Middle-East Journal of Scientific Research 19 (11): 1478-1485, 2014
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2014.19.11.11237

Analysis of a Low Power Solar Energy Tracking Method for Simple Photovoltaic Applications

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Abstract: This paper details the design of a low power solar energy tracking method. This method that is followed here is the most simple and cost effective of all the methods that are implemented till now. The method that is detailed here is the Fractional Open Circuit Voltage Method, that is best suited for low power, low cost and simple voltage applications. Here, the sampling of a portion of the array voltage is performed via a Sample and Hold Amplifier circuit. Thus, a reference voltage is generated, which is compared with the array voltage. Care is taken so that the sampling period is neither too long nor too short. The temporary disconnection between the array and load is achieved successfully through two high speed MOSFET switches.

Key words: Open Circuit Voltage (Voc) · Maximum Power Point Tracking(MPPT) · Reference Voltage(V_{ref}) · Photovoltaic (PV) cells · S&H amplifier · Maximum Power(P_{max}) · Sampling period

INTRODUCTION

Interest in renewable resources of energy is on the rise. This is due to the fact that non-renewable sources of energy are diminishing at a quick rate. Also the after-math created due to these non-renewable energy sources is the main cause for mankind to switch over to renewable sources.

These resources are renewable and can be naturally replenished. Therefore, for all practical purposes, these resources can be considered to be inexhaustible, unlike dwindling conventional fossil fuels. The global energy crunch has provided a renewed impetus to the growth and development of Clean and Renewable Energy sources. Clean Development Mechanisms (CDMs) [1] are being adopted by organizations all across the globe.

Apart from the rapidly decreasing reserves of fossil fuels in the world, another major factor working against fossil fuels is the pollution associated with their combustion. Contrastingly, renewable energy sources are known to be much cleaner and produce energy without the harmful effects of pollution unlike their conventional counterparts [2].

Photovoltaic (PV) systems, present the desirable features of being modular and easily deployable on rooftops, close to the consumers. Also photovoltaic offers an environmentally friendly source of electricity [1], of which the fuel is sunshine, a renewable energy. This method of power generation, however, has been relatively costly compared to other methods. The success of a PV application depends on whether the power electronics device can extract sufficiently high power from the PV arrays to keep overall output power per unit cost low.

The maximum power point tracking (MPPT) [3] of the PV output for all sunshine conditions, therefore, becomes a key control in the device operation for successful PV applications.

The MPPT control [3] is challenging, because the solar irradiance and temperature that determines the amount of solar energy into the PV array may change all the time and the current voltage characteristic of PV arrays is highly nonlinear. The optimal operation of a PV system is important. A real time MPPT technique is required to obtain maximum power from a PV system.

Tracking Methods: The effective methods of harnessing solar energy are very important as the source of energy is not continuous. The various methods 2 methods are considered most important. They are:

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- Fractional Open Circuit Voltage Method.
- Short Circuit Method.

The first method is employed in the project, which is tracking the maximum power point (MPP) [4] and making the solar array to operate at the MPP constantly MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules [2] are able to deliver maximum available power.

The components for the systems includes

- PV Array
- Sample & Hold Amplifier (for MPP Tracking)
- MOSFET switches
- Load (e.g. a compact fluorescent lamp – CFL)

PV Array Modelling: A PV array consists of several photovoltaic cells in series and parallel connections. Series connections are responsible for increasing the voltage of the module whereas the parallel connection is responsible for increasing the current in the array. Typically a solar cell can be modelled by a current source and an inverted diode connected in parallel to it. It has its own series and parallel resistance that can be computed using simple techniques.

Series resistance is due to hindrance in the path of flow of electrons from n to p junction and parallel resistance is due to the leakage current.

In this model [5] we consider a current source (I) along with a diode and series resistance (Rs). The shunt resistance (R_{SH}) in parallel is very high, has a negligible effect and can be neglected. The output current from the photovoltaic array is:

$I = I_{SC} - I_d$

$I_d = I_o(e^{qvd/KT} - 1)$

where, Io is the reverse saturation current of the diode, q is the electron charge, Vd is the voltage across the diode, k is Boltzmann constant (1.38 * 10-19 J/K) and T is the junction temperature in Kelvin (K)

$I = I_{SC} - I_o(e^{qvd/KT} - 1)$

Using suitable approximations,

$I = I_{SC} - I_o(e^{q((V+IRs)/nKT} - 1)$

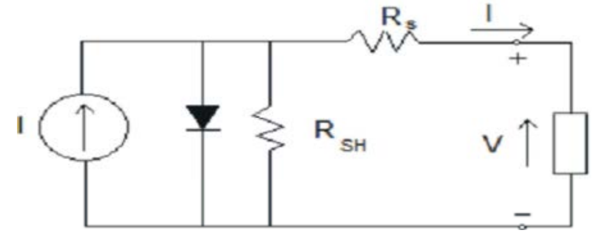


Fig. 1: Single diode model of a PV cell

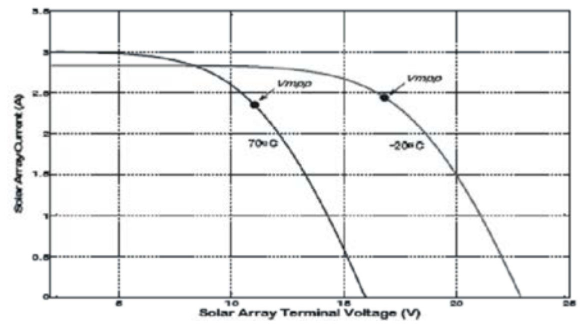


Fig. 2: I-V Characteristics of a solar panel

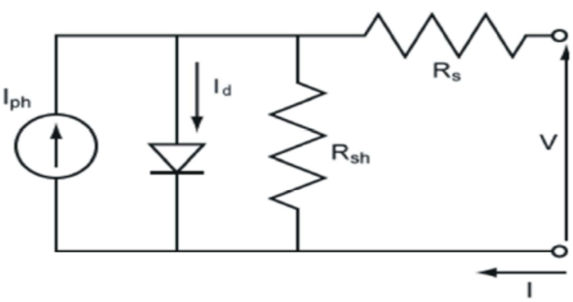


Fig. 3: Solar cell – Equivalent Circuit

where, I is the photovoltaic cell current, V is the PV cell voltage, T is the temperature (in Kelvin) and n is the diode ideality factor. In order to model the solar panel accurately we can use two diode model [3] but in our project our scope of study is limited to the single diode model. Also, the shunt resistance is very high and can be neglected during the course of our study.

Fractional Open Circuit Voltage: The near linear relationship between VMPP and V_{OC} [3] of the PV array, under varying irradiance and temperature levels, has given rise to the fractional VOC method.

$V_{MPP} = K_1 Voc$

where k_1 is a constant of proportionality [3]. Since k_1 is dependent on the characteristics of the PV array being used, it usually has to be computed before hand by empirically determining V_{MPP} and V_{OC} for the specific PV array at different irradiance and temperature levels. The factor k_1 has been reported to be between 0.71 and 0.78 [2].

Once k_1 is known, V_{MPP} can be computed with Voc measured periodically by momentarily shutting down the power converter. However, this incurs some disadvantages, including temporary loss of power. To prevent this, uses pilot cells [3] from which V_{OC} can be obtained. These pilot cells must be carefully chosen to closely represent the characteristics of the PV array.

The voltage generated by pn-junction diodes is approximately 75% of V_{OC}[*6*]. This eliminates the need for measuring V_{OC} and computing V_{MPP}. Once V_{MPP} has been approximated, a closed loop control on the array power converter can be used to asymptotically reach this desired voltage. This only an approximation, the PV array technically never operates at the MPP. Depending on the application of the PV system, this can sometimes be adequate.

Even if fractional V_{OC} is not a true MPPT technique [5], it is very easy and cheap to implement as it does not necessarily require DSP or microcontroller control [4]. However, it points out that k_1 is no more valid in the presence of partial shading (which causes multiple local maxima) of the PV array and proposes sweeping the PV array voltage to update *k*. This obviously adds to the implementation complexity and incurs more power loss.

Maximum Voltage Tracker: The voltage based MPPT technique is based on the fact that the PV array voltage corresponding to the maximum power exhibits a linear dependence with respect to the array open circuit voltage for different irradiation and temperature levels [4], i.e.,

$$V_{mpp} = M_{v.} V_{oc}$$

where,
Vmpp is the maximum power point voltage,
Voc is the open circuit voltage of the PV array
Mv is the voltage factor.

The voltage factor has the value between 0.7-0.8 [6] depending upon the PV array characteristics.

To operate the PV panel at the MPP, the actual PV array voltage Vpv is compared with the reference voltage V_{ref} which corresponds to the Vmpp. The error signal is then processed to make Vpv = V_{ref} . Normally, the panel is disconnected from the load momentarily to sample it's open circuit voltage.

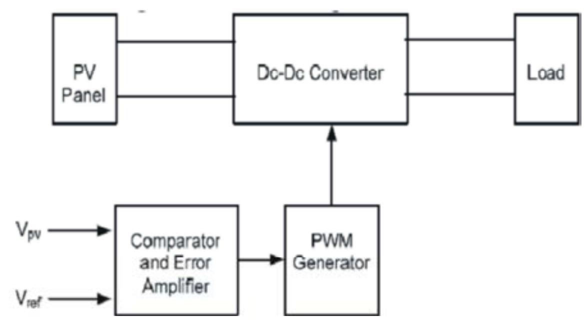


Fig. 4: Block Diagram of Voltage based MPPT

The fraction of the open circuit voltage corresponding to the Vmpp is measured and is kept in a hold circuit [7] to function as V_{ref} for the control loop. Even though the voltage based MPPT method is classified as quasi seek method, but research has shown that this method has efficiency comparable to the P&O and IC [3] method under normal illumination conditions. This method is also considered to be the simplest and cost effective. Low-power systems for tracking the peak power point are presented. They exploit microcontroller and analog circuits to track MPP during light variations. The size of the adopted PV modules is greater than 20cm square, which is enough to provide tens of milli-watts and to perform an efficient power collection. In particular, supports different power sources and tries to eliminate the overhead in cost and power consumption caused by a microprocessor-based algorithm for MPPT.

The harvesting unit is independent from the target system and it requires the presence of a rechargeable battery as secondary buffer to work when the primary buffer is empty. The adopted technique to estimate the position of the MPP relies on a light sensor (e.g., photodiode) and they associate this information to the solar-cell characteristic.

Hardware Description: The basic circuit diagram for FVoc method [4] is indicated below. It consists of 2 major portions. They are listed below:

- Main harvester circuit with PV panel.
- Triggering circuit [4] with one astable multivibrator and 2 monostable multivibrator.

The above figures show the circuit diagram of the proposed MPPT. S0 is the static switch used for disconnecting the PV array from the load for the sampling of the array voltage. D0 is the reverse blocking diode and S1 is the main switching.

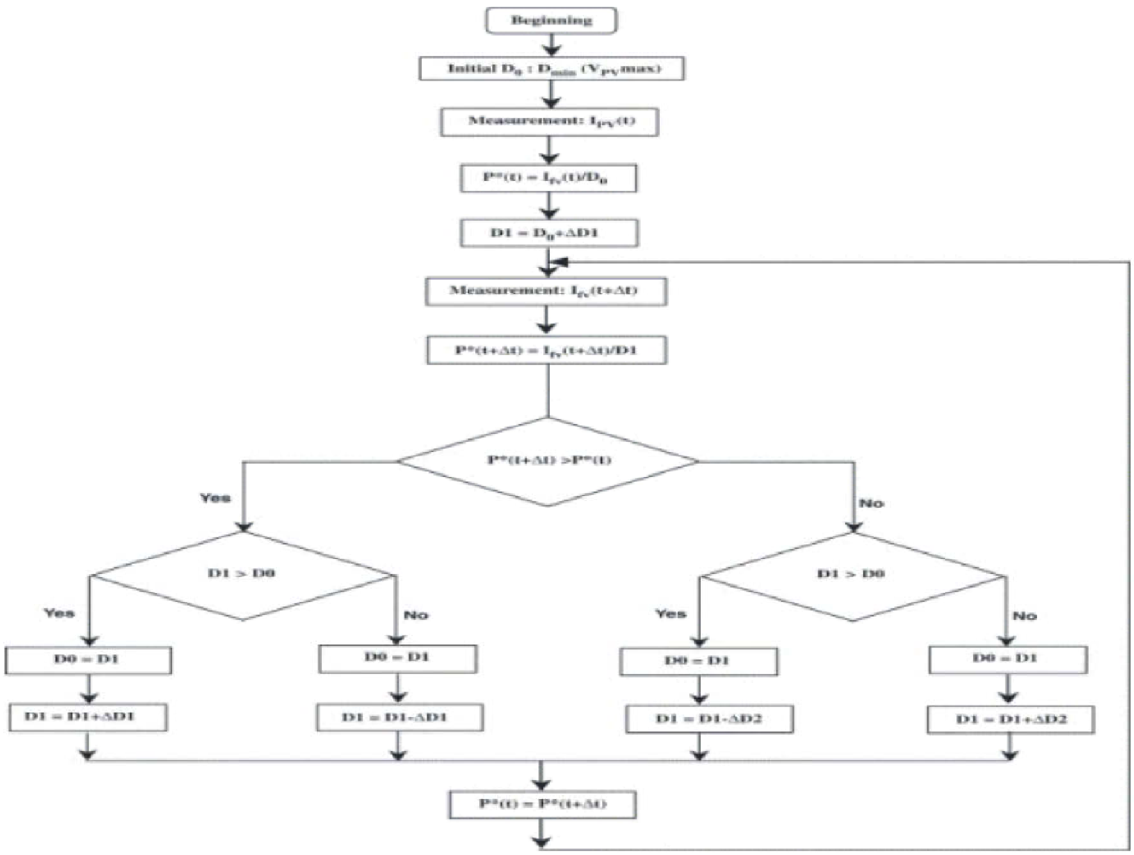


Fig. 5: Procedure Flowchart

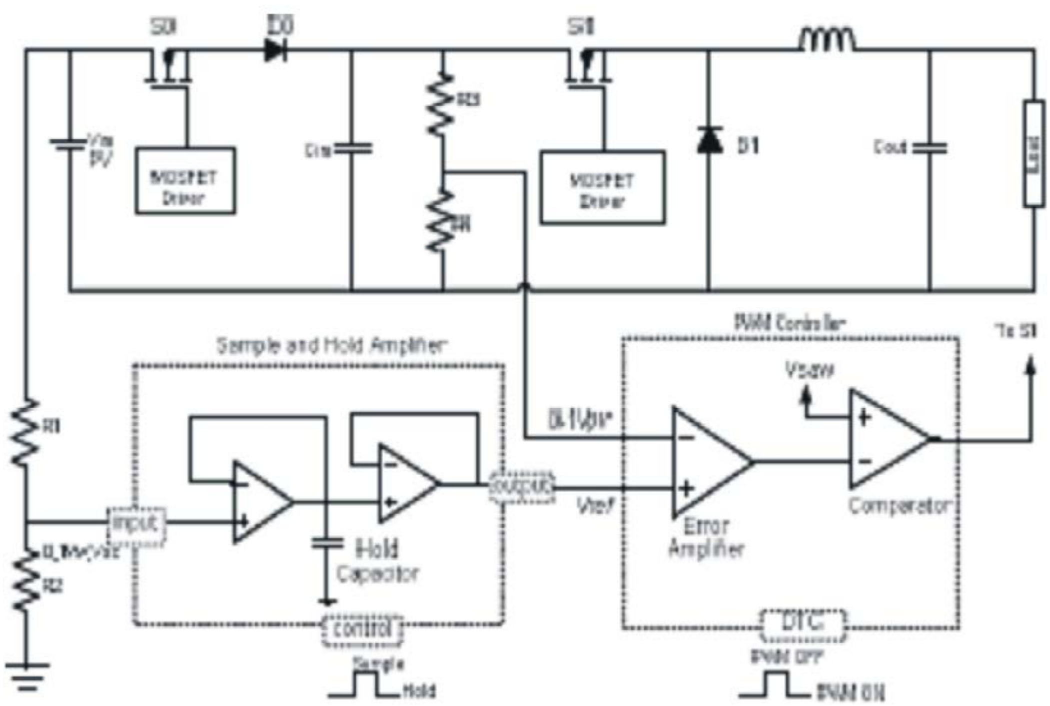


Fig. 6: Circuit diagram without controller

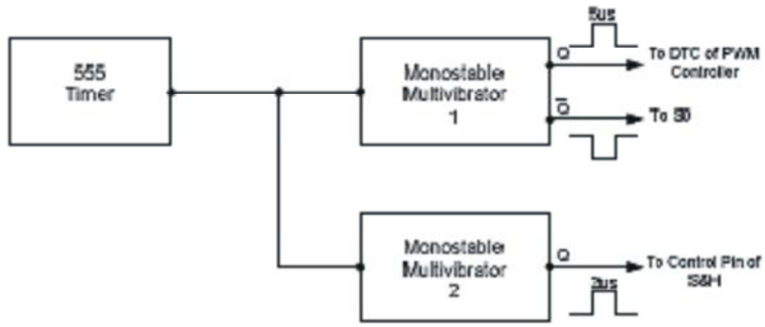


Fig. 7: Block diagram of the circuit controlling the sampling interval and the sampling period

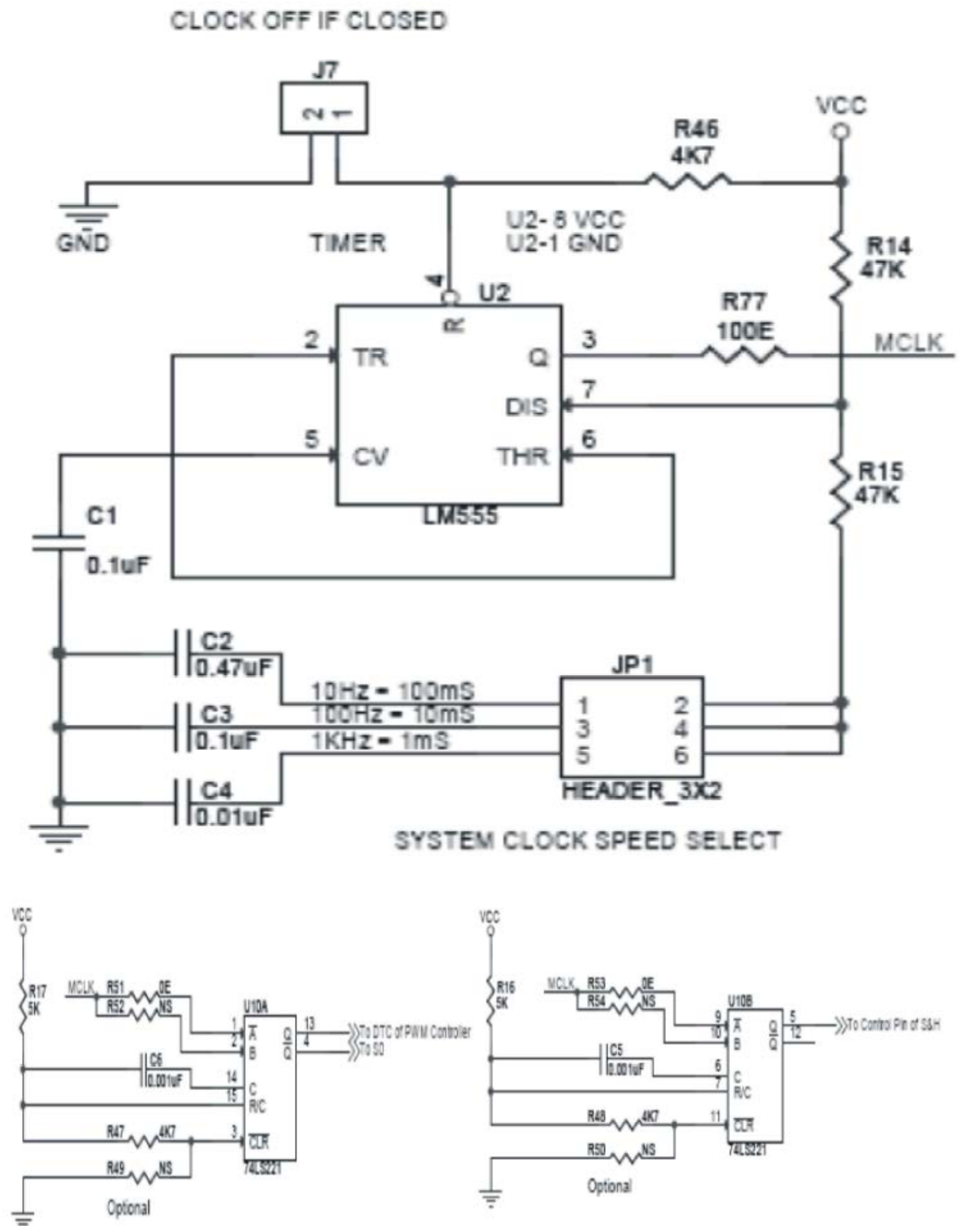


Fig. 8: Circuit diagram of trigger circuit

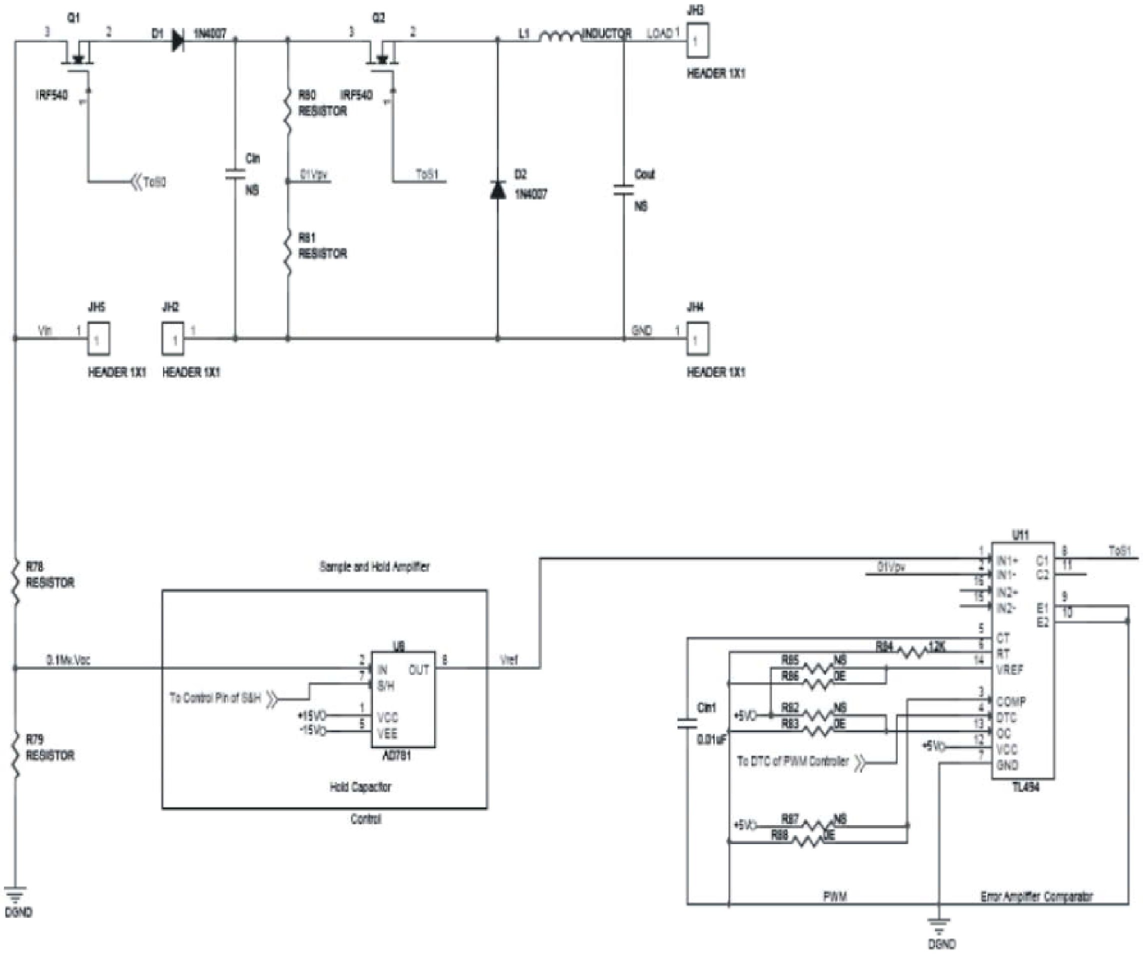


Fig. 9: Sample & Hold Amplifier in Harvester Platform

MOSFET. In the proposed MPPT the S&H [7] has a fast acquisition time.

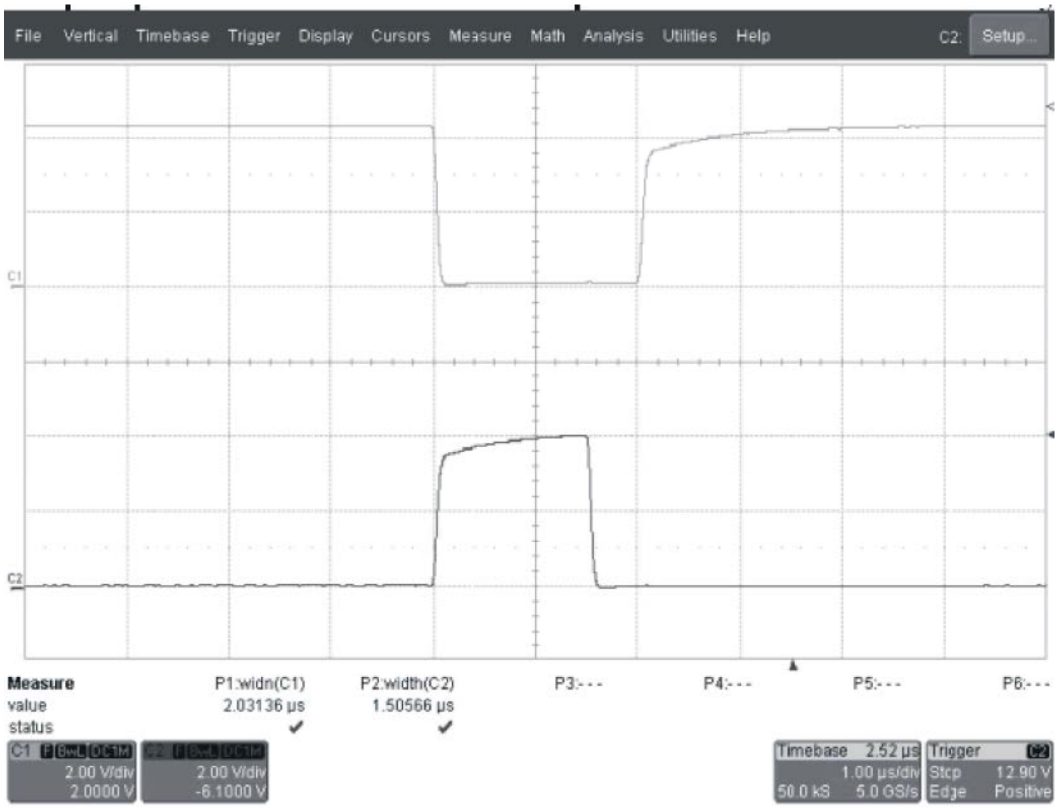
The reason for choosing the S&H with fast acquisition time is to reduce the sampling time and, consequently, the power annulment period. The S&H also has a low droop rate to avoid the deviation of the PV operating point from the MPP during the sampling period, as discussed in the previous section. The sampling period is chosen to be 100ms. The combination of short sampling period and low droop rate of the S&H obviates the need for using extended hold time S&H thereby decreasing the number of components in the proposed MPPT.

Circuit Operation: In the proposed MPPT, the PV array is disconnected from the load for sampling of its open circuit voltage. During the sampling interval the S&H is triggered into the sampling mode [7]. The array voltage is sampled by the S&H and a fraction thereof is kept in the hold capacitor to act as V_{ref} for the converter to latch on to. The sampling time and the sampling period is controlled by a 555 timer and a dual monostable multivibrator (MMV) [8]. This is shown schematically in Fig. 7.

Both the MMVs are negative edge triggered. The timer produces a falling edge after every 100ms which is the duration of the sampling period. The output pulse width at the true output of the MMV1 is 5us.

As shown in Figure 7, the true output of the MMV1connected to the dead time control (DTC) of the pulse width modulation (PWM) controller [9], to turn off its output during the sampling interval. The complementary output of MMV1, which is connected to the driving circuit of S0, turns it off and the PV array is disconnected from the load for 5us.

The MMV2 is triggered into the timing state synchronously with MMV1. The output of the MMV2 triggers the S&H into the sampling mode [7]. To ensure that the PV array voltage is sampled well before the array



Scope Outputs

Fig. 10: Output waveforms of MMV1 & MMV2

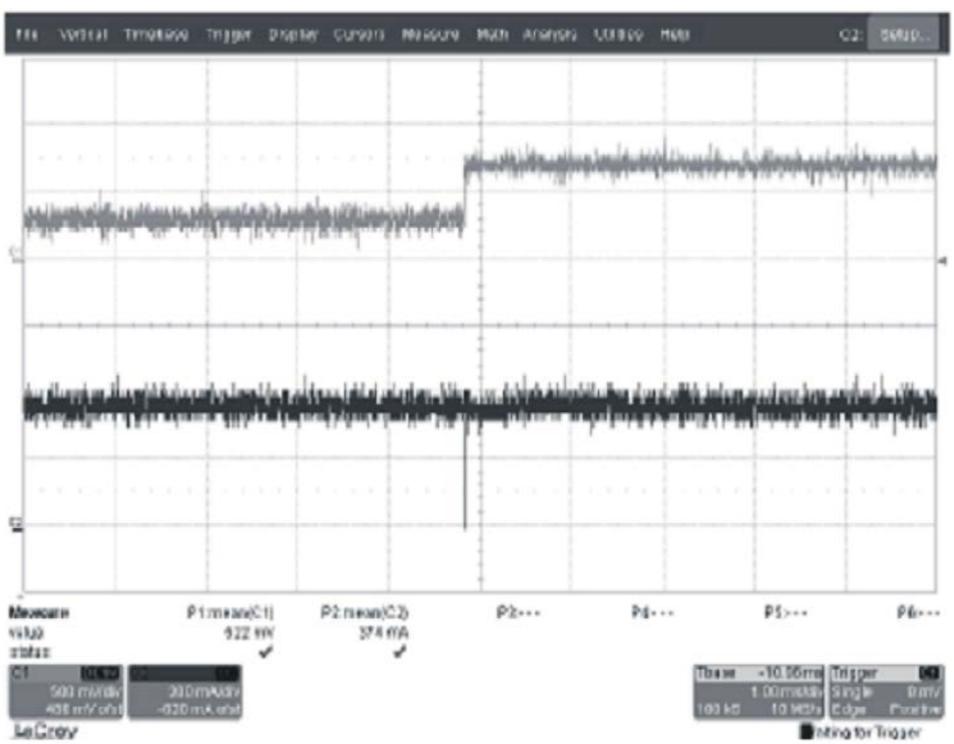


Fig. 11: Acquisition of New Vref

is reconnected to the load and to make allowance for the hold mode [7] settling time of the S&H, the width of the output pulse of the MMV2 is kept shorter than MMV1.

End Results: The proposed circuit was implemented successfully and indoor testing was also performed. A variable DC voltage source was used in series with a variable resistor. Therefore it is evident that the MPPT should always track the input voltage to the converter, such that the input voltage at least receives half of the supply voltage. The voltage factor was accordingly designed to be at 0.5 and switching frequency at 100 kHz. It is to be noted that the MOSFET is switched of f during sampling of the array voltage to produce Vref. After obtaining the corresponding pwm output via the S&H circuit, it is fed to S1, which transfers the PV array voltage to the connected load.

CONCLUSION

From the above analysis it is evident that the fractional open circuit voltage method is the most simple of all the MPPT techniques. It is best suited for small scale voltage applications. The primary reason for employing this method is that the circuit does not utilize microcontroller or a digital signal processor and is thus suitable for low cost and low power photovoltaic applications.

The circuit performs a high-efficiency conversion through an ultra-low-power circuit that requires less than 1 Mw. The estimation of the peak power point is done automatically, using a small PV module as reference, whereby sensing operation does not require additional power. The scavenger can be used with any kind of embedded system.

Hence, for low-power, low cost applications this method is the most suited one. In addition, design and implementation of the circuit is also relatively simple. Thereby, it is evident that energy from the sun can be acquired very easily.

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