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(54) Device for tracking a maximum power point of a power source

Vorrichtung zur Verfolgung eines Punktes maximaler Leistung einer Stromquelle

Dispositif de suivi de point d'alimentation maximale d'une source d'alimentation

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Description

[0001] The present invention relates generally to a device for tracking a maximum power point of a power source like a photovoltaic cell or an array of cells or a fuel cell.

[0002] A photovoltaic cell directly converts solar energy into electrical energy. The electrical energy produced by the photovoltaic cell can be extracted over time and used in the form of electric power. The direct electric power provided by the photovoltaic cell is provided to energy conversion devices like DC-DC up/down converter circuits and/or DC/AC inverter circuits.

[0003] However, the current-voltage characteristics of photovoltaic cells cause the output power to change nonlinearly with the current drawn from photovoltaic cells. The power-voltage curve changes according to climatic variations like light radiation levels and operation temperatures.

[0004] Current-voltage characteristics are modelled as $I_{pv} = I_{sc}(L) - I_o(T) (\exp(V_{pv}/V_{br})-1)$, where I_{sc} is the shortcut circuit current of the photovoltaic cell under irradiance L, and Io is the cell body diode current under temperature T, V_{br} is the breakdown voltage of the PV cell, which is independent on irradiance and has low variation with cell temperature.

[0005] The near optimal point at which to operate photovoltaic cells or arrays of cells is at or near the region of the current-voltage curve where the power is greatest. This point is denominated as the Maximum Power Point (MPP).

[0006] The location of the Maximum Power Point is not known, but can be located, either through calculation models or by search algorithms.

[0007] Therefore Maximum Power Point Tracking techniques are needed to maintain the photovoltaic cells or arrays of cells operating point at its Maximum Power Point.

[0008] As the power-voltage curve changes according to climatic variations, the Maximum Power Point also changes according to climatic variations.

[0009] It is then necessary to be able to identify the Maximum Power Point at any time.

[0010] If Maximum Power point tracking algorithm uses fixed voltage step in order to track the maximum power point, the use of fixed voltage steps leads to some problems. If the voltage step is big, loss of the power provided by the power source occurs due to large oscillations around the maximum power point value. If the voltage step is small, the convergence to the maximum power point value is slow.

[0011] The paper of Fangrui Liu entitled "A variable step Size INC MPPT method for PV systems" published in IEEE transactions on industrial electronics, vol 55, n° 7, pages 2622 to 2628 discloses variable step size determination using derivative of the estimated derivative of the power provided by the power source.

[0012] The paper of Fang Luo entitled " A variable step maximum power point tracking method using differential equation solution" published in 2nd IEEE conference on industrial electronics and applications pages 2259-2263 discloses a variable step MPPT tracking method.

[0013] The paper of Zhang entitled "A maximum power point tracking algorithm based on gradient descent method" published in Power and Energy society general meeting, pages 1-5 discloses a variable step MPPT tracking method.

[0014] The paper of Lee entitled "Advance incremental conductance MPPT algorithm with a variable step size" published in the 12th international power electronics and motion control conference pages 603-607 discloses a variable step MPPT tracking method.

[0015] The present invention aims at providing a device which enables to provide a tracking of the maximum power point which is robust to climatic variations and with a limited increase of the duration of the perturbation cycle.

[0016] To that end, the present invention concerns a device for tracking the maximum power point of a power source, the device comprising:

- means for estimating, at a first voltage provided by the power source, a derivative of the power provided by the power source with respect to a change of the voltage provided by the power source,
- means for estimating the current provided by the power source when the power source provides the first voltage,
- means for determining a voltage step value from the estimated derivative of the power provided by the power source and from the estimated current,
- means for controlling the voltage of the power source in order to bring the voltage of the power source to a second voltage value which is equal to the first voltage value plus the determined voltage step.

[0017] The present invention concerns also a method for tracking the maximum power point of a power source, the method comprising the steps of:

- estimating, at a first voltage provided by the power source, a derivative of the power provided by the power source with respect to a change of the voltage provided by the power source,
- estimating the current provided by the power source when the power source provides the first voltage,

- determining a voltage step value from the estimated derivative of the power provided by the power source and from the estimated current,
- controlling the voltage of the power source in order to bring the voltage of the power source to a second voltage value which is equal to the first voltage value plus the determined voltage step.

[0018] Thus, the voltage step is almost equal to the voltage difference between the first voltage and the voltage corresponding to the maximum power point. As a result, the device converges faster to the maximum power point. The tracking of the maximum power point is then robust to climatic variations.

[0019] According to a particular feature, the voltage step is determined from a logarithm of one minus the estimated derivative of the power provided by the power source divided by the estimated current, the logarithm being divided by a parameter which is dependent of nominal characteristics of the power source.

[0020] Thus, if the parameter is set to one over the breakdown voltage, the determined step is equal to the voltage difference between the first voltage and the voltage corresponding to the maximum power point. The device can converge to the maximum power point in one step. The speed of acquisition of the maximum power point is greatly shortened. It should be noted that direct convergence to maximum power point can be obtained for any climatic conditions (L,T) without the need for climatic sensors.

[0021] According to a particular feature, the parameter is further dependent of a coefficient comprised between one and two.

[0022] Thus, as breakdown voltage may experience small variation due to unknown variations of the cell temperature, the breakdown voltage can be underestimated; leading the device to converge to the maximum power point in more than one step. Oscillations around the maximum power point can be minimised.

[0023] According to a particular feature, the parameter is determined according to the following formula:

$$\mathrm{Param} = -\frac{\dfrac{I_{mp0}}{I_{sc0} - I_{mp0}} + \ln\left(1 - \dfrac{I_{mp0}}{I_{sc0}}\right)}{2V_{mp0} - V_{oc0}} * \mathrm{coeff}\ ,$$

wherein I_{mp0} is the current at maximum power at nominal characteristics of the power source, I_{sc0} is the short circuit current at nominal characteristics of the power source, V_{mp0} is the voltage at maximum power at nominal characteristics of the power source and v_{oc0} is the voltage at open circuit at nominal characteristics of the power source.

[0024] Thus, the breakdown voltage of the power source can easily be determined at the setup of the power source. As breakdown voltage is independent of irradiance conditions, the proposed method will be effective at any irradiance conditions. As breakdown voltage has small variation with temperature condition, the proposed method is effective at any cell temperature.

[0025] According to a particular feature, the derivative of the power provided by the power source with respect to a change of the voltage provided by the power source is estimated from the power provided by the power source at the first voltage and from a power provided by the power source at another voltage.

[0026] Thus, an accurate derivative of the power with voltage can be determined in static irradiance conditions.

[0027] According to a particular feature, the derivative of the power provided by the power source with respect to a change of the voltage provided by the power source is estimated from:

- the first voltage value and a first power provided by the power source at a first time instant when the voltage provided by the power source is the first voltage value,
- a third voltage value and a second power provided by the power source at a second time instant when the voltage provided by the power source is the third voltage value,
- the first voltage value and a third power provided by the power source at a third time instant when the voltage provided by the power source is the first voltage.

[0028] Thus, an accurate derivative of the power with voltage can be determined in ramping irradiance conditions. The method for tracking the maximum power point of a power source is effective under ramping conditions.

[0029] According to a particular feature, the device for tracking the maximum power point is included in an energy conversion device.

[0030] Thus, the energy conversion device can operate the power source to its maximum power point, in dynamic climatic conditions and with very fast tracking ability.

[0031] According to a particular feature, if the determined voltage step value is greater than a first predetermined positive value, the determined voltage step is set at the first predetermined positive value or if the determined voltage step value is lower than a second predetermined negative value, the determined voltage step is set at the second predetermined negative value.

[0032] Thus, when noisy power measurement yields mistake in determining the distance to the maximum power point, the voltage step is limited and the difference between the second voltage and the voltage corresponding to the maximum power point can be reduced. As a result, power losses can be minimised.

[0033] According to a particular feature, if the estimated derivative of the power provided by the power source divided by the estimated current is upper than one, the determined voltage step is set at a predetermined value which has the sign of the estimated derivative of the power provided by a voltage step used for determining the first voltage value.

[0034] Thus, when noisy power measurement yields mistake in determining the distance to the maximum power point, the voltage step is limited and the difference between the second voltage and the voltage corresponding to the maximum power point can be reduced. As a result, power losses can be minimised.

[0035] The characteristics of the invention will emerge more clearly from a reading of the following description of an example embodiment, the said description being produced with reference to the accompanying drawings, among which :

Fig. 1 is an example of a curve representing the output current variations of a power source according to the output voltage of the power source;

Fig. 2 is an example of an energy conversion system wherein the present invention may be implemented;

Fig. 3a is an example of an algorithm for tracking the maximum power point of the power source according to a first mode of realization of the present invention; Fig. 3b is an example of an algorithm for determining the voltage step value according to the present invention;

Fig. 4 is an example of an algorithm for tracking the maximum power point of the power source according to a second mode of realization of the present invention;

Fig. 5 shows plural curves representing the power variations versus voltage of the photovoltaic cells or arrays of cells at different climatic conditions and power measurement points taken according to the first mode of realization of the present invention.

[0036] **Fig. 1** is an example of a curve representing the output current variations of a power source according to the output voltage of the power source.

[0037] On the horizontal axis of Fig. 1, voltage values are shown. The voltage values are comprised between null value and the open circuit voltage V_{OC}.

[0038] On the vertical axis of Fig. 1, current values are shown. The current values are comprised between null value and the short circuit current I_{SC}.

[0039] For example, if the power source PV is a photovoltaic array, at any given light level and photovoltaic array temperature, there is an infinite number of current-voltage pairs, or operating points, at which the photovoltaic array can operate. However, there exists a single maximum power point for a given light level and photovoltaic array temperature.

[0040] **Fig. 2** is an example of an energy conversion system wherein the present invention may be implemented.

[0041] The energy conversion system is composed of a power source PV like a photovoltaic cell or an array of cells or a fuel cell connected to an energy conversion device Conv like a DC-DC step-down/step-up converter and/or a DC/AC converter also named inverter, which output provides electrical energy to the load Lo.

[0042] The energy conversion device Conv comprises at least one switch S.

[0043] The power source PV provides current intended to the load Lo. The current I_{in} and the voltage V_{in} provided by the power source PV are converted by the energy conversion device Conv in output current I_{out} and output voltage V_{out} prior to be used by the load Lo.

[0044] According to the invention, the energy conversion system further comprises a controller device 20.

[0045] The controller device 20 determines, from successive power measurements, a regulation voltage value. The regulation voltage value is an estimation of the input voltage value which maximizes the energy produced by the power source PV.

[0046] It has to be noted here that successive power measurements used by the controller device 20 can be realised at the input or at the output of the energy conversion device Conv.

[0047] The controller device 20 controls the input voltage of the energy conversion device Conv, by controlling a duty cycle according to the regulation voltage value V_{pvref}.

[0048] The duty cycle drives the ON/OFF state of the at least one switch S of the energy conversion device Conv.

[0049] The controller device 20 has, for example, an architecture based on components connected together by a bus 201 and a processor 200 controlled by the program related to the algorithm as disclosed in the Figs. 3a, 3b or 4.

[0050] It has to be noted here that the processor 200 is, in a variant, implemented under the form of one or several dedicated integrated circuits which execute the same operations as the one executed by the processor 200 as disclosed hereinafter.

[0051] The bus 201 links the processor 200 to a read only memory ROM 202, a random access memory RAM 203, an analogue to digital converter ADC 206 and to an interface 205.

[0052] The read only memory ROM 202 contains instructions of the program related to the algorithm as disclosed in the Figs. 3a, 3b or 4 which are transferred, when the controller device 20 is powered on to the random access memory RAM 203.

[0053] The RAM memory 203 contains registers intended to receive variables, and the instructions of the program related to the algorithm as disclosed in the Figs. 3a, 3b or 4.

[0054] The analogue to digital converter 206 is connected to the input and the output of the energy conversion device Conv and converts voltages and currents at the input and the output of the energy conversion device Conv into binary information.

[0055] The processor 200 transfers, through interface module 205, the duty cycle D to be applied by the energy conversion device Conv.

[0056] According to the invention, the controller device 20 comprises:

- means for estimating, at a first voltage provided by the power source, a derivative of the power provided by the power source with respect to a change of the voltage provided by the power source,
- means for estimating the current provided by the power source when the power source provides the first voltage,
- means for determining a voltage step value from the estimated derivative of the power provided by the power source and from the estimated current,
- means for controlling the voltage of the power source in order to bring the voltage of the power source to a second voltage value which is equal to the first voltage value plus the determined voltage step.

[0057] **Fig. 3** is an example of an algorithm for tracking the maximum power point of the power source according to a first mode of realization of the present invention.

[0058] More precisely, the present algorithm is executed by the processor 200 of the controller device 20.

[0059] At step S300 of Fig. 3a, the processor 200 obtains the current I_{mp0} at maximum power at nominal characteristics of the power source PV, the short circuit current I_{sc0} at nominal characteristics of the power source PV, the voltage at maximum power V_{mp0} at nominal characteristics of the power source PV, the voltage v_{oc0} at open circuit at nominal characteristics of the power source and a coefficient coeff which is a predetermined value comprised between one and two.

[0060] These current and voltage values are provided by the power source maker. These current and voltage values are stored in the ROM memory 202 or stored by the technical staff which installs the power source PV and the energy conversion device Conv.

[0061] The coefficient coeff is stored in the ROM memory 202.

[0062] At next step S301, the processor 200 obtains, according to the present invention, a parameter Param.

[0063] The parameter Param is determined by the processor 200 according to the following formula:

$$\mathrm{Param} = -\frac{\frac{I_{mp0}}{I_{sc0} - I_{mp0}} + \ln\left(1 - \frac{I_{mp0}}{I_{sc0}}\right)}{2V_{mp0} - V_{oc0}} * \mathrm{coeff}$$

[0064] It has to be noted here that in a variant, instead of being calculated by the processor 200, the parameter Param is stored in the RAM memory 203 by the technical staff which installs the power source PV and the energy conversion device Conv.

[0065] At next step S302, the processor 200 checks if a variable noted Idx is equal to one.

[0066] It has to be noted here that, at initialization of the energy conversion device Conv, the variable Idx is set to one.

[0067] If the variable Idx is equal to one, the processor 200 moves to step S303. Otherwise, the processor 200 moves to step S305.

[0068] At step S303, the processor 200 is controlling the voltage provided by the power source PV to a voltage value V_{vref} which is equal to a voltage value V_A and commands the analogue to digital converter ADC 206 in order to proceed to a measurement of the current I_{in} at voltage V_A.

[0069] At first execution of present algorithm, the processor 200 reads in memory 203 initial value of the voltage V_A.

[0070] For example, the initial voltage of V_A is equal to the null value or V_{OC0}.

[0071] From the voltage V_A and the current I_{in} values, the processor 200 determines a power value P1 provided by the power source PV at voltage value V_A.

[0072] At next step S304, the processor 200 sets the voltage value V_{vref} to a voltage value V_B and controls, through the interface 206 and the switch S, the voltage provided by the power source PV to the voltage value V_{vref}.

[0073] At first execution of present algorithm, the processor 200 reads in memory 203 initial value of the voltage V_B.

[0074] For example, the initial voltage of V_B is equal to the initial voltage VA plus a predetermined voltage step ΔV_{AB} read in memory 203. For example, the predetermined voltage step ΔV_{AB} is set to one volt.

[0075] At next step S304, the processor 200 steps the variable Idx to two.

[0076] After that, the processor 200 moves to step S314 and waits a predetermined time period Δt. The predetermined time period is for example equal to one second. The predetermined time period is representative of the periodicity of execution of the maximum power point tracking algorithm.

[0077] After that, the processor 200 returns to step S302.

[0078] At step S305, the processor 200 checks if a variable noted Idx is equal to two.

[0079] If the variable Idx is equal to two, the processor 200 moves to step S306. Otherwise, the processor 200 moves to step S309.

[0080] At step S306, the processor 200 is controlling, through the interface 206 and the switch S, the voltage provided by the power source PV to a voltage value V_{vref} which is equal to the voltage value V_B and commands the analogue to digital converter ADC 206 in order to proceed to a measurement of the current I_{in} at voltage V_B.

[0081] From the voltage V_B and the current I_{in} values, the processor 200 determines a power value P2 provided by the power source PV at V_B.

[0082] At next step S307, the processor 200 sets the voltage value V_{vref} to the voltage value V_A and controls, through the interface 206 and the switch S, the voltage provided by the power source PV to the voltage value V_{vref}.

[0083] At next step S308, the processor 200 steps the variable Idx to three.

[0084] After that, the processor 200 moves to step S314 already disclosed.

[0085] At step S309, the processor 200 is controlling the voltage provided by the power source PV, through the interface 206 and the switch S, to a voltage value V_{vref} which is equal to the voltage value V_A and commands the analogue to digital converter ADC 206 in order to proceed to a measurement of the current I_{in} at voltage V_A.

[0086] From the voltage V_A and the current I_{in} values, the processor 200 determines a power value P3 provided by the power source PV at V_A.

[0087] At next step S310, the processor 200 computes a voltage step value ΔV to be used for tracking the maximum power point.

[0088] The voltage step value is computed from the estimated derivative of the power provided by the power source and from the estimated current.

[0089] The computation of the voltage step value will be disclosed in reference to the Fig. 3b.

[0090] At next step S311, the processor 200 sets the variable V_A to $V_A + \Delta V$ and the variable V_B to $V_B + \Delta V$.

[0091] At next step S312, the processor 200 sets the voltage value V_{vref} to the voltage value V_A.

[0092] At next step S313, the processor 200 sets the variable Idx to one.

[0093] After that, the processor 200 moves to step S314 already disclosed.

[0094] **Fig. 3b** is an example of an algorithm for determining the voltage step value according to the present invention.

[0095] At step S315, the processor 200 sets a variable P_B to the value of P_2 and determines a mean value P_A of P_3 and P_1.

$$P_A = (P_1 + P_3)/2$$

[0096] At next step S316, the processor 200 determines an estimated current value I of the current provided by the power source PV from the power values PA and PB determined at step S315 according to the following formula:

$$I = (PA/VA+PB/VB)/2.$$

[0097] At next step S317, the processor 200 determines an estimate of the derivative of the power according to the following formula:

$$dP/dV=(PA-PB)/(VA-VB).$$

[0098] At next step S318, the processor 200 checks if the estimated derivative of the power provided by the power source PV divided by the estimated current value is lower than one.

[0099] If the estimated derivative of the power provided by the power source PV divided by the estimated current value is lower than one, the processor 200 moves to step S320. Otherwise, the processor 200 moves to step S319.

[0100] At step S320, the processor 200 determines the voltage step ΔV to be applied for tracking the maximum power point from a logarithm of one minus the estimated derivative of the power provided by the power source PV divided by the estimated current, the logarithm being divided by the parameter Param determined at step S301 which is dependent of nominal characteristics of the power source PV.

[0101] More precisely, the voltage step ΔV is determined according to the following formula:

$$\Delta V = \log(1 - dP/dV/I)/Param.$$

[0102] When there is some noise effecting measurements, it may occur that the estimated derivative of the power provided by the power source PV divided by the estimated current value is lower than one. In order to take into account such cases, the check of step S318 avoids that error may occur in the calculation of the voltage step ΔV at step S320.

[0103] At next step S321, the processor 200 checks if the voltage step ΔV determined at step S320 is upper than a first predetermined value.

[0104] If the voltage step ΔV determined at step S320 is higher than the first predetermined value, the processor 200 moves to step S322. Otherwise, the processor 200 moves to step S324.

[0105] For example, the first predetermined value is comprised between five and fifteen volts.

[0106] For example, the first predetermined value is equal to ten volts.

[0107] At step S324, the processor 200 checks if the voltage step ΔV determined at step S320 is lower than a second predetermined value.

[0108] If the voltage step ΔV determined at step S320 is lower than the second predetermined value, the processor 200 moves to step S325. Otherwise, the processor 200 moves to step S311 of Fig. 3a.

[0109] For example, the second predetermined value is comprised between minus five and minus fifteen volts.

[0110] For example, the second predetermined value is equal to minus ten volts.

[0111] At step S319, the processor 200 sets the voltage step ΔV at a third predetermined value, for example five volts, the sign of which is same as the sign of the estimated derivative dP/dV of the power provided by the power source.

[0112] At step S322, the processor 200 sets the voltage step ΔV at the first predetermined value and moves to step S311 of Fig. 3a.

[0113] At step S325, the processor 200 sets the voltage step ΔV at the second predetermined value and moves to step S311 of Fig. 3a.

[0114] **Fig. 4** is an example of an algorithm for tracking the maximum power point of the power source according to a second mode of realization of the present invention.

[0115] More precisely, the present algorithm is executed by the processor 200 of the controller device 20.

[0116] At step S400, the processor 200 obtains the current I_{mp0} at maximum power at nominal characteristics of the power source PV, the short circuit current I_{sc0} at nominal characteristics of the power source PV, the voltage at maximum power V_{mp0} at nominal characteristics of the power source PV, the voltage v_{oc0} at open circuit at nominal characteristics of the power source PV and a coefficient coeff which is a predetermined value comprised between one and two.

[0117] These current and voltage values are provided by the power source maker. These current and voltage values are stored in the ROM memory 202 or stored in the RAM memory 203 by the technical staff which installs the power source PV and the energy conversion device Conv.

[0118] The coefficient coeff is stored in the ROM memory 202.

[0119] At next step S401, the processor 200 obtains, according to the present invention, a parameter Param.

[0120] The parameter Param is determined by the processor 200 according to the following formula:

$$Param = -\frac{\frac{I_{mp0}}{I_{sc0} - I_{mp0}} + \ln(1 - \frac{I_{mp0}}{I_{sc0}})}{2V_{mp0} - V_{oc0}} * coeff$$

[0121] It has to be noted here that in a variant, instead of being calculated by the processor 200, the parameter Param is stored in the RAM memory 203 by the technical staff which installs the power source PV and the energy conversion device Conv.

[0122] At next step S402, the processor 200 is controlling, through the interface 206 and the switch S, the voltage provided by the power source PV to a voltage value V_{vref} and commands the analogue to digital converter ADC 206 in order to proceed to a measurement of the current I_{in} at voltage V_{vref}.

[0123] At first execution of present algorithm, the processor 200 reads in memory 203 initial value of the voltage V_{vref}.

[0124] For example, the initial voltage of V_{vref} is equal to the null value or V_{OC0}.

[0125] From the voltage V_{vref} and the current I_{in} values, the processor 200 determines a power value P provided by the power source PV at V_{vref}.

[0126] At next step S403, the processor 200 sets the variable I to I_{in} value and memorises the variable I.

[0127] At next step S404, the processor 200 determines an estimate of the derivative of the power according to the following formula:

$$dP/dV=(P-Pprevious)/(\Delta Vprevious)$$

wherein ΔVprevious is the previous voltage step determined by the present algorithm and Pprevious is the previous power P determined by the present algorithm.

[0128] At the first execution of the present algorithm, ΔVprevious is equal to a predetermined value. As example, the predetermined value is equal to one volt.

[0129] At next step S405, the processor 200 checks if the estimated derivative of the power provided by the power source PV divided by the current I is lower than one.

[0130] If the estimated derivative of the power provided by the power source PV divided by the current value I is lower than one, the processor 200 moves to step S407. Otherwise, the processor 200 moves to step S406.

[0131] At step S407, the processor 200 determines the voltage step ΔV to be applied for tracking the maximum power point from a logarithm of one minus the estimated derivative of the power provided by the power source PV divided by the estimated current, the logarithm being divided by the parameter Param which is dependent of nominal characteristics of the power source PV.

[0132] More precisely, the voltage step ΔV is determined according to the following formula:

$$\Delta V=\log(1-dP/dV/I)/Param.$$

[0133] When there is some noise effecting measurements, it may occur that the estimated derivative of the power provided by the power source divided by the estimated current value is lower than one. In order to take into account such cases, the check of step S405 avoids that error may occur in the calculation of the voltage step ΔV at step S407.

[0134] At next step S408, the processor 200 sets the variable V_{ref} to V_{ref} +ΔV.

[0135] At next step S409, the processor 200 set the variables ΔVprevious to the value of ΔV determined at step S407 or at step S406 and Pprevious to the value of P measured at step S402.

[0136] After that, the processor 200 moves to step S410 and waits a predetermined time period Δt. The predetermined time period is for example equal to one second. The predetermined time period is representative of the periodicity of execution of the maximum power point tracking algorithm.

[0137] Once the predetermined time period Δt ends, the processor 200 returns to step S402 already described.

[0138] At step S406, the processor 200 sets the voltage step ΔV at a predetermined value, for example five volts, the sign of which is same as the sign of the estimated derivative dP/dV of the power provided by the power source.

[0139] After that, the processor moves to step S408 already disclosed.

[0140] Fig. 5 shows plural curves representing the power variations versus voltage of the photovoltaic cells or arrays of cells at different climatic conditions and power measurement points taken according to the first mode of realization of the present invention.

[0141] On the horizontal axis, the voltage provided by the power source PV is shown.

[0142] The vertical axis representing the power provided by the power source PV is shown.

[0143] Three different curves show the variations of the maximum power point of the power source PV.

[0144] A first curve marked by label Idx1 corresponds to the measurement of the power at step S303 of the algorithm of Fig. 3a.

[0145] A second curve marked by label Idx2 corresponds to the measurement of the power at step S306 of the algorithm of Fig. 3a.

[0146] A third curve marked by label Idx3 corresponds to the measurement of the power at step S309 of the algorithm of Fig. 3a.

[0147] The power values PA and PB determined at step S315 of the algorithm of Fig. 3b are shown.

[0148] The voltage VA at which the powers P1 and P3 are measured and the voltage VB at which the power P2 is measured are shown.

[0149] Naturally, many modifications can be made to the embodiments of the invention described above without departing from the scope of the present invention.

Claims

1. Device for tracking the maximum power point of a power source, the device comprising:

- means for estimating (20), at a first voltage provided by the power source, a derivative of the power provided by the power source with respect to a change of the voltage provided by the power source,
- means for estimating (20)the current provided by the power source when the power source provides the first voltage,
- means for determining (20) a voltage step value from the estimated derivative of the power provided by the power source and from the estimated current, the voltage step being determined from a logarithm of one minus the estimated derivative of the power provided by the power source divided by the estimated current, the logarithm being divided by a parameter which is dependent of nominal characteristics of the power source,
- means for controlling (20) the voltage of the power source in order to bring the voltage of the power source to a second voltage value which is equal to the first voltage value plus the determined voltage step.

2. Device according to claim 1, **characterized in that** the parameter is further dependent of a coefficient comprised between one and two.

3. Device according to claim 2, **characterized in** the parameter is determined according to the following formula:

$$Param = -\frac{\frac{I_{mp0}}{I_{sc0} - I_{mp0}} + \ln(1 - \frac{I_{mp0}}{I_{sc0}})}{2V_{mp0} - V_{oc0}} * coeff \ ,$$

wherein I_{mp0} is the current at maximum power at nominal characteristics of the power source, I_{sc0} is the short circuit current at nominal characteristics of the power source, V_{mp0} is the voltage at maximum power at nominal characteristics of the power source and v_{oc0} is the voltage at open circuit at nominal characteristics of the power source.

4. Device according to any of the claims 1 to 3, **characterized in that** the derivative of the power provided by the power source with respect to a change of the voltage provided by the power source is estimated from the power provided by the power source at the first voltage and from a power provided by the power source at another voltage.

5. Device according to any of the claims 1 to 3, **characterized in that** the derivative of the power provided by the power source with respect to a change of the voltage provided by the power source is estimated from :

- the first voltage value and a first power provided by the power source at a first time instant when the voltage provided by the power source is the first voltage value,
- a third voltage value and a second power provided by the power source at a second time instant when the voltage provided by the power source is the third voltage value,
- the first voltage value and a third power provided by the power source at a third time instant when the voltage provided by the power source is the first voltage.

6. Device according to any of the claims 1 to 5, **characterised in that** the device for tracking the maximum power point is included in an energy conversion device.

7. Device according to any of the claims 1 to 6, **characterized in that** if the determined voltage step value is greater than a first predetermined positive value, the determined voltage step is set at the first predetermined positive value or if the determined voltage step value is lower than a second predetermined negative value, the determined voltage step is set at the second predetermined negative value.

8. Device according to any of the claims 1 to 7, **characterized in that** if the estimated derivative of the power provided by the power source divided by the estimated current is greater than one, the determined voltage step is set at a predetermined value which has the sign of the estimated derivative of the power provided by a voltage step used for determining the first voltage value.

9. Method for tracking the maximum power point of a power source, the method comprising the steps of:

- estimating, at a first voltage provided by the power source, a derivative of the power provided by the power source with respect to a change of the voltage provided by the power source,
- estimating the current provided by the power source when the power source provides the first voltage,
- determining a voltage step value from the estimated derivative of the power provided by the power source and from the estimated current, the voltage step being determined from a logarithm of one minus the estimated derivative of the power provided by the power source divided by the estimated current, the logarithm being divided by a parameter which is dependent of nominal characteristics of the power source,
- controlling the voltage of the power source in order to bring the voltage of the power source to a second voltage value which is equal to the first voltage value plus the determined voltage step.

Patentansprüche

1. Vorrichtung zum Verfolgen der Stelle maximaler Energie einer Energiequelle, wobei die Vorrichtung folgendes aufweist:

- eine Einrichtung zum Schätzen (20), bei einer durch die Energiequelle zur Verfügung gestellten ersten Spannung, eines abgeleiteten Werts der durch die Energiequelle zur Verfügung gestellten Energie in Bezug auf eine Änderung der durch die Energiequelle zur Verfügung gestellten Spannung,
- eine Einrichtung zum Schätzen (20) des durch die Energiequelle zur Verfügung gestellten Stroms, wenn die Energiequelle die erste Spannung zur Verfügung stellt,
- eine Einrichtung zum Bestimmen (20) eines Spannungsstufenwerts aus dem geschätzten abgeleiteten Wert der durch die Energiequelle zur Verfügung gestellten Energie und aus dem geschätzten Strom, wobei die Spannungsstufe aus einem Logarithmus von Eins minus dem geschätzten abgeleiteten Wert der durch die Energiequelle zur Verfügung gestellten Energie, geteilt durch den geschätzten Strom, bestimmt wird, wobei der Logarithmus durch einen Parameter geteilt wird, der von Nominalmerkmalen der Energiequelle abhängt,
- eine Einrichtung zum Steuern (20) der Spannung der Energiequelle, um die Spannung der Energiequelle zu einem zweiten Spannungswert zu bringen, der gleich dem ersten Spannungswert plus der bestimmten Spannungsstufe ist.

2. Vorrichtung nach Anspruch 1, **dadurch gekennzeichnet, dass** der Parameter weiterhin von einem Koeffizienten abhängt, der zwischen Eins und Zwei umfasst ist.

3. Vorrichtung nach Anspruch 2, **dadurch gekennzeichnet, dass** der Parameter gemäß der folgenden Formel bestimmt wird:

$$Param = -\frac{\frac{I_{mpO}}{I_{scO}-I_{mpO}}+ln\left(1-\frac{I_{mpO}}{I_{scO}}\right)}{2V_{mpO}-V_{ocO}} * coeff,$$

wobei I_{mpO} der Strom bei maximaler Energie bei Nominalmerkmalen der Energiequelle ist, I_{scO} der Kurzschlussstrom bei Nominalmerkmalen der Energiequelle ist, V_{mpO} die Spannung bei maximaler Energie bei Nominalmerkmalen der Energiequelle ist und V_{ocO} die Spannung bei Leerlauf bei Nominalmerkmalen der Energiequelle ist.

4. Vorrichtung nach einem der Ansprüche 1 bis 3, **dadurch gekennzeichnet, dass** der abgeleitete Wert der durch die Energiequelle zur Verfügung gestellten Energie in Bezug auf eine Änderung der durch die Energiequelle zur Verfügung gestellten Spannung aus der durch die Energiequelle zur Verfügung gestellten Energie bei der ersten Spannung und aus einer durch die Energiequelle zur Verfügung gestellten Energie bei einer anderen Spannung geschätzt wird.

5. Vorrichtung nach einem der Ansprüche 1 bis 3, **dadurch gekennzeichnet, dass** der abgeleitete Wert der durch die Energiequelle zur Verfügung gestellten Energie in Bezug auf eine Änderung der durch die Energiequelle zur Verfügung gestellten Spannung geschätzt wird aus:

- dem ersten Spannungswert und einer durch die Energiequelle bei einem ersten Zeitpunkt zur Verfügung gestellten ersten Energie, wenn die durch die Energiequelle zur Verfügung gestellte Spannung der erste Spannungswert ist,

- einem dritten Spannungswert und einer durch die Energiequelle bei einem zweiten Zeitpunkt zur Verfügung gestellten zweiten Energie, wenn die durch die Energiequelle zur Verfügung gestellte Spannung der dritte Spannungswert ist,
- dem ersten Spannungswert und einer durch die Energiequelle bei einem dritten Zeitpunkt zur Verfügung gestellten dritten Energie, wenn die durch die Energiequelle zur Verfügung gestellte Spannung die erste Spannung ist.

6. Vorrichtung nach einem der Ansprüche 1 bis 5, **dadurch gekennzeichnet, dass** die Vorrichtung zum Verfolgen der Stelle maximaler Energie in einer Energieumwandlungsvorrichtung enthalten ist.

7. Vorrichtung nach einem der Ansprüche 1 bis 6, **dadurch gekennzeichnet, dass**, wenn der bestimmte Spannungsstufenwert größer als ein erster vorbestimmter positiver Wert ist, die bestimmte Spannungsstufe auf den ersten vorbestimmten positiven Wert eingestellt wird, oder, wenn der bestimmte Spannungsstufenwert kleiner als ein zweiter vorbestimmter negativer Wert ist, die bestimmte Spannungsstufe auf den zweiten vorbestimmten negativen Wert eingestellt wird.

8. Vorrichtung nach einem der Ansprüche 1 bis 7, **dadurch gekennzeichnet, dass**, wenn der geschätzte abgeleitete Wert der durch die Energiequelle zur Verfügung gestellten Energie, geteilt durch den geschätzten Strom, größer als Eins ist, die bestimmte Spannungsstufe auf einen vorbestimmten Wert eingestellt wird, der das Vorzeichen des geschätzten abgeleiteten Werts der durch eine zum Bestimmen des ersten Spannungswerts verwendeten Spannungsstufe zur Verfügung gestellten Energie hat.

9. Verfahren zum Verfolgen der Stelle maximaler Energie einer Energiequelle, wobei das Verfahren die folgenden Schritte aufweist:

- Schätzen, bei einer durch die Energiequelle zur Verfügung gestellten ersten Spannung, eines abgeleiteten Werts der durch die Energiequelle zur Verfügung gestellten Energie in Bezug auf eine Änderung der durch die Energiequelle zur Verfügung gestellten Spannung,
- Schätzen des durch die Energiequelle zur Verfügung gestellten Stroms, wenn die Energiequelle die erste Spannung zur Verfügung stellt,
- Bestimmen eines Spannungsstufenwerts aus dem geschätzten abgeleiteten Wert der durch die Energiequelle zur Verfügung gestellten Energie und aus dem geschätzten Strom, wobei die Spannungsstufe aus einem Logarithmus von Eins minus dem geschätzten abgeleiteten Wert der durch die Energiequelle zur Verfügung gestellten Energie, geteilt durch den geschätzten Strom, bestimmt wird, wobei der Logarithmus durch einen Parameter geteilt wird, der von Nominalmerkmalen der Energiequelle abhängt,
- Steuern der Spannung der Energiequelle, um die Spannung der Energiequelle zu einem zweiten Spannungswert zu bringen, der gleich dem ersten Spannungswert plus der bestimmten Spannungsstufe ist.

Revendications

1. Dispositif de suivi du point de puissance maximum d'une source de puissance, le dispositif comportant :

- des moyens pour estimer (20), à une première tension fournie par la source de puissance, une dérivée de la puissance fournie par la source de puissance par rapport à une variation de la tension fournie par la source de puissance,
- des moyens pour estimer (20) le courant fourni par la source de puissance lorsque la source de puissance fournit la première tension,
- des moyens pour déterminer (20) une valeur de pas de tension à partir de la dérivée estimée de la puissance fournie par la source de puissance et à partir du courant estimé, le pas de tension étant déterminé à partir d'un logarithme de un moins la dérivée estimée de la puissance fournie par la source de puissance divisée par le courant estimé, le logarithme étant divisé par un paramètre qui dépend des caractéristiques nominales de la source de puissance,
- des moyens pour commander (20) la tension de la source de puissance afin d'amener la tension de la source d'alimentation à une seconde valeur de tension qui est égale à la première valeur de tension plus le pas de tension déterminée.

2. Dispositif selon la revendication 1, **caractérisé en ce que** le paramètre dépend en outre d'un coefficient compris entre un et deux.

3. Dispositif selon la revendication 2, **caractérisé en ce que** le paramètre est déterminé selon la formule suivante:

$$Param = -\frac{\frac{I_{mp0}}{I_{sc0} - I_{mp0}} + \ln(1 - \frac{I_{mp0}}{I_{sc0}})}{2V_{mp0} - V_{oc0}} * coeff ,$$

où I_{mp0} est le courant à la puissance maximale aux caractéristiques nominales de la source de puissance, I_{sc0} est le courant de court-circuit aux caractéristiques nominales de la source de puissance, V_{mp0} est la tension à la puissance maximale aux caractéristiques nominales de la source de puissance et v_{oc0} est la tension en circuit ouvert aux caractéristiques nominales de la source de puissance.

4. Dispositif selon l'une quelconque des revendications 1 à 3, **caractérisé en ce que** la dérivée de la puissance fournie par la source de puissance par rapport à une variation de la tension fournie par la source de puissance est estimée à partir de la puissance fournie par la source de puissance à la première tension et d'une puissance fournie par la source de puissance à une autre tension.

5. Dispositif selon l'une quelconque des revendications 1 à 3, **caractérisé en ce que** la dérivée de la puissance fournie par la source de puissance par rapport à une variation de la tension fournie par la source de puissance est estimée à partir de :

- la première valeur de tension et une première puissance fournie par la source de puissance à un premier instant lorsque la tension fournie par la source de puissance est la première valeur de tension,
- une troisième valeur de tension et une seconde puissance fournie par la source de puissance à un second instant lorsque la tension fournie par la source de puissance est la troisième valeur de tension,
- la première valeur de tension et une troisième puissance fournie par la source de puissance à un troisième instant lorsque la tension fournie par la source de puissance est la première tension.

6. Dispositif selon l'une quelconque des revendications 1 à 5, **caractérisé en ce que** le dispositif de suivi du point de puissance maximum est inclus dans un dispositif de conversion d'énergie.

7. Dispositif selon l'une quelconque des revendications 1 à 6, **caractérisé en ce que**, si la valeur de pas de tension déterminée est supérieure à une première valeur positive prédéterminée, le pas de tension déterminé est mis à la première valeur positive prédéterminée ou si la valeur de pas de tension détermine est inférieure à une seconde valeur négative prédéterminée, le pas de tension déterminé est mis à la seconde valeur négative prédéterminée.

8. Dispositif selon l'une quelconque des revendications 1 à 7, **caractérisé en ce que** si la dérivée estimée de la puissance fournie par la source de puissance divisée par le courant estimé est supérieur à un, le pas de tension déterminé est fixé à une valeur prédéterminée qui a le signe de la dérivée estimée de la puissance fournie par un pas de tension utilisé pour déterminer la première valeur de tension.

9. Procédé de suivi du point de puissance maximum d'une source de puissance, le procédé comportant les étapes de :

- estimation, à une première tension fournie par la source de puissance, d'une dérivée de la puissance fournie par la source de puissance par rapport à une variation de la tension fournie par la source de puissance,
- estimation du courant fourni par la source de puissance lorsque la source de puissance fournit la première tension,
- détermination d'une valeur de pas de tension à partir de la dérivée estimée de la puissance fournie par la source de puissance et à partir du courant estimé, le pas de tension étant déterminé à partir d'un logarithme de un moins la dérivée estimée de la puissance fournie par la source de puissance divisée par le courant estimé, le logarithme étant divisé par un paramètre qui dépend des caractéristiques nominales de la source de puissance,
- commande de la tension de la source de puissance afin d'amener la tension de la source d'alimentation à une seconde valeur de tension qui est égale à la première valeur de tension plus le pas de tension déterminé.

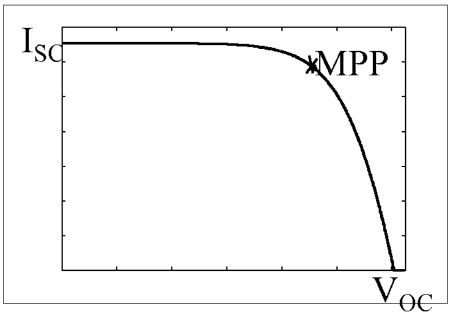
ISC
MPP
VOC

Fig. 1

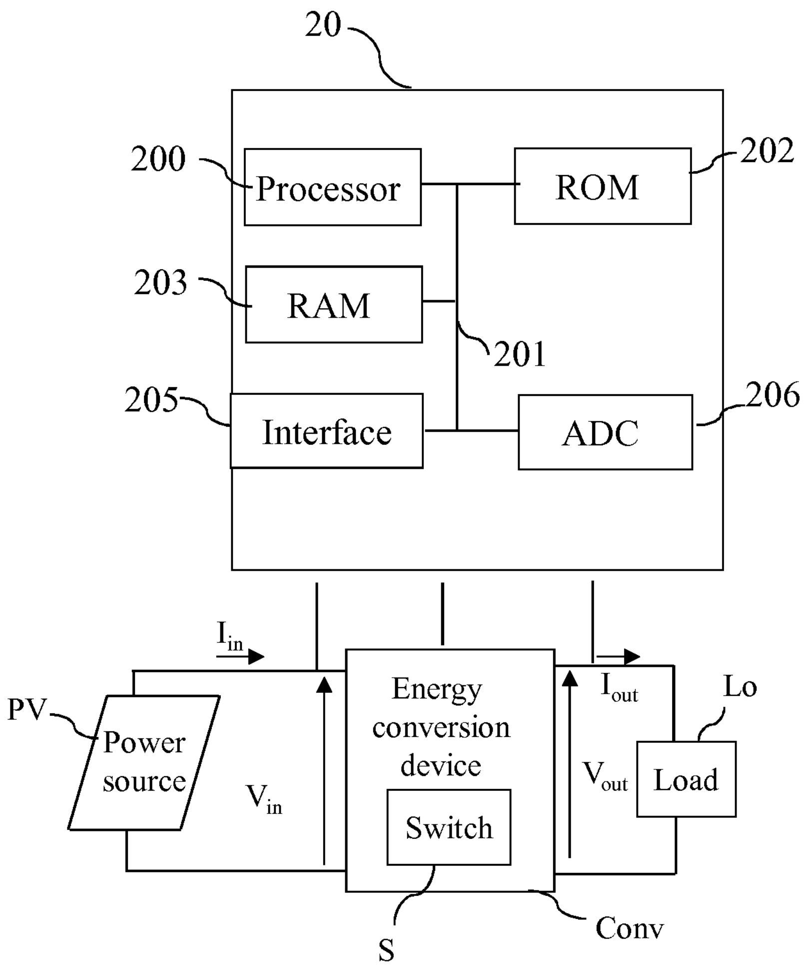
20
200
Processor
ROM
202
203
RAM
201
205
Interface
ADC
206
Iin
PV
Power
source
Vin
Energy
conversion
device
Switch
Iout
Lo
Vout
Load
S
Conv

Fig. 2

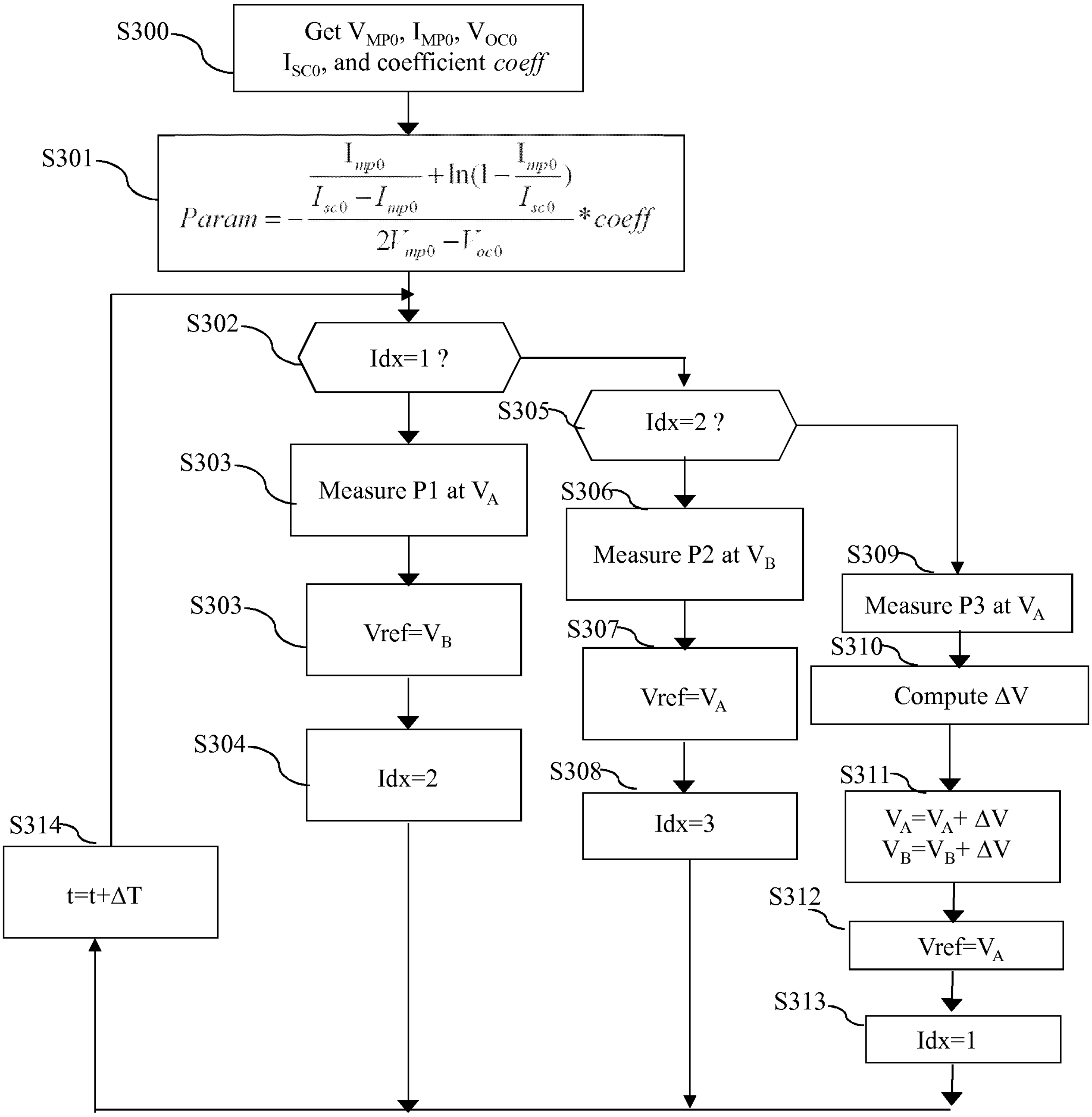
S300
Get V_{MP0}, I_{MP0}, V_{OC0} I_{SC0}, and coefficient *coeff*
S301
$$Param = -\frac{\frac{I_{mp0}}{I_{sc0}-I_{mp0}} + \ln(1-\frac{I_{mp0}}{I_{sc0}})}{2V_{mp0}-V_{oc0}} * coeff$$
S302
Idx=1 ?
S303
Measure P1 at V_A
S303
$Vref=V_B$
S304
Idx=2
S305
Idx=2 ?
S306
Measure P2 at V_B
S307
$Vref=V_A$
S308
Idx=3
S309
Measure P3 at V_A
S310
Compute ΔV
S311
$V_A=V_A+\Delta V$
$V_B=V_B+\Delta V$
S312
$Vref=V_A$
S313
Idx=1
S314
$t=t+\Delta T$

Fig. 3a

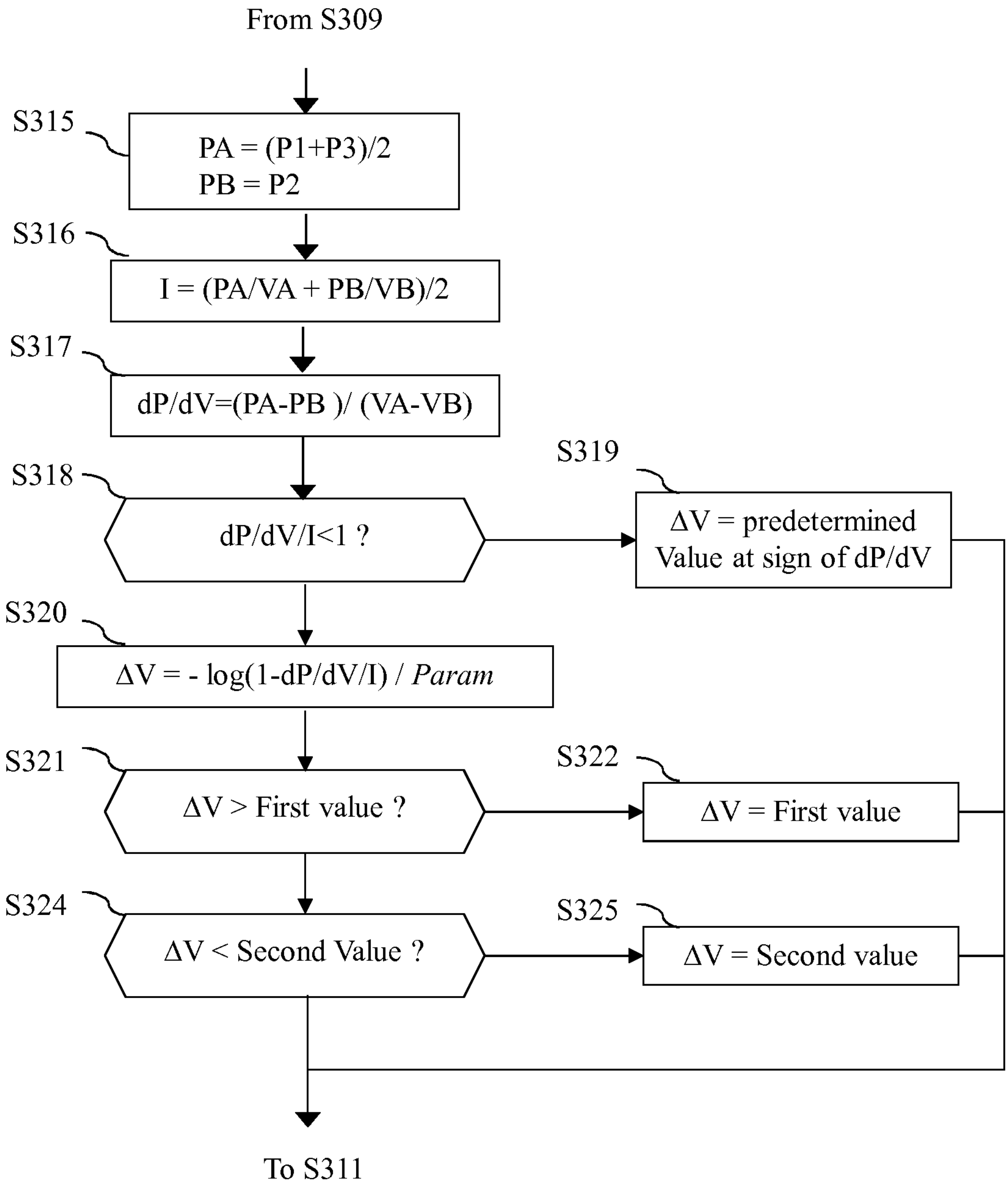
From S309
S315
PA = (P1+P3)/2
PB = P2
S316
I = (PA/VA + PB/VB)/2
S317
dP/dV=(PA-PB)/ (VA-VB)
S318
dP/dV/I<1 ?
S319
ΔV = predetermined Value at sign of dP/dV
S320
ΔV = - log(1-dP/dV/I) / Param
S321
ΔV > First value ?
S322
ΔV = First value
S324
ΔV < Second Value ?
S325
ΔV = Second value
To S311

Fig. 3b

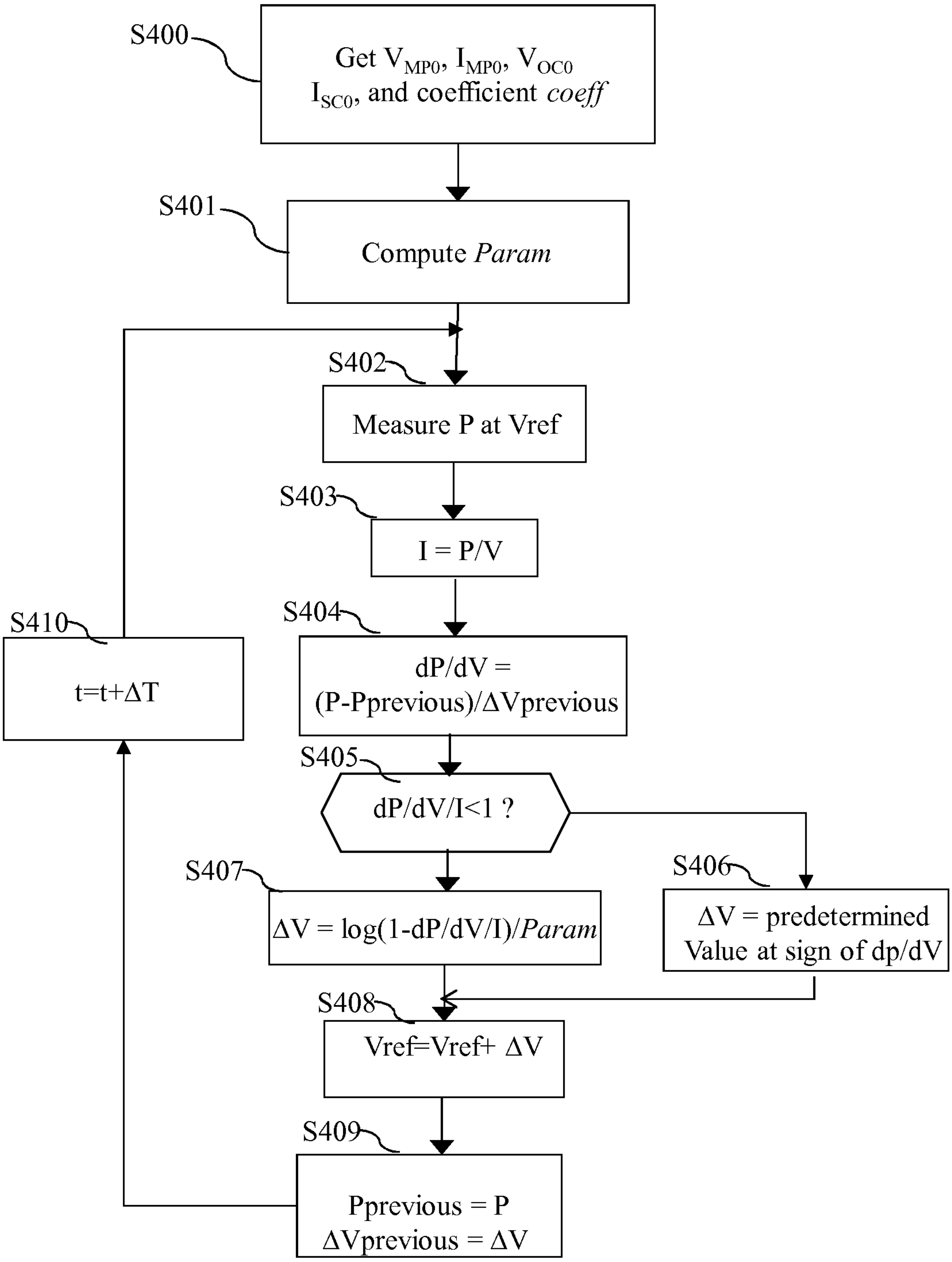
S400
Get V_{MP0}, I_{MP0}, V_{OC0}
I_{SC0}, and coefficient *coeff*
S401
Compute *Param*
S402
Measure P at Vref
S403
I = P/V
S404
dP/dV =
(P-Pprevious)/ΔVprevious
S405
dP/dV/I<1 ?
S406
ΔV = predetermined
Value at sign of dp/dV
S407
ΔV = log(1-dP/dV/I)/*Param*
S408
Vref=Vref+ ΔV
S409
Pprevious = P
ΔVprevious = ΔV
S410
t=t+ΔT

Fig. 4

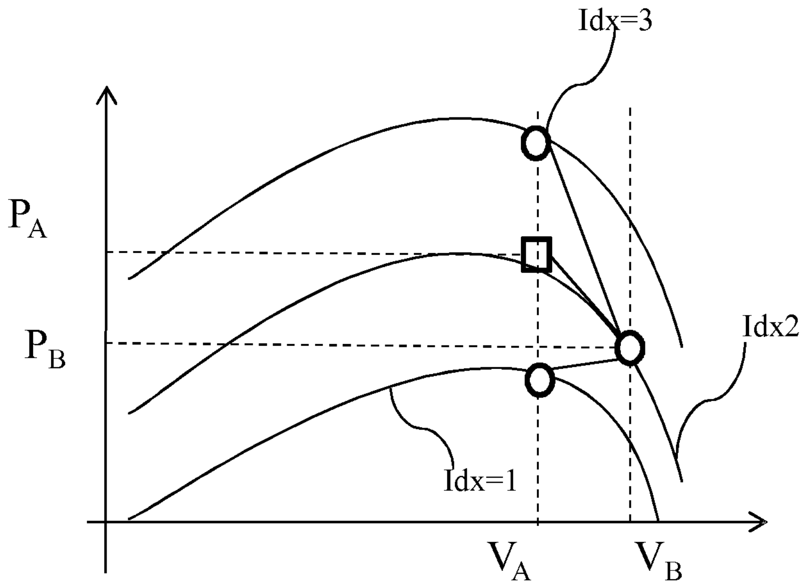

Fig. 5

REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

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- **FANG LUO.** A variable step maximum power point tracking method using differential equation solution. *2nd IEEE conference on industrial electronics and applications,* 2259-2263 **[0012]**
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- **LEE.** Advance incremental conductance MPPT algorithm with a variable step size. *12th international power electronics and motion control conference,* 603-607 **[0014]**