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(54) **Apparatus for obtaining information enabling the determination of a characteristic like the maximum power point of a power source**

(57) The present invention concerns an apparatus for obtaining information enabling the determination of a characteristic like the maximum power point of a power source, the apparatus for obtaining information enabling the determination of the characteristic of the power source comprises means for monitoring the voltage on a capacitor of an energy conversion device, the capacitor being placed between the terminals of the power source and means for monitoring the current provided by the power source, characterised in that the means for monitoring the voltage monitor the voltage during the discharge of the capacitor through the energy conversion device and the means for monitoring the current provided by the power source monitor the current provided by the power source during the discharge of the capacitor through the energy conversion device.

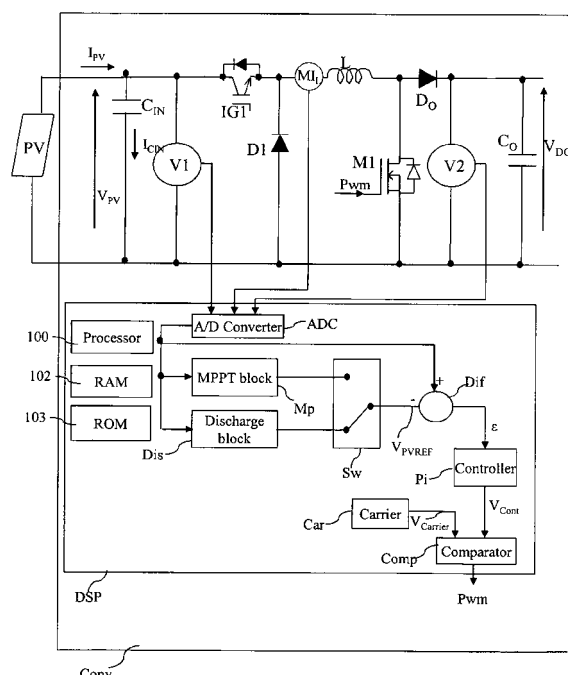


Fig. 3

Description

[0001] The present invention relates generally to an apparatus for obtaining information enabling the determination of a characteristic like the 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 conversion devices like DC/DC up/down converter circuits and/or DC/AC inverter circuits.

[0003] However, the current-voltage droop 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] 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 power is greatest. This point is denominated as the Maximum Power Point (MPP).

[0005] It is important to operate the photovoltaic cells around the MPP to optimize their power generation efficiency in grid-connected applications.

[0006] As the power-voltage curve changes according to climatic variations, the MPP also changes according to climatic variations.

[0007] It is then necessary to be able to identify the MPP at any time.

[0008] The present invention aims at providing an apparatus which enables to obtain information representative of the output current and voltage variations of the power source, for example an array of photovoltaic cells, in order to determine the MPP.

[0009] To that end, the present invention concerns an apparatus for obtaining information enabling the determination of a characteristic like the maximum power point of a power source, the apparatus for obtaining information enabling the determination of the characteristic of the power source comprises means for monitoring the voltage on a capacitor of an energy conversion device, the capacitor being placed between the terminals of the power source and means for monitoring the current provided by the power source, the energy conversion device comprising at least one switch, characterised in that the means for monitoring the voltage monitor the voltage during the discharge of the capacitor through the energy conversion device and the means for monitoring the current provided by the power source monitor the current provided by the power source during the discharge of the capacitor through the energy conversion device and the voltage on the capacitor is decreased by controlling the conduction or not of the switch using at least one mathematical function.

[0010] The present invention concerns also a method for obtaining information enabling the determination of a characteristic like the maximum power point of a power source, characterised in that the method comprises the steps of:

- decreasing the voltage on a capacitor of an energy conversion device by controlling the conduction or not of a switch of an energy conversion device using at least one mathematical function,
- monitoring the voltage on the capacitor of the energy conversion device, the capacitor being placed between the terminals of the power source, the monitoring of the voltage being executed during the discharge of the capacitor through the energy conversion device,
- monitoring the current provided by the power source during the discharge of the capacitor through the energy conversion device.

[0011] Thus, it is possible to obtain information representative of the output current and voltage variations of the power source, for example, in order to determine the MPP or to determine a fault of the power source or to determine the fill factor of the power source.

[0012] Furthermore, it is possible to limit the current peak that could appear on the converter inductor if there was an abrupt voltage step change on the control loop.

[0013] According to a particular feature, the at least one mathematical function is a first-degree polynomial function of one variable.

[0014] Thus, if one first-degree polynomial function is used, it is possible to obtain equally spaced voltage samples leading to the same accuracy of power samples for any part of the power versus voltage curve for a given sampling frequency.

[0015] According to a particular feature, the time duration of the discharge of the capacitor is defined so as to enable that a given number of measurements is performed.

[0016] Thus, it is always possible to obtain the same number of samples at any operation condition and independent on the voltage and current levels of the power source.

[0017] Furthermore, by adjusting the time duration of the capacitor discharge, it is always possible to obtain a desired number of samples, independently of the sampling frequency of the monitored signals.

[0018] According to a particular feature, the means for monitoring the current provided by the power source monitor the current going through an inductor of the energy conversion device and derive the current provided by the capacitor from the voltage samples of the capacitor.

[0019] Thus, it is possible to estimate the current outputted by the power source without adding a current sensor in series with the power source.

[0020] According to a particular feature, the current going through the inductor is monitored by a current sensor.

[0021] Thus, it is possible to make use of the usually available current sensor in series with the inductor for control purposes, without adding any other component and associated cost to the converter.

[0022] According to a particular feature, the current going through the inductor is obtained taking into account the switching on and the switching off states of a switch of the energy conversion device.

[0023] Thus, it is possible to estimate the actual average current on the inductor for a sampling frequency equal to the switching frequency of the energy conversion device at any condition, since during transient conditions the sampled current values are not necessarily equal to the actual average current values such as it may happen in steady state operation.

[0024] According to a particular feature, the current going through the inductor is obtained taking into account, for each switching on and switching off states, one measurement of the voltage provided by the power source, one measurement of the voltage at the output of the energy conversion device and one measurement of the current going through the inductor.

[0025] According to a particular feature, the current going through the inductor is derived from the voltage between the terminals of the inductor.

[0026] Thus, it is possible to further reduce the cost of the converter by avoiding the use of any current sensor within the energy conversion device for the purpose of characterizing the power source.

[0027] According to a particular feature, the energy conversion device is a DC/DC step-down/step-up converter and/or a DC/AC converter.

[0028] Thus, all the passive components needed for performing the power curve characterization are already available on the system, avoiding the need of adding any other extra component to it.

[0029] 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 an energy conversion system wherein the present invention may be implemented;

Fig. 2 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. 3 represents an example of an energy conversion device according to the present invention;

Fig. 4 is an example of an algorithm for determining information enabling the determining of a MPP according to the present invention;

Fig. 5a is an example of the power source voltage variations obtained according to the present invention;

Fig. 5b is an example of reference voltage used for controlling the operation of the power source according to the present invention;

Fig. 5c is an example of the power source current variations obtained according to the present invention;

Fig. 5d is an example of the envelope of inductor current variations obtained according to the present invention;

Fig. 5e is an example of the envelope of patterns used for controlling at least one switch in order to control the operation of the power source according to the present invention;

Fig. 6a is an example of the inductor current variations in the second phase as disclosed in the algorithm of Fig. 4;

Fig. 6b is an example of the patterns used for controlling at least one switch during the second phase as disclosed in the algorithm of Fig. 4;

Fig. 7 is an algorithm used for determining the average values of the inductor current during the second phase as disclosed in the algorithm of Fig. 4;

Figs. 8a to 8c represent curves used for reconstructing the inductor current waveform in a first moment and for determining the average of the inductor current during the second phase as disclosed in the algorithm of Fig. 4;

Fig. 9 is an example of an algorithm for determining the voltage and current through the input capacitor according to the present invention;

Fig. 10 is an example of a power versus voltage curve that can be obtained according to the present invention.

[0030] Fig. 1 is an example of an energy conversion system wherein the present invention may be implemented.

[0031] 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.

[0032] The power source PV provides current intended to the load Lo. The current is converted by the conversion

device Conv prior to be used by the load Lo.

[0033] Fig. 2 is an example of a curve representing the output current variations of a power source according to the output voltage of the power source.

[0034] On the horizontal axis of Fig. 2, voltage values are shown. The voltage values are comprised between null value and the open circuit voltage V_{oc} .

[0035] On the vertical axis of Fig. 2, current values are shown. The current values are comprised between null value and the short circuit current I_{sc} .

[0036] 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 MPP for a given light level and photovoltaic array temperature.

[0037] Fig. 3 represents an example of an energy conversion device according to the present invention.

[0038] The positive terminal of the power source PV is connected to the first terminal of a capacitor C_{IN} and the negative terminal of the power source PV is connected to a second terminal of the capacitor C_{IN} .

[0039] The voltage on the capacitor C_{IN} is monitored by voltage measurement means V1. The voltage on the capacitor C_{IN} is equal to the voltage V_{PV} provided by the power source PV.

[0040] The first terminal of the capacitor C_{IN} is connected to a switch IG1.

[0041] For example the switch IG1 is an IGBT (Insulated Gate Bipolar Transistor) and the first terminal of the capacitor C_{IN} is connected to the collector of the switch IG1.

[0042] The switch IG1 is always in ON state, i.e. in conduction mode, when the energy conversion device Conv converter is operating in Boost mode (step-up configuration).

[0043] The emitter of the switch IG1 is connected to the cathode of a diode D1. The anode of the diode D1 is connected to the negative terminal of the power source PV.

[0044] The emitter of the switch IG1 is also connected to a first terminal of current measurement means MI_L , which measures the current I_L going through the inductor L, and the second terminal of the current measurement means MI_L is connected to a first terminal of an inductor L.

[0045] If there is no current sensor for measuring the current I_L going through the inductor L, the emitter of the switch IG1 is connected to the first terminal of the inductor L.

[0046] The second terminal of the inductor L is connected to a switch M1.

[0047] The switch M1 is for example a NMOSFET (N channel Metal Oxide Semiconductor Field Effect Transistor).

[0048] The second terminal of the inductor L is connected to the drain of the NMOSFET M1. The source of the NMOSFET is connected to the negative terminal of the power source PV.

[0049] The gate of the NMOSFET is driven by a driver circuit controlled by a DSP (Digital Signal Processor) through a signal Pwm which will be disclosed hereinafter.

[0050] The DSP controls the switch M1, in this case when operating in Boost mode (step-up converter), in order to modify the voltage and current provided by the power source for a fixed output voltage value V_{DC} .

[0051] The second terminal of the inductor L is also connected to the anode of a diode D_o .

[0052] The cathode of the diode D_o is connected to a first terminal of a capacitor C_o . The second terminal of the capacitor C_o is connected to the negative terminal of the power source PV.

[0053] The cathode of the diode D_o is connected to a first terminal of voltage measurement means V2 which measures the voltage between the second terminal of the inductor L and the negative terminal of the power source PV.

[0054] The output voltage of the converter Conv is named V_{DC} .

[0055] The voltage V_{PV} and V_{DC} measured by measurement means V1 and V2 and current I_L measured by the current measurement means MI_L are converted into digital data by an analogue to digital converter ADC included in the DSP (Digital Signal Processor).

[0056] The DSP has an architecture based on components connected together by a bus not shown in Fig. 1 and a processor 100 controlled by the programs related to the algorithms as disclosed in the Figs. 4, 7 and 9.

[0057] The bus links the processor 100 to a read only memory ROM 103, a random access memory RAM 102 and an analogue to digital converter ADC.

[0058] The read only memory ROM 103 contains instructions of the programs related to the algorithms as disclosed in the Figs. 4, 7 and 9 which are transferred, when the energy conversion device Conv is powered on to the random access memory RAM 102.

[0059] The RAM memory 102 contains registers intended to receive variables, and the instructions of the programs related to the algorithms as disclosed in the Figs. 4, 7 and 9.

[0060] The DSP comprises an MPPT (Maximum Power Point Tracker) control block Mp, a capacitor discharge control block Dis, a switch Sw, subtracting means Dif, a controller Pi, a carrier generation module Car and a comparator Comp.

[0061] It has to be noted here that the MPPT control block Mp, the capacitor discharge control block Dis, the switch Sw, the subtracting means Dif, the controller Pi, the carrier generation module Car and the comparator Comp may be implemented under the form of software.

[0062] The output of the analogue to digital converter ADC is provided to the MPPT control block Mp, to the capacitor discharge control block Dis and to the subtracting means Dif.

[0063] The MPPT control block Mp received the digitally converted voltage V_{PV} , the digitally converted current I_L , if there is a current sensor, and the capacitor discharge control block Dis receives the digitally converted voltages V_{PV} , V_{DC} and the current I_L if there is a current sensor.

[0064] The switch Sw enables the selection of the operation mode of the converter Conv in MPPT tracking phase or in capacitor C_{IN} discharging phase which will be disclosed in reference to the Fig. 4.

[0065] The voltage at the output of the switch Sw is denoted V_{PVREF} and is subtracted to the digitally converted voltage V1 by the subtracting means Dif.

[0066] The output error ε of the subtracting means Dif is controlled by the controller Pi and provided to the comparator Comp which compares it with a carrier signal $V_{Carrier}$ provided by the carrier generation module Car. The carrier signal $V_{carrier}$ operates with a frequency f_{sw} and it is usually a triangular or a saw tooth waveform.

[0067] The controller Pi can be a Proportional-Integral (PI) controller or a Proportional-Integral-Derivative (PID) controller.

[0068] The output of the comparator Comp provides the control signal Pwm.

[0069] Fig. 4 is an example of an algorithm for determining information enabling the determining of a MPP according to the present invention.

[0070] More precisely, the present algorithm is executed by the processor 100.

[0071] The algorithm for obtaining information enabling the determination of the maximum power point of the power source monitors at least the voltage V1 on the capacitor C_{IN} , the voltage V2 and the current I_L if there is a current sensor.

[0072] At step S400, the phase PH1 starts. The phase PH1 is shown in the Figs. 5a to 5e.

[0073] Fig. 5a is an example of the power source voltage variations obtained according to the present invention.

[0074] The time is represented on horizontal axis of the Fig. 5a and the voltage is represented on the vertical axis of the Fig. 5a.

[0075] Fig. 5b is an example of reference voltage used for controlling the operation of the power source according to the present invention.

[0076] The time is represented on horizontal axis of the Fig. 5b and the voltage is represented on the vertical axis of the Fig. 5b.

[0077] Fig. 5c is an example of the power source current variations obtained according to the present invention.

[0078] The time is represented on horizontal axis of the Fig. 5c and the current is represented on the vertical axis of the Fig. 5c.

[0079] Fig. 5d is an example of the envelope of inductor current variations obtained according to the present invention.

[0080] The time is represented on horizontal axis of the Fig. 5d and the current is represented on the vertical axis of the Fig. 5d.

[0081] The hashed area represents the envelope of the inductor current variations.

[0082] Fig. 5e is an example of the envelope of the patterns used for controlling at least one switch in order to control the operation of the power source according to the present invention.

[0083] The time is represented on horizontal axis of the Fig. 5e and the voltage is represented on the vertical axis of the Fig. 5e.

[0084] The hashed area represents the envelope of the Pwm signal variations.

[0085] During the phase PH1, the energy conversion device Conv acts, for example, as a boost (step-up) DC/DC converter. It has to be noted here that the energy conversion device may act as a buck (step-down) DC/DC converter as well.

[0086] During the phase PH1, the energy conversion device Conv controls the operation point of the power source and operates in Perturb and Observe (P&O) maximum power point tracking (MPPT) mode, for example.

[0087] During the phase PH1, the switch Sw enables the reference voltage provided by the MPPT control block Mp to be compared to the voltage V_{PV} provided by the power source PV, measured by the measurement means V1, and which is digitally converted.

[0088] The error ε generated by the difference between V_{PVREF} and V_{PV} is compensated by the controller Pi which may be a proportional integral derivative (PID) controller or a proportional integral controller (PI), resulting in a V_{Cont} signal.

[0089] V_{Cont} signal is then compared to a carrier waveform $V_{Carrier}$ which may be a triangular waveform, or even a saw tooth waveform, with maximum value V_M and frequency f_{sw} .

[0090] If $V_{Carrier} < V_{Cont}$, the switch M1 is conducting or ON, otherwise the switch M1 is not conducting or OFF.

[0091] During the phase PH1, the voltage V_{PV} provided by the power source PV is regulated around the desired value V_{PVREF} , defined by the MPPT block Mp every second for example, while the output voltage V_{DC} is theoretically constant.

[0092] For example, the output voltage V_{DC} may be imposed by a battery or the output voltage V_{DC} may be a regulated DC link of an inverter that regulates this voltage V_{DC} through a specific control loop depending on the sort of application, like a grid-connected application or not.

[0093] During the phase PH1, the voltage V_{PV} as shown in Fig. 5a and consequently the current I_{PV} as shown in Fig. 5c, follow the reference value V_{PVREF} supplied by the MPPT algorithm and which is regularly updated.

[0094] The current I_L varies according to the switching of the switch M1 as shown in Fig. 5d.

[0095] At next step S401, the phase PH2 starts.

[0096] The phase PH2 corresponds to a time period during which the power curve of the power source PV is obtained between the voltage value V_{MPP} used by the MPPT block Mp and a minimal voltage value V_{MIN} which is for example the minimum allowed voltage operation value of the energy conversion device Conv.

[0097] According to the invention, the time duration of the phase PH2 is defined so as to enable that a given number N of measurements is performed, for example N is equal to one hundred.

[0098] One sample corresponds to one measurement of V_{PV} performed by voltage measurement means V1, one measurement of V_{DC} performed by voltage measurement means V2 and one measurement of I_L performed by current measurement means MI_L .

[0099] Samples are obtained at the sampling frequency F_{SAMP} of the analogue to digital converter ADC. In some cases the sampling frequency f_{SAMP} is equal to f_{SW} .

[0100] The phase PH2 time duration is set as $\Delta t = N \cdot f_{SAMP}$.

[0101] During the phase PH2, the capacitor C_{IN} is discharged as the voltage V_{PV} of the power source PV is led by the reference value V_{PVREF} and its control loop to the minimal voltage value, herein called V_{MIN} .

[0102] During the phase PH2, the switch Sw enables the voltage provided by the discharge block Dis to be compared to the voltage V_{PV} provided by the power source measured by the measurement means V1 and which is digitally converted. The discharge block Dis provides a voltage V_{PVREF} which is defined according to a given mathematical function decreasing from an initial value V_{PV} , which corresponds here to the V_{MPP} value of that PH1 to V_{MIN} .

[0103] For example, the mathematical function is a linear function like a first-degree polynomial function of one variable.

[0104] During the phase PH2, at step S402, all the samples of V_{PV} and I_L obtained during phase PH2 are stored.

[0105] It has to be noted here that the samples of the voltage V_{DC} may also be stored if there is no current measurement means MI_L .

[0106] At next step S403, the samples of the voltage V_{PV} are used to evaluate the current I_{CIN} through the capacitor C_{IN} . The determination of I_{CIN} will be disclosed in more detail in reference to Fig. 9.

[0107] At next step S404, the current samples of I_L are processed in order to determine the average values of I_L during this transient condition of current variation.

[0108] As shown in Fig. 5d and Fig. 5e, the current I_L varies according to the switching of the switch M1.

[0109] A more enlarged view of I_L and Pwm variations during the phase PH2 is given in Figs. 6a and 6b.

[0110] Fig. 6a is an example of the inductor current variations in the second phase as disclosed in the algorithm of Fig. 4.

[0111] The time is represented on horizontal axis of the Fig. 6a and the current is represented on the vertical axis of the Fig. 6a.

[0112] Fig. 6b is an example of the patterns used for controlling at least one switch during the second phase as disclosed in the algorithm of Fig. 4.

[0113] The time is represented on horizontal axis of the Fig. 6b and the voltage is represented on the vertical axis of the Fig. 6b.

[0114] During the phase PH2, the duty cycle of the Pwm signal varies continuously according to the sampling frequency F_{SAMP} . It has to be noted here that, if $f_{SAMP} = f_{SW}$ the duty-cycle is constant for every switching period.

[0115] The current I_L increases and decreases according to the conduction or not of the switch M1.

[0116] As the duty cycle of Pwm varies during transient conditions, the voltage V_{PV} also varies such as the slope of I_L . Such situation deteriorates the measure of the current I_L in the cases where it is desired to know the I_{PV} value by only means of the current measurement means MI_L .

[0117] It has to be noted here that in steady-state condition with $f_{SAMP} = f_{SW}$, if the sampling is done at the moment that the signal $V_{Carrier}$ is at null value, the measured current I_L value corresponds to its average value which is equal to the I_{PV} current value. However, it is not true anymore in transient state, i.e. in phase PH2, since the sampling is done always at the moment that the signal $V_{Carrier}$ is at null value. In this case, the measured current I_L value does not correspond to the I_L current average value.

[0118] Such variations during the phase PH2 are taken into account by the algorithm which will be disclosed in reference to Fig. 7, and which will be disclosed hereinafter.

[0119] At next step S405, the power source characteristic is determined.

[0120] The current I_{PV} shown in Fig. 5c provided by the power source PV is determined by summing the current I_{CIN} and the average of I_L . It must be noted that due to the method used in Fig. 9 for evaluating the current I_{CIN} , the high frequency ripple that may appear during phase PH2 is already filtered by the method itself.

[0121] Fig. 10 is an example of a power versus voltage curve that can be obtained according to the present invention.

[0122] The voltage V_{PV} is represented on horizontal axis of the Fig. 10 and the power outputted by the power source PV is represented on the vertical axis of the Fig. 10.

[0123] Bold part of the curve represents the part of the curve obtained from I_{PV} and V_{PV} determined by the present invention considering a case where V_{PV} is varying from a value V_{MAX} , which can be equal or greater than V_{MPP} used in phase PH1 to V_{MIN} .

[0124] The MPP corresponds to the maximum power that can be outputted by the power source.

[0125] The new MPP information is provided to the MPPT block Mp.

[0126] At next step S406, the phase PH3 starts. Using the newly determined MPP value, the energy conversion device Conv controls the operation of the power source PV and operates again in P&O maximum power point tracking MPPT mode.

[0127] Although at the beginning of the phase PH3, the V_{PVREF} is already set, it may take some additional time to the power source PV voltage to follow the reference as shown in Figs. 5a and 5b. This is due to the fact that during the phase PH3, the energy provided by the power source PV is given in totality to the input capacitor C_{IN} .

[0128] At next step S407, the phase PH4 starts. The voltage value V_{PV} is very close to V_{PVREF} meaning a very small error. The power source PV starts to supply power to the load Lo at this moment. The voltage value V_{PV} finally converges to the desired V_{PVREF} value and the P&O MPPT algorithm is now operating in normal conditions again as disclosed in phase PH1.

[0129] Fig. 7 is an algorithm used for determining the average value of the inductor current during the second phase as disclosed in the algorithm of Fig. 4.

[0130] The algorithm of Fig. 7 is used for determining the average value of the inductor current I_L during the second phase PH2 in a case where $f_{SAMP}=f_{SW}$.

[0131] At step S700, the samples of the current I_L and of the voltages V_{PV} and V_{DC} are obtained.

[0132] At next step S701, the variations of the current I_L during the switching ON and switching OFF of the switch M1 are rebuild respectively from the samples of the current I_L and from voltage samples of V_{PV} and V_{DC} associated with the Pwm signal values at transition times from ON to OFF or OFF to ON states. In other words, the high frequency current ripple is completely reproduced.

[0133] Example of variations of the current I_L are shown in Fig. 8a to 8c.

[0134] Figs. 8a to 8c represent curves used for reproducing the inductor current waveform and for determining the average of the inductor current during the second phase as disclosed in the algorithm of Fig. 4.

[0135] Fig. 8a represents the instants where two consecutive samples are obtained at two consecutive switching periods.

[0136] Fig. 8b represents the voltage variation of the signal Pwm and the voltage provided by the signal V_{Cont} that is compared with the carrier signal $V_{Carrier}$, generated by the carrier generation module Car.

[0137] The transition times t_1 and t_2 are the exact time moments in which $V_{Cont}=V_{Carrier}$, where V_{Cont} is the compensated control signal generated by the controller Pi.

[0138] When the signal Pwm is high, the current I_L increases with a slope which is equal to V_{PV} divided by inductor L value and multiplied by the time duration, in this case from t_0 to t_1 and also from t_2 to t_3 . This time duration is simply obtained by monitoring V_{Cont} and $V_{Carrier}$ within the DSP.

[0139] When the signal Pwm is low, the current I_L decreases with a slope which is equal to V_{PV} minus V_{DC} , both divided by inductor L value and multiplied by the time duration, in this case from t_1 to t_2 . This time duration is simply obtained by monitoring V_{Cont} and $V_{Carrier}$ within the DSP.

[0140] From the samples and signal Pwm it is then possible to reconstruct the current variations of I_L as shown in Fig. 8c.

[0141] At next step S702, the average value of I_L is determined using the reconstructed current variations of I_L and a digital low-pass filter with cut-off frequency much smaller than f_{sw} , for example lower than half of f_{sw} .

[0142] Fig. 9 is an example of an algorithm for determining the voltage and current through the input capacitor according to the present invention.

[0143] More precisely, the present algorithm is executed by the processor 100.

[0144] From a general point of view, with the present algorithm, the capacitor current I_{CIN} for the given sample is determined by multiplying the capacitance value of the capacitor C_{IN} by the voltage derivative of the given sample, the voltage derivative being obtained through a fitted mathematical function, for example a polynomial function with real coefficients.

[0145] The fitted mathematical function is obtained by minimizing the sum of the squares of the difference between the measured voltage y_i with $i=1$ to N at consecutive time samples x_i and mathematical functions $f(x_i)$ in order to obtain a processed voltage for the given time sample. It is done as follows.

[0146] Given N samples $(x_1, y_1), (x_2, y_2), \dots, (x_N, y_N)$, the required fitted mathematical function can be written, for example, in the form:

$$f(x)=C_1 \cdot f_1(x)+C_2 \cdot f_2(x)+\dots+C_K \cdot f_K(x)$$

where $f_j(x)$, $j=1,2...K$ are mathematical functions of x and the C_j , $j=1,2...K$ are constants which are initially unknown.
[0147] The sum of the squares of the difference between $f(x)$ and the actual values of y is given by

$$E = \sum_{i=1}^N [f(x_i) - y_i]^2 = \sum_{i=1}^N [C_1 f_1(x_i) + C_2 f_2(x_i) + \dots + C_K f_K(x_i) - y_i]^2$$

[0148] This error term is minimized by taking the partial first derivative of E with respect to each of constants, C_j , $j=1,2,...K$ and putting the result to zero. Thus, a symmetric system of K linear equation is obtained and solved for C_1 , $C_2, \dots, C_K$. This procedure is also known as Least Mean Squares (LMS) algorithm.

[0149] With the voltage samples of V_{PV} , a curve is obtained based on the fitting of suitable mathematical functions, for example polynomial functions with real coefficients, in pre-defined windows which will move for each sample. Thus, the voltage is filtered and its derivative can be simultaneously calculated for every central point in the window in a very simple and direct way, resulting in the determination of current without the need of any additional current sensor.

[0150] At step S900, the processor 100 gets the N samples of V_{PV} obtained during the phase PH2. For example at least one hundred samples are obtained. Each sample is a bi-dimensional vector, the coefficients of which are the voltage value and time to which voltage has been measured.

[0151] At next step S901, the processor 100 determines the size of a moving window. The size of the moving window indicates the number N_{pt} of samples to be used for determining a curve based on the fitting of suitable mathematical functions, for example polynomial functions with real coefficients. The size of the moving window is odd. For example, the size of the moving window is equal to twenty one.

[0152] At next step S902, the processor 100 determines the central point N_c of the moving window.

[0153] At next step S903, the processor 100 sets the variable i to the value N_{pt} .

[0154] At next step S904, the processor 100 sets the variable j to $i - N_c + 1$.

[0155] At next step S905, the processor 100 sets the variable k to one.

[0156] At next step S906, the processor 100 sets the value of $x(k)$ to the time coefficient of sample j .

[0157] At next step S907, the processor 100 sets the value of $y(k)$ to the voltage coefficient of sample j .

[0158] At next step S908, the processor 100 increments the variable k by one.

[0159] At next step S909, the processor 100 increments the variable j by one.

[0160] At next step S910, the processor 100 checks if the variable j is strictly lower than the sum of i and N_c minored by one.

[0161] If the variable j is strictly lower than the sum of i and N_c minored by one, the processor 100 returns to step S906. Otherwise, the processor 900 moves to step S911.

[0162] At step S911, the processor 100 determines the fitted mathematical function, for example the polynomial function $y(x)=ax^2+bx+c$, using the Least Mean Square algorithm and all the $x(k)$ and $y(k)$ values sampled at steps S906 and S907 until the condition on S910 is reached.

[0163] The processor 100 obtains then the a , b and c real coefficients of the second degree polynomial function ($[a, b, c] \in R^3$).

[0164] At next step S912, the processor 100 evaluates the filtered voltage value and the needed currents according to the following formulas:

$$V_{PV}(\text{time}[i]) = a \cdot \text{time}[i]^2 + b \cdot \text{time}[i] + c$$

$$I_{CIN}(\text{time}[i]) = C_{IN} \cdot (a \cdot \text{time}[i] + b)$$

[0165] At next step S913, the processor 900 increments the variable i by one unit.

[0166] At next step S914, the processor 100 checks if i is strictly lower than N minored by N_c .

[0167] If i is strictly lower than N minored by N_c , the processor 100 returns to step S904. Otherwise, the processor 300 moves to step S915 and outputs voltage and current pairs determined by the present algorithm.

[0168] After that, the processor 100 interrupts the present algorithm and returns to step S404 of the algorithm of Fig. 4.

[0169] It has to be noted here that, instead of monitoring the current going through the inductor using a current sensor, a similar algorithm as the algorithm disclosed in Fig. 9 may be used for monitoring the current going through the inductor from voltage measurements of the voltage on the inductor L , for example by subtracting V_{PV} to V_{DC} when the switch $M1$ is in OFF state and assuming that the voltage is equal to V_{PV} when $M1$ is in ON state.

[0170] It has to be noted here that, instead of evaluating any derivative, it is necessary to use a suitable integration numerical method for evaluating the current through the inductor by only voltage measurements.

[0171] Naturally, many modifications can be made to the embodiments of the invention described above without departing from the scope of the present invention.

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Claims

- 10 1. Apparatus for obtaining information enabling the determination of a characteristic like the maximum power point of a power source, the apparatus for obtaining information enabling the determination of the characteristic of the power source comprises means for monitoring the voltage on a capacitor of an energy conversion device, the capacitor being placed between the terminals of the power source and means for monitoring the current provided by the power source, the energy conversion device comprising at least one switch, **characterised in that** the means for monitoring the voltage monitor the voltage during the discharge of the capacitor through the energy conversion device and the means for monitoring the current provided by the power source monitor the current provided by the power source during the discharge of the capacitor through the energy conversion device and **in that** the voltage on the capacitor is decreased by controlling the conduction or not of the switch using at least one mathematical function.
- 15 2. Apparatus according to claim 1, **characterised in that** the at least one given mathematical function is a first-degree polynomial function of one variable.
- 20 3. Apparatus according to claim 1 or 2, **characterised in that** the time duration of the discharge of the capacitor is defined so as to enable that a given number of measurements is performed.
- 25 4. Apparatus according to any of the claims 1 to 3, **characterised in that** the means for monitoring the current provided by the power source monitor the current going through an inductor of the energy conversion device and derive the current provided by the capacitor from the voltage of the capacitor.
- 30 5. Apparatus according to claim 4, **characterised in that** the current going through the inductor is monitored by a current sensor.
6. Apparatus according to claim 5, **characterised in that** the current going through the inductor is obtained taking into account the switching on and the switching off states of a switch of the energy conversion device.
- 35 7. Apparatus according to claim 6, **characterised in that** the current going through the inductor is obtained taking into account, for each switching on and switching off states, one measurement of the voltage provided by the power source, one measurement of the voltage at the output of the energy conversion device and one measurement of the current going through the inductor.
- 40 8. Apparatus according to claim 4, **characterised in that** the current going through the inductor is derived from the voltage between the terminals of the inductor.
9. Apparatus according to any of the claims 1 to 8, **characterised in that** the energy conversion device is a DC-DC step-down/step-up converter and/or a DC/AC converter.
- 45 10. Method for obtaining information enabling the determination of a characteristic like the maximum power point of a power source, **characterised in that** the method comprises the steps of:
 - 50 - decreasing the voltage on a capacitor by controlling the conduction or not of a switch of an energy conversion device using at least one mathematical function,
 - monitoring the voltage on the capacitor of an energy conversion device, the capacitor being placed between the terminals of the power source, the monitoring of the voltage being executed during the discharge of the capacitor through the energy conversion device,
 - 55 - monitoring the current provided by the power source during the discharge of the capacitor through the energy conversion device.

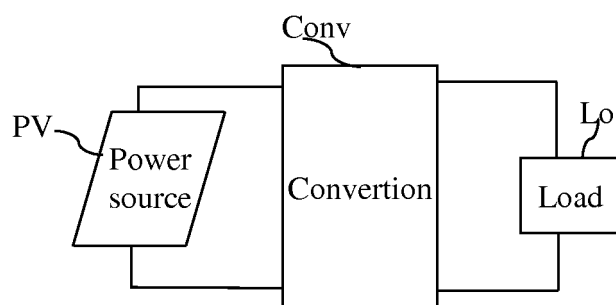


Fig. 1

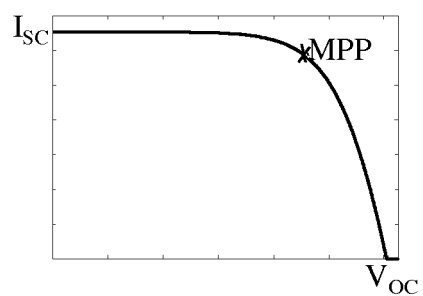


Fig. 2

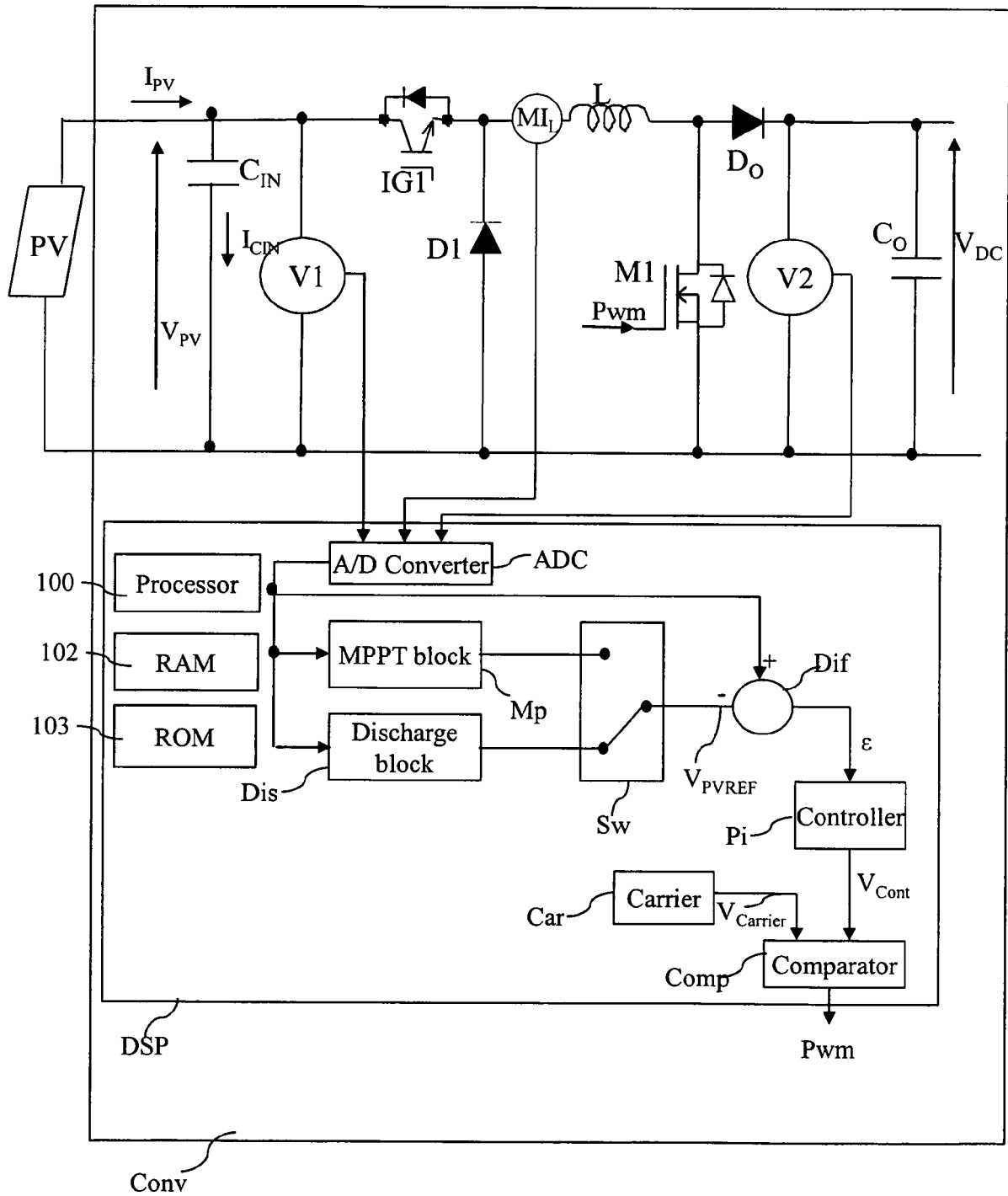


Fig. 3

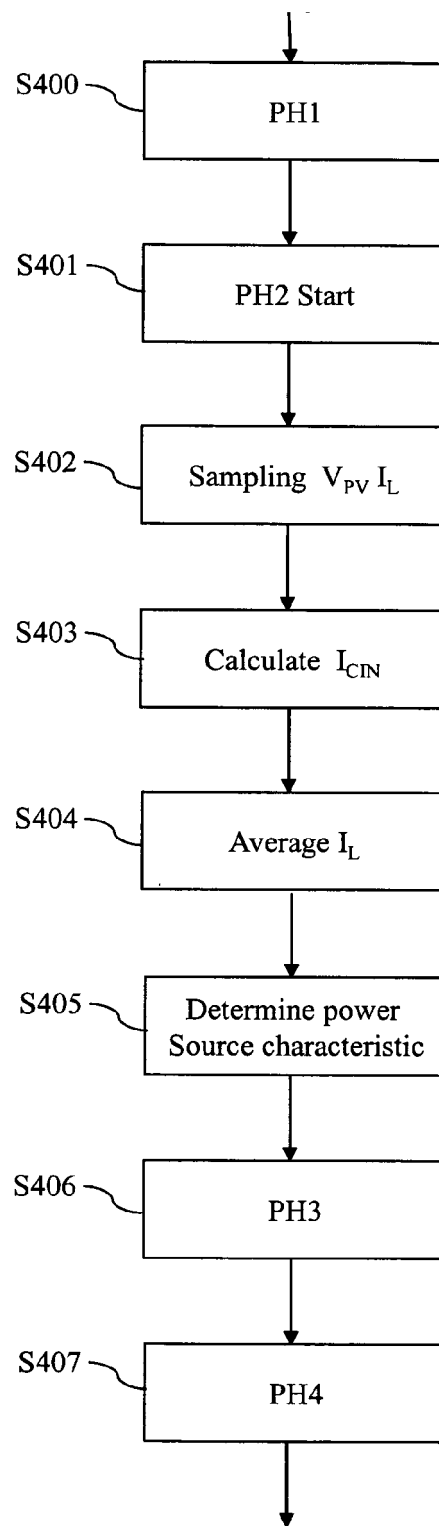


Fig. 4

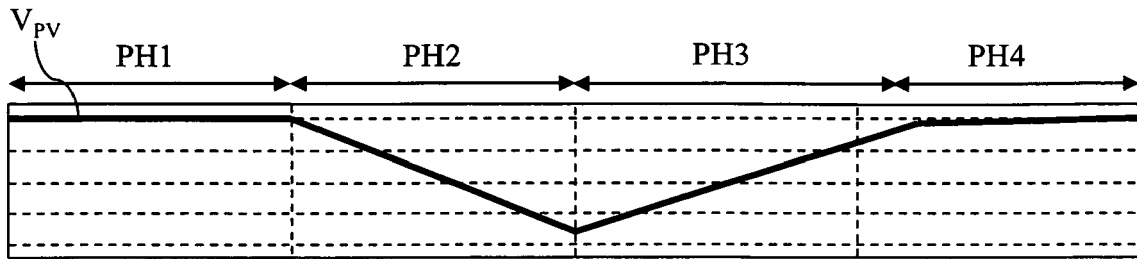


Fig. 5a

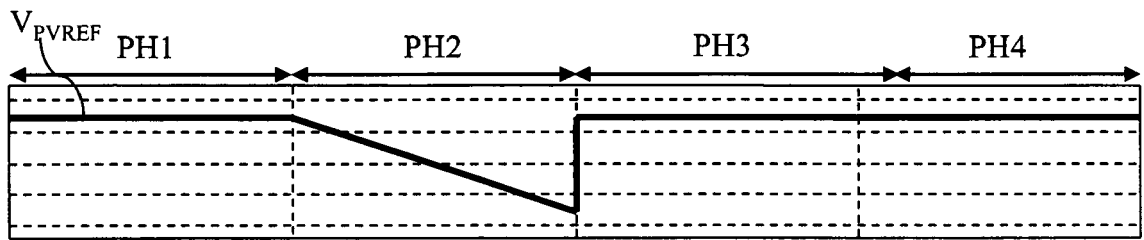


Fig. 5b

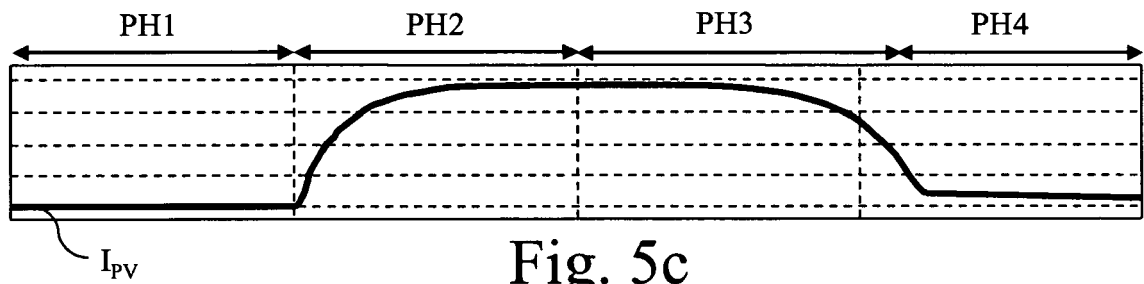


Fig. 5c

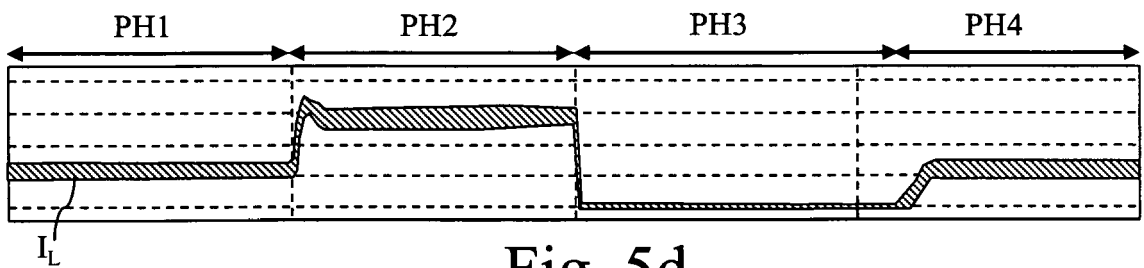


Fig. 5d

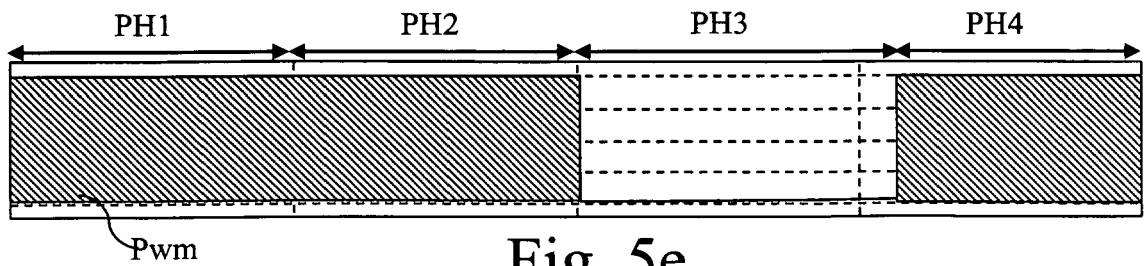


Fig. 5e

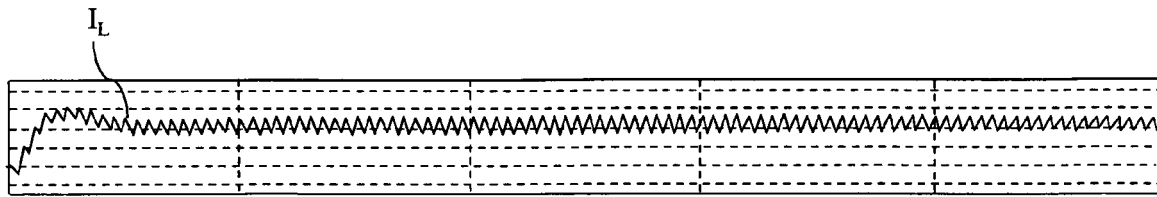


Fig. 6a

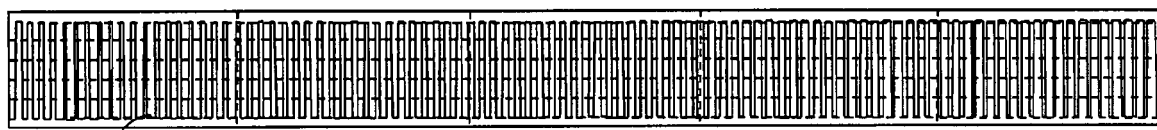


Fig. 6b

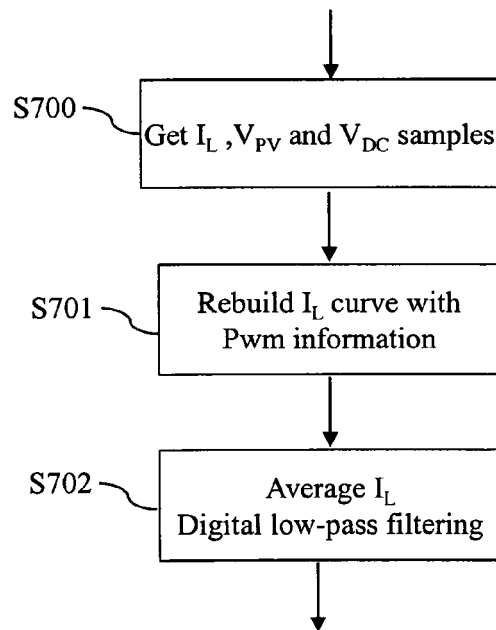
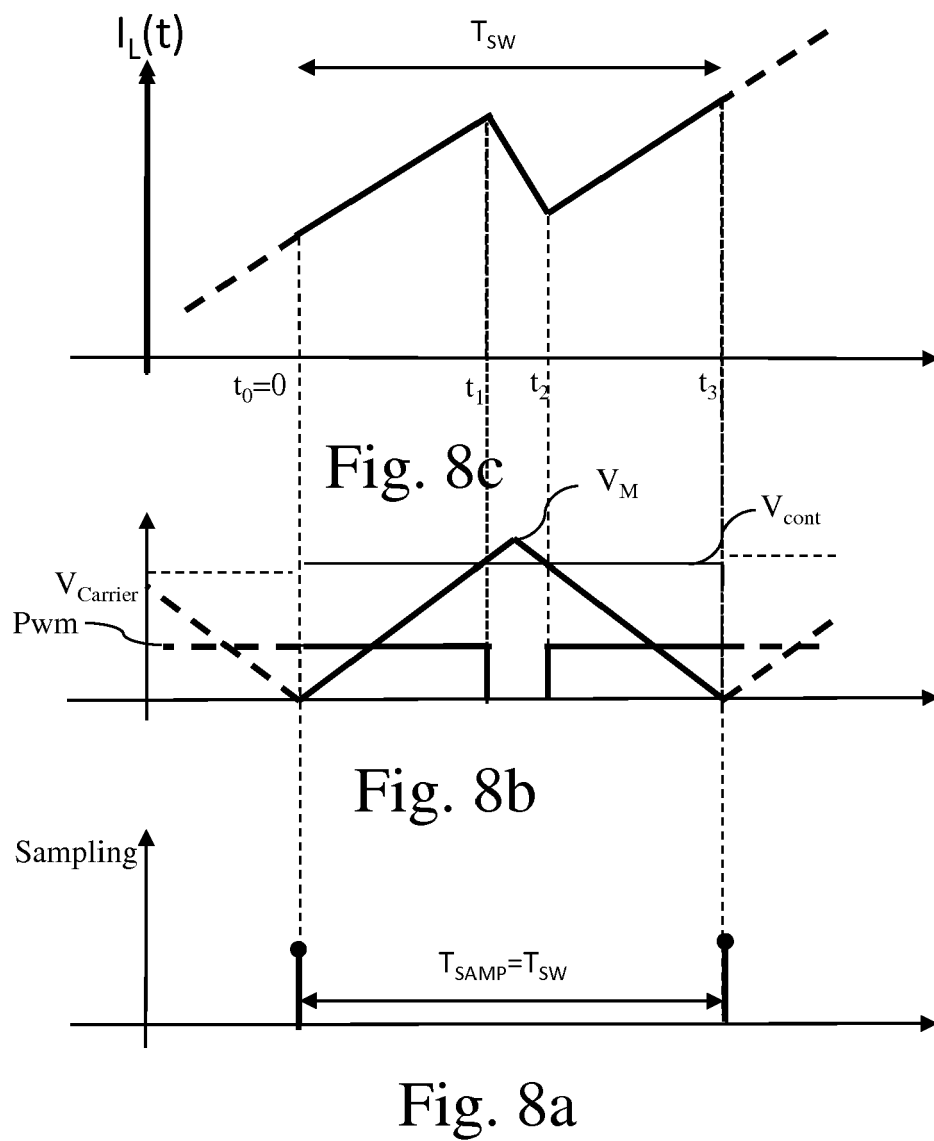


Fig. 7



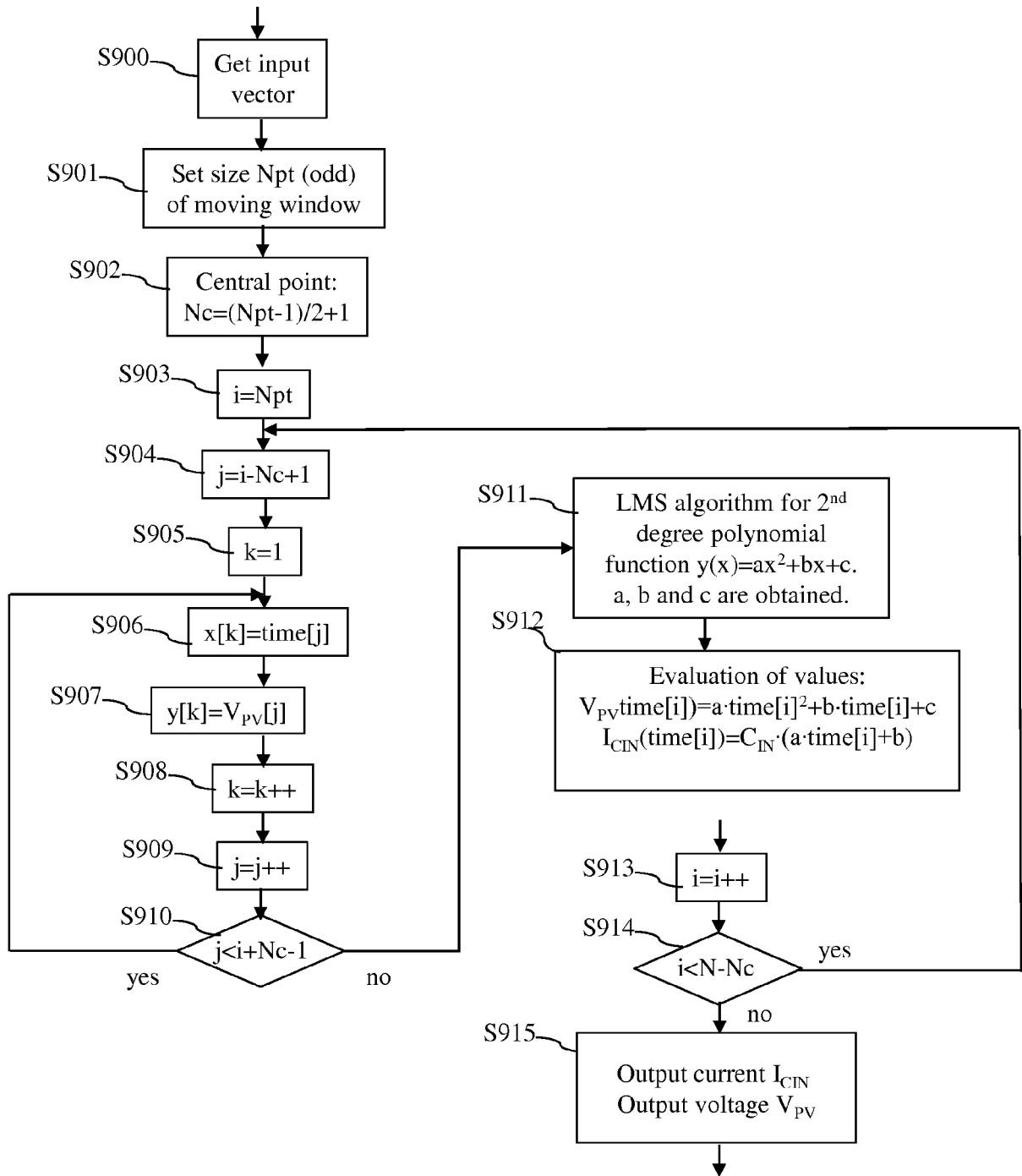


Fig. 9

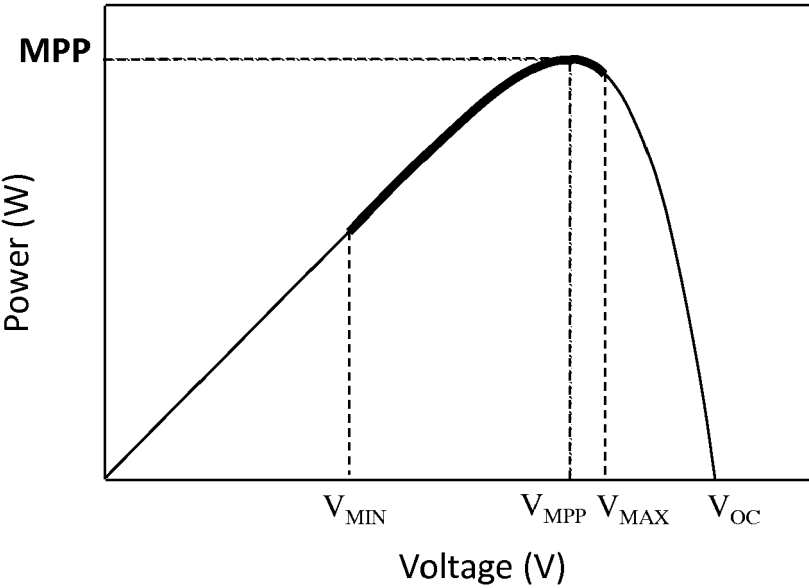


Fig. 10



EUROPEAN SEARCH REPORT

Application Number
EP 11 16 3037

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	EP 2 280 329 A1 (MITSUBISHI ELEC R&D CT EUROPE [NL]; MITSUBISHI ELECTRIC CORP [JP]) 2 February 2011 (2011-02-02) * paragraph [0001] - paragraph [0201]; figure 5a; examples 1, 3 * -----	1-10	INV. G05F1/67
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A	US 2010/091532 A1 (FORNAGE MARTIN [US]) 15 April 2010 (2010-04-15) * the whole document * -----	1-10	
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (IPC) G05F H02M
Place of search Munich		Date of completion of the search 31 October 2012	Examiner Hernandez Serna, J
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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EPO FORM 1503 03.82 (P04C01)

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EP 11 16 3037

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The members are as contained in the European Patent Office EDP file on
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31-10-2012

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