Maximum power point tracking for low power photovoltaic solar panels

Conference Paper · May 1994

DOI: 10.1109/MELCON.1994.380992 · Source: IEEE Xplore

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Maximum Power Point Tracking for Low Power Photovoltaic Solar Panels

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Abstract — A maximum power point tracker unit is developed for the optimum coupling of a photovoltaic panel (PVP) to the batteries and load through a controlled dc-dc converter (chopper). The system consists of three main units; (i) the photovoltaic panels that converts solar power to electricity, (ii) a chopper which couples the power of PVP to the load or batteries at a constant voltage, and (iii) maximum power point (MPP) computing unit that determines the set point of the chopper to keep the panel voltage at maximum power transfer (MPT) condition.

The tracking of MPP for low power PVP ($50W \dots 1kW$) is feasible only when the power consumption of the tracking unit is lower than the increase of the output power that they provide. The developed and tested circuit consumes only $40mW$, and therefore is suitable even for low power applications down to $50W$. The tracking unit performs MPP computation periodically through analog computing stages. The computation mode requires $20mA$ from the $\pm 5V$ source for a $50ms$ period. In the control and sleep mode, the consumption falls down to $4mA$. The developed unit regulates the panel output voltage at the optimum value in the control mode. The modes are switched by a timing circuit. The sleep mode is initiated when maximum PVP output power of the existent illumination level drops to a preset value, which cannot balance the losses of the chopper and the consumption of the MPP tracker unit.

INTRODUCTION

The photovoltaic solar panels are semiconductor devices that converts the solar illumination power directly to electricity. Their operational characteristics depend on the incident sun light (insolation) level and the surface temperature that developed on the cell surface as the insolation, ambient temperature and current flow varies [1].

In Figure 1 the $i - v$ characteristics of the *M55* cell are shown for varying insolation and surface temperature values. The main parameters are the cell open circuit voltage, the cell short circuit current and the rate of decrease of the cell current on the portion of the characteristic where the voltage approaches the open circuit voltage value. The maximum power points in Figure 1 correspond to the point where the power $p = vi$ is maximum at the operational condition of the characteristics curve. The maximum power points on the $p - i$ curves of the PVP are shown in Figure 2. Since the power delivered by the PVP is maximum at the MPP condition, the derivative of p with respect to i and v is zero

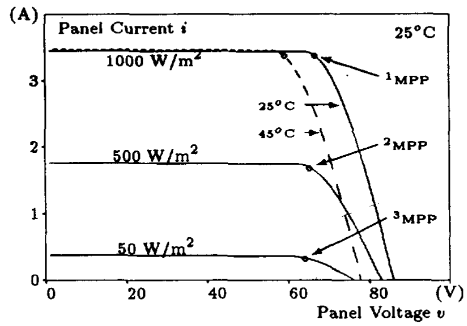

Figure 1: Panel $i - v$ characteristics for varying insolation and surface temperatures of a panel with 4 M55 cells in series.

$$\frac{dp(i)}{di} = 0; \text{ and } \frac{dp(v)}{dv} = 0.; \qquad (1)$$

In general, the PV energy conversion systems of medium and large sizes incorporate three possible approaches of maximizing power extraction. These approaches are sun tracking and MPP tracking or both. For small size systems; however, it is only possible/feasible to implement MPP tracking techniques. But a general trend is to connect the PVP to the battery group through a simple regulator/controller circuitry.

There are various methods of performing MPP tracking on PVP systems; such as the "look-up table", the "perturb and observe" and the "pilot-cell" methods. The pilot cell method is an open-loop control for MPP tracking [2]. The perturb and observe method is an iterative method that perturbs the operation point of PVP to find the direction of change for maximizing the power [3]. The short circuit current capacity of the PVP is an indicaton of the insolation and an approximate MPP is obtained using this value for initiation of the iterations. The perturb and observe algorithm is suitable for implementing by a microprocessor [4, 5]. Divan and Hassan detected the maximum power condition through an analog peak detector at the output of an analog multiplier [6].

In this paper, a novel method of obtaining MPP voltage

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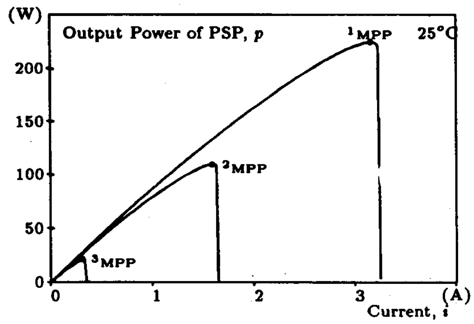


Figure 2: Panel $p - i$ characteristics for varying insolation at $25°C$ of a panel made of 4 M55 cells in series.

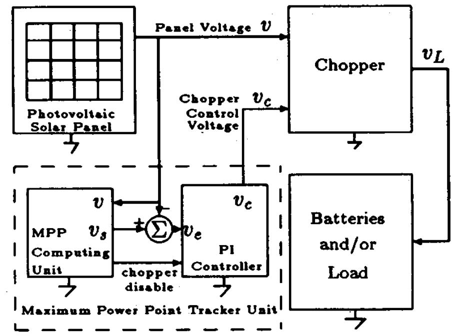


Figure 3: The overall block scheme of the implemented maximum power point tracking photovoltaic solar energy system.

or current of a PVP is proposed. The proposed method is able to compute the panel voltage or current for the maximum power point condition without computing the voltage–current product explicitely as the panel power. The implementation requires only the time derivative, scaling (multiplication by a constant) and addition operations, which can be easily and precisely implemented by using analog operational amplifiers.

A New Approach

A direct method of obtaining the MPP is to obtain the $i-v$ characteristic of the PVP at its operating condition. Once the $i-v$ curve is obtained, the PVP voltage that provides MPP condition can be computed using the measured $i-v$ curve. The PVP current i can be manipulated in the range of the characteristic curve that is determined by the present operating conditions of the PVP. For the operating panel current $i(t)$, the output voltage v of PVP will satisfy the characteristic curve, which is valid for the given solar insolation and cell temperature.

The electrical time constants of the PVP's are around microseconds, and this fast response gives the opportunity of obtaining the $i-v$ characteristics only in $10 \ldots 50ms$ sweep periods. The implemented method obtains the $i-v$ characteristics of the PVP periodically after a prespecified time period that can be set between 10 seconds to 5 minutes. For the 50 ms period in which the characteristic is measured, the power of chopper is interrupted, and an analog MPP computing unit processes the characteristics curve to achieve and hold the maximum power voltage v_s.The simplified block diagram of the system is shown in Figure 3. During the next operation period of the chopper unit, a PI controller keeps the PVP voltage v equal to v_s through a feedback by manipulating the control voltage v_c of the chopper unit.

The maximum power point corresponds to the peak of the power $p(t) = v(t)i(t)$. A peak power detector can be constructed using a differentiating op–amp and a comparator to get the instant of the maximum power. At this instant, an analog hold can latch the maximum power point voltage v_s of the PVP under the present operation conditions. For this purpose, an analog multiplier is required to compute the product of $v(t)$ and $i(t)$.

To get rid of employing an analog multiplier, the sweep waveform of the panel current can be manipulated as a predetermined function of time

$$i(t) = f(t). \tag{2}$$

The power of the panel along this sweep waveform will be

$$p(t) = v(t)i(t) = v(t)f(t). \tag{3}$$

The panel will deliver maximum power when the derivative of $p(t)$ is zero

$$\frac{d\,p(t)}{d\,t} = v(t)\frac{d\,f(t)}{d\,t} + f(t)\frac{d\,v(t)}{d\,t} = 0. \tag{4}$$

Further simplification of the equation (4) is obtained by selecting the sweep waveform directly proportional to its derivative

$$f(t) = k\frac{d\,f(t)}{d\,t} \tag{5}$$

where k is a real constant.

By selecting $f(t)$ in this manner, the maximum power point condition (4) simplifies to

$$\frac{d\,p(t)}{d\,t} = \left(k\frac{d\,v(t)}{d\,t} + v(t)\right)\frac{d\,f(t)}{d\,t} = 0. \tag{6}$$

Assuming the derivative of $f(t)$ is not zero in the range of the sweep waveform, both sides of (6) can be divided by $\frac{df}{dt} = \frac{di}{dt}$ to obtain $\frac{dp}{di}$

$$\frac{d\,p}{d\,i} = k\frac{d\,v(t)}{d\,t} + v(t). \tag{7}$$

The maximum power point condition given by (6) can be tested only using the PVP voltage v and its derivative

$$k\frac{d\,v(t)}{d\,t}+v(t)=0. \tag{8}$$

The solution of the differential equation (5) is unique and is

$$f(t)=ce^{t/k}, \tag{9}$$

where c is the arbitrary constant of the general solution. Note that in (9), if k is selected as a negative real number, the sweep waveform corresponds to an exponentially decreasing function with a time constant $\tau = -k$, and in that case c corresponds simply to the maximum PVP current I_{max} at the beginning of the sweep when $t = 0$. Selection of the constants $k < 0$ and $c = I_{max}$ simplifies the generation of the sweep waveform since it corresponds to the voltage (or current) of a capacitor discharging through a resistor. At the instant when the test condition is satisfied, the PVP voltage v_s can be hold by an analog hold circuit as the set point of the controller of the chopper for the period of the power delivery to the load and batteries.

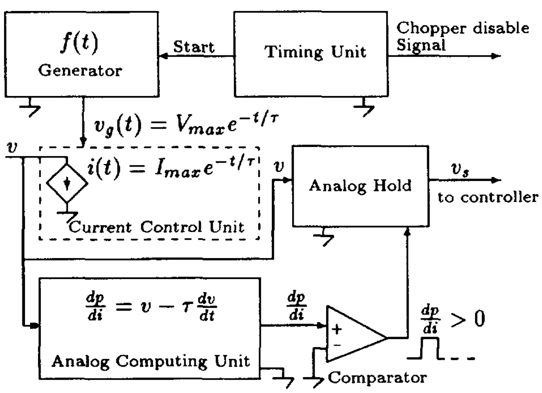


Figure 4: The block scheme of the maximum power point computing unit.

Implementation of the System

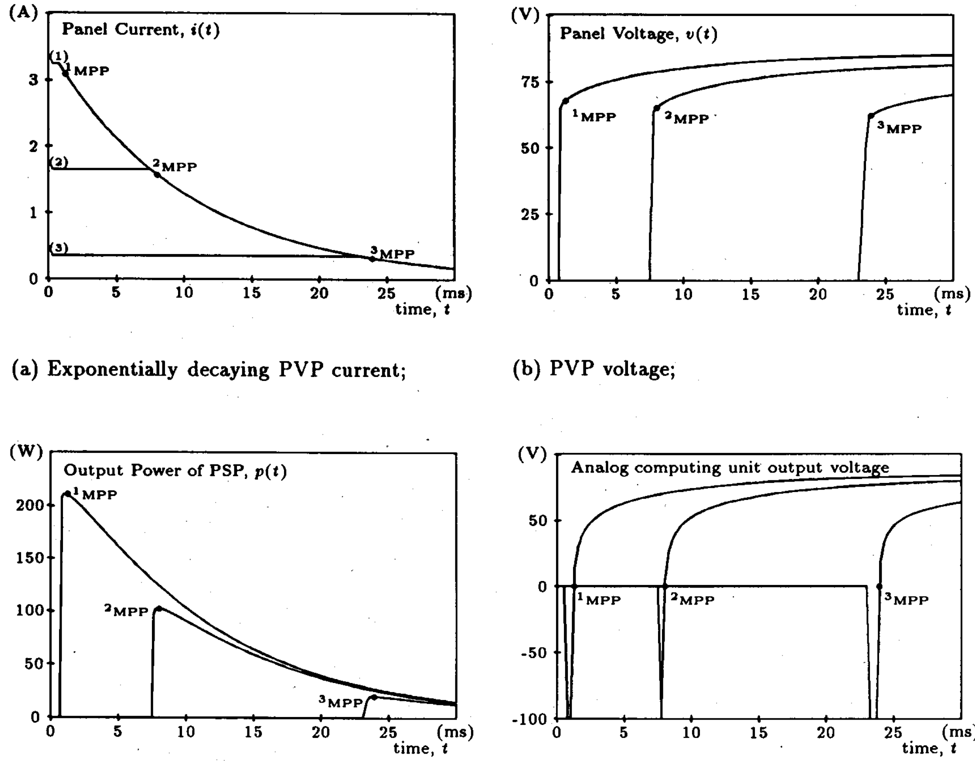
The block diagram of the overall photovoltaic solar energy system is given in Figure 3. In the application, 4 of the M55 cells are connected in series to form a PVP array of maximum ratings 80 V and 3.5 A dc. A high eficiency MOSFET chopper is used in dc-dc conversion for impedance matching of load and PVP. The proportional–integral controller manipulates the control voltage v_c of the chopper to reduce the error between the panel voltage v and the computed MPP voltage v_s. The MPP computing unit sends a disable signal to the controller when it starts an MPP computing period, so that the chopper is disabled, and $i(t)$ is swept as $f(t)$. The MPP voltage v_s is computed while the $i-v$ characteristics is obtained by this sweep. After holding v_s, MPP computing unit enables the controller, and PVP feeds the loads and batteries at the maximum power point condition.

The block diagram of the MPP computing unit is given in Figure 4. The characteristics tracing begins after receiving a start signal of the timing unit. Prior to this operation the chopper is disabled by the timer unit. The start signal initiates the discharge of the capacitor C through a resistor R from an initial voltage V_{max} resulting in an exponentially decaying voltage waveform at a time constant $\tau = RC$. The current control unit manipulates the PVP current $i(t)$ to follow the sweep waveform $i(t) = I_{max}e^{-t/\tau}$. During the sweep period, the analog computing unit computes $\frac{dp}{di}$ according to (7). The analog hold is activate during the period $\frac{dp}{di} > 0$, to hold the panel voltage $v(t)$ just measured at MPP condition. The exponentially decaying PVP current continues to flow until drooping to a prespecified level I_{min} which is taken as the lowest feasible current for the PVP system. The PVP current is measured at the end of the period, and if its value is lower than I_{min} the timer unit forces the system to a "sleep" mode, in which all units are forced into power down mode until the timer unit awakes them for a new MPP measurement for an adjustable period between 2...10 minutes. In the sleep mode, only the timer circuit remains active and draws about 50 μA from a single 5 V source.

The important waveshapes in the MPP computing unit are as given in Figure 5. The exponential decay of the current begins from the maximum PVP current corresponding to the present insolation value. The current control unit operates under the saturation condition until the exponential decay starts. In this period, the current remains constant at the maximum possible current that can be delivered at this insolation. In the saturation condition, the panel voltage $v(t)$ remains at almost zero volts. The voltage starts to increase when the current begins to decrease. The panel voltage is divided by 30 at the input of the analog computing unit by a resistive divider, so that the voltage can swing between -3 and 3 volts at the output of the unit. The voltage v_s, and the panel voltage input of the controller unit are also divided by 30. The analog hold is implemented as two cascaded stages to prevent the hysteresis effects in the capacitors in holding fast rising voltage $v(t)$. The first hold stage has a very low time constant of around 0.04 μs. The second hold stage has a sufficiently large hold capacitor which provides a drift of less than 0.1 μV/s.

Conclusion

A novel maximum power tracking method is proposed for matching the photovoltaic solar panels to the load and batteries. The proposed method is based on the determination of the derivative of the panel output power with respect to



(a) Exponentially decaying PVP current;

(b) PVP voltage;

(c) PVP output power $p(t) = i(t)v(t)$.

(d) Analog computing unit output $v(t) - \tau \frac{dv}{dt}$

Figure 5: Various waveforms for the current sweep period. The plots contain three sweeps at different insolations: (1) 1000 W/m^2; (2) 500 W/m^2; (3) 50 W/m^2. ^{n}MPP is the maximum power point for the corresponding insolation.

the panel current while the panel current is manipulated as a decaying exponential sweep function. In the presented method, analog multipliers are not required to compute the maximum power point.

The proposed method is implemented on a 250 W photovoltaic solar panel successfully. In the experimental setup, a sleep mode is also implemented to minimize the energy loss of the chopper when the panel output power becomes less than a preset power value.

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