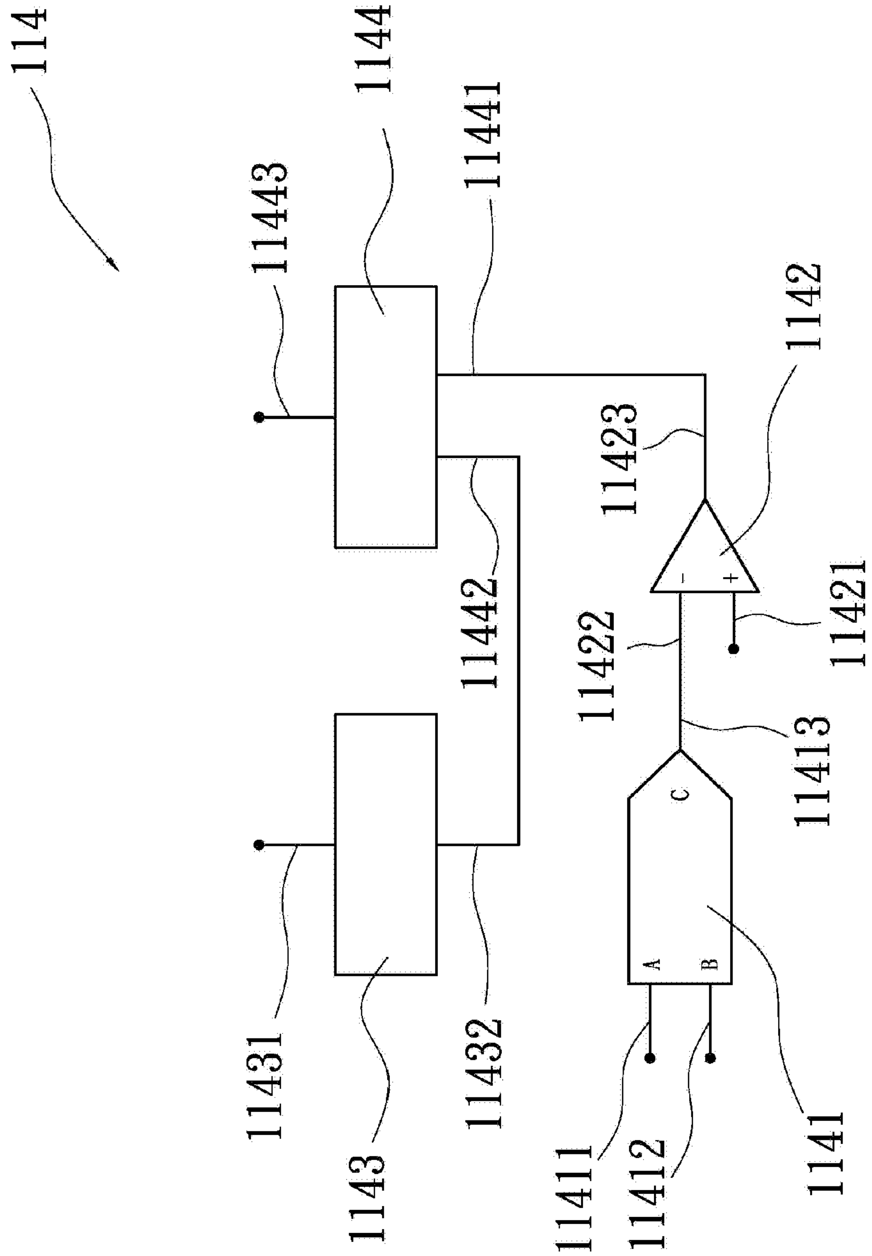

114
1144
11441
11443
1142
11423
11421
11422
11413
11442
1143
11431
11432
11411
11412
1141
A
B
C
-
+

Fig. 10

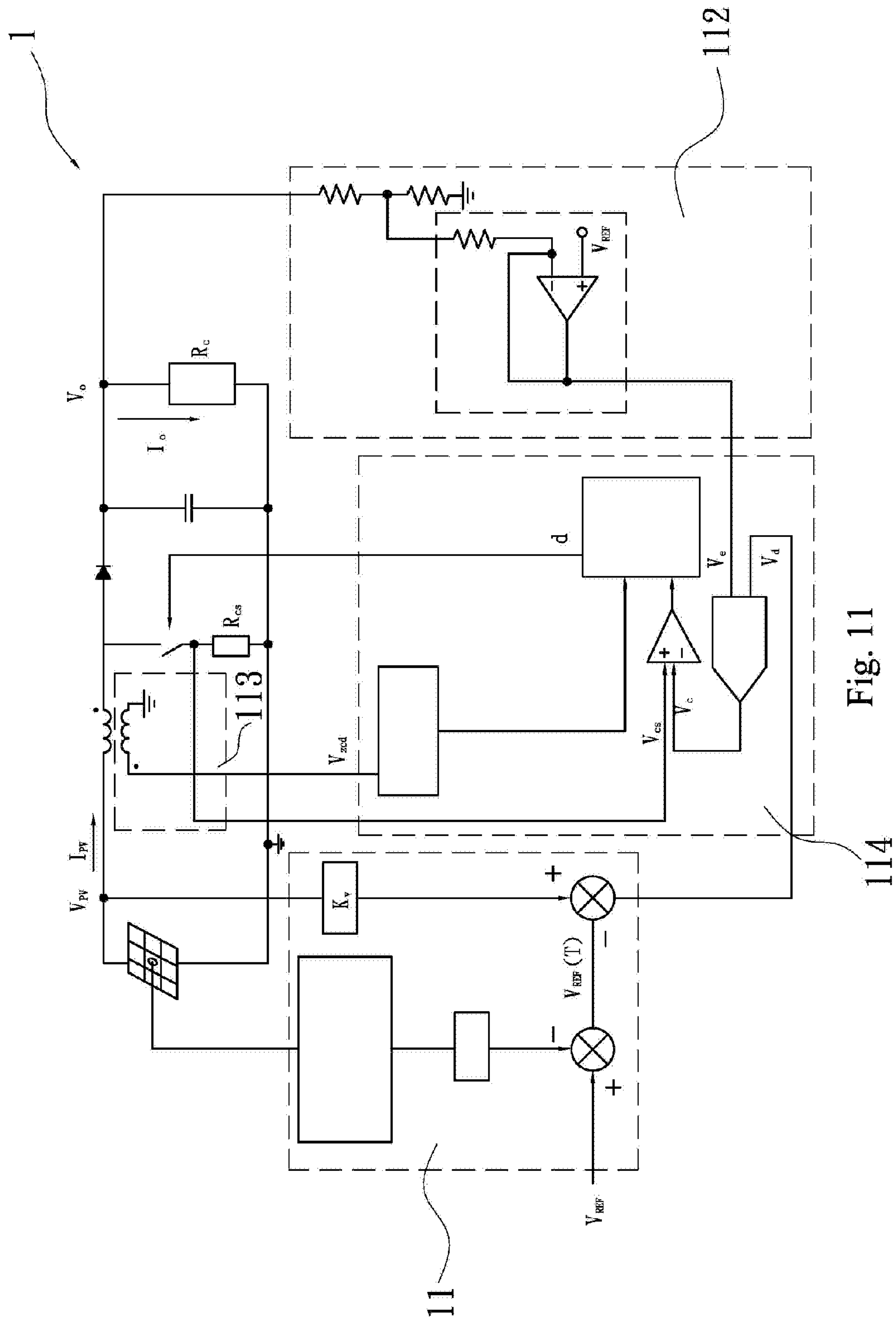

1
112
113
114
11
$V_o$
$I_o$
$R_c$
$R_{cs}$
$I_{PV}$
$V_{PV}$
$K_v$
$V_{REF}$
$V_{REF}(T)$
$V_{zcd}$
$V_{cs}$
$V_c$
$V_e$
$V_d$
d

Fig. 11