

SPICE Modeling and Simulation of a MPPT Algorithm

Miona Andrejević Stošović, Marko Dimitrijević, Duško Lukač, and Vančo Litovski

Abstract— One among several equally important subsystems of a standalone photovoltaic (PV) system is the circuit for maximum power point tracking (MPPT). There are several algorithms that may be used for this purpose. In these proceedings we will choose one among them based on the maximum simplicity criteria. Then we will make some small modification to it in order to make it more robust. Then, we will synthesize a circuit built out of elements belonging to the list of elements recognized by SPICE. The inputs will be the voltage and the current at the PV panel to DC-DC converter interface. Its task will be to generate a pulse width modulated pulse train whose duty ratio is defined so that to keep the input impedance of the DC-DC converter at optimal value.

Index Terms—Modeling; Simulation; MPPT algorithm.

I. INTRODUCTION

A typical standalone PV system is depicted in Fig. 1. As it can be seen from the figure it contains the following main subsystems: the PV panel, the line capacitor C_L , the DC to DC converter, the MPPT subsystem, the Battery, and the Load which is here represented as a resistor R_L .

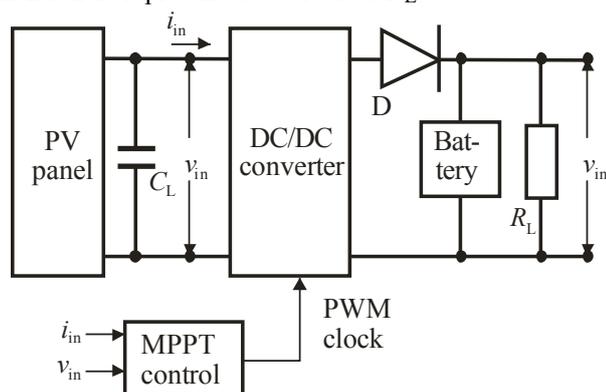


Fig. 1. System level schematic of a standalone PV system

Every single part of the system may be realized in variants. For example there are several circuit architectures for the DC to DC converter; there are different technologies implemented

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for production of the batteries and, most frequently, the load is a specific electronic system, e.g. metrological measurement station, working remotely.

To design the complete system one has to have circuit models of all subsystems and that is not the case. Namely, to our knowledge there are no published circuit simulations of the whole system. The published simulations are most frequently behavioural using Matlab-Simulink [1,2] which is successful when looking at the system level but makes it difficult to implement models of real components due to lack of proper libraries.

Circuit simulation with SPICE [3] and SPICE-like software enables easier data transfer to a PCB layout design tool so making the design process continuous, reducing the format translation activities, and minimizing the risk of error during manipulation of data.

To our knowledge most of the parts of the PV system depicted in Fig. 1. are already modeled and simulated in SPICE e.g. [4,5,6]. There is no, however, published results reporting SPICE modeling and simulation of the MPPT circuit. By creation of such a model, we expect, one will be capable to simulate and design the whole standalone system, hence the importance of our work.

The paper is organized as follows. First we will describe the basic properties of the PV panel from the sensitivity to illumination and temperature point of view in order to establish the feeling about the reason why the maximum power point is migrating during the operation of the PV system. Then, we will describe the most frequently used algorithm for MPPT named Perturb and Observe (P&O) as described in [7,8,9]. A minor improvement of the way how the algorithm is expressed will be introduced leading to a Modified Perturb and Observe (MP&O) algorithm. Finally, the SPICE model of the MPPT and simulation results verifying the model reported will be introduced.

II. THE MPPT ALGORITHM

Fig. 2. depicts the dependence of the photovoltaic power produced by a PV panel on the voltage on it with the illumination as a parameter [7]. As it may be seen the MPP migrates slightly due to the change of the output resistance of the panel [10].

As a counterpart to this dependence the migration of the MPP with changes of the temperature is depicted in Fig. 3. [7]. Due to these reasons every PV system is equipped with a specific circuitry which controls the duty cycle of the pulse train controlling the switches within the converter (inverter).

These changes lead to changes of the input resistance of the converter and if the control is properly tailored the PV panel will be kept in a position to deliver maximum power to the converter.

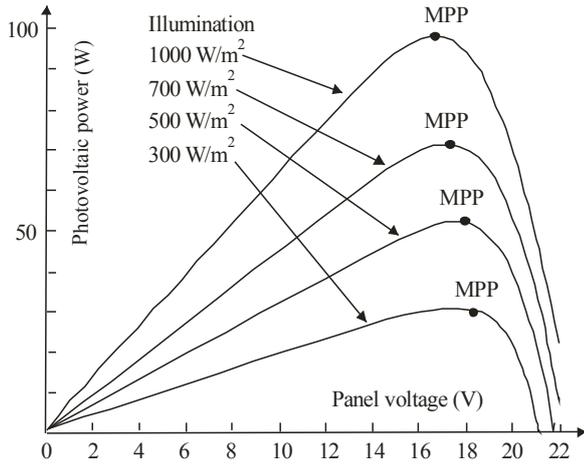


Fig. 2. Photovoltaic power versus panel voltage for different illumination intensities

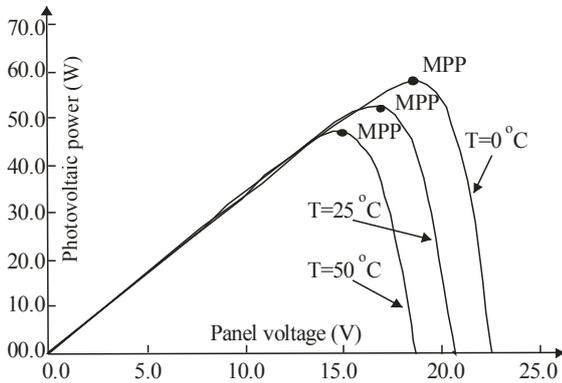


Fig. 3. Photovoltaic power versus cell voltage for different temperatures

As already mentioned in the introduction there are several techniques and algorithms enabling implementation of the idea of tracking the MPP. Among them the most popular is the so called Perturb and Observe (P&O) which is depicted in Fig. 4. [8,9]. One may see from the figure that as a result a fixed increment (positive or negative) of the PV panel voltage is produced after each sampling period (of the voltage and the power of the PV panel). In real circuit this increment is used as information to a pulse width modulated (PWM) oscillator to control its duty ratio.

There are four branches in this algorithm that lead to two signs of the increment. If $(P_k - P_{k-1} > 0$ and $V_k - V_{k-1} > 0$) and if $(P_k - P_{k-1} < 0$ and $V_k - V_{k-1} < 0$) the increment is positive. The value of the increment is negative if $(P_k - P_{k-1} < 0$ and $V_k - V_{k-1} > 0$) and if $(P_k - P_{k-1} > 0$ and $V_k - V_{k-1} < 0$). By careful inspection one may conclude that the sign of the increment is associated to the sign of $Q_k = (P_k - P_{k-1})(V_k - V_{k-1})$. If $Q_k > 0$ the increment is positive and if $Q_k < 0$ the increment is negative. This way of expression simplifies the whole diagram and probably the electronic circuitry implementing the algorithm.

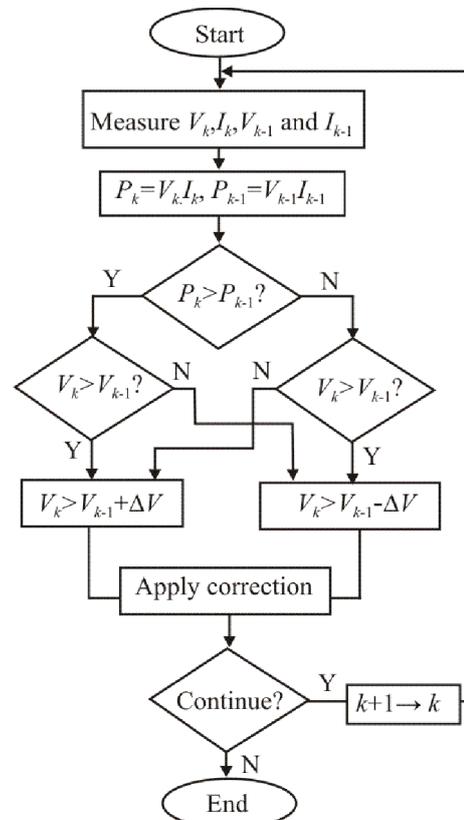


Fig. 4. The perturb and observe algorithm

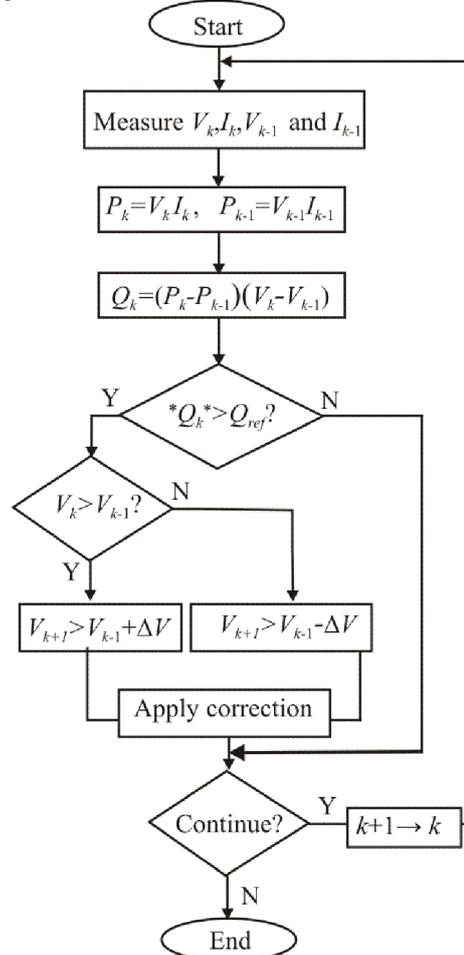


Fig. 5. The modified perturb and observe algorithm

Note that the algorithm is generating an increment no matter how large the differences ($P_k - P_{k-1}$) and ($V_k - V_{k-1}$) are which, generally speaking, for small differences, may lead to a change in the duty cycle being much larger than necessary which may even become counterproductive i.e. to lead the quiescent point out of MPP region by "overshooting" it.

Having all that in mind we propose a modification of the algorithm as depicted in Fig. 5. In this algorithm, after calculation of Q_k one first makes a comparison with a threshold value Q_{ref} . If $|Q_k|$ is not larger than Q_{ref} there is no need for perturbation i.e. for change of the duty cycle. If it is larger, only the sign of Q_k is used to create the sign of the voltage increment.

Note that implementation of this idea may lead to an additional benefit. Namely, by proper choice of Q_{ref} and ΔV , larger increments (ΔV) may be implemented since overshooting is disabled. In other words one may expect faster recovery of the MPPT.

III. SPICE MODEL OF THE MPPT ALGORITHM AND SIMULATION RESULTS

The SPICE implementation of the algorithm in Fig. 5. is depicted in Fig. 6. In the next we will shortly describe its parts.

First, since the measured output voltage (v) and current (i) of the PV panel contain constant, slowly time varying (due to change of temperature, illumination and the load) and very fast varying (due to the commutation within the converter) component, we implement a filtering function to eliminate the high frequency component. That is done by a L-R low-pass filter as shown at the top left part of the figure.

Next, we sample both the voltage and the power. That is done by a sample and hold circuit that starts at T_{s1s} and ends at T_{s1d} . The sampling circuits is depicted in the top part of the figure (associated with S_1) while the timing diagram is given at the bottom. After this operation the capacitors in these two circuits are memorising the sampled values of p_1 and v_1 .

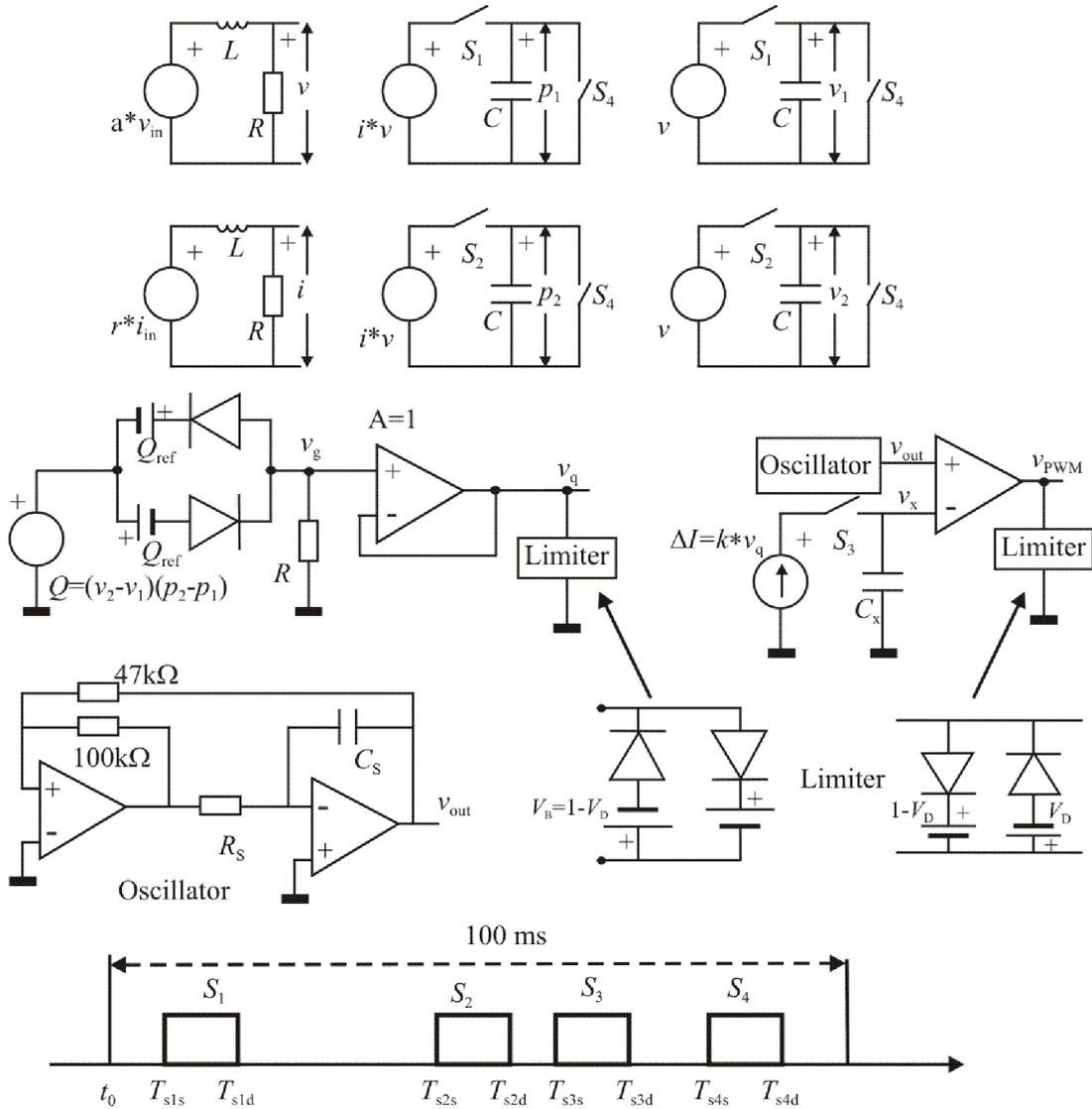


Fig. 6. The SPICE schematic modelling the MPPT control circuit

The next sampling takes place after a relatively long period which is adjustable based on how fast changes of temperature and illuminations are expected. Here the sampling instant (associated with S_2) is denoted by T_{s2s} . So after T_{s2d} we have two new samples: p_2 and v_2 .

Having these four quantities we compute $Q=(p_2-p_1)(v_2-v_1)$ which is represented in Fig. 6. as a controlled voltage source. That signal is contrasted to Q_{ref} and the result is brought to a limiter so that v_q takes (approximately) values 0, 1V and -1V, only.

The resulting v_q is used to create the voltage increment at C_x . It is $\Delta v_x=k \cdot v_q \cdot \Delta t / C_x$, where $\Delta t=T_{s3d}-T_{s3s}$. This increment is brought to one of the inputs of a comparator. The second input of the comparator is excited by the output (voltage) signal of an oscillator that produces symmetrical alternatively linearly rising and linearly falling signal. The oscillation period is equal to the switching period of the converter so that at the output of the limiter connected to the comparator's output one gets pulse width modulated signal.

After completion of the sampling at S_3 , using S_4 the sampled values of v_1 , v_2 , p_1 , and p_2 , are erased and new measurement and control cycle is enabled. Here, to shorten the computer elapsed time, a measurement/control period of 100 ms was used. In real world that interval is supposed to be larger.

The following set of parameter values was used to enable the simulation of the circuit of Fig. 6: $a=1$, $r=1\Omega$, $C=1\mu\text{F}$, $L=1\text{H}$, $R=1\text{k}\Omega$, $Q_{ref}=0.5\text{V}$, $R_s=10\text{k}\Omega$, $C_s=0.9\text{nF}$, $k=10^{-3}$, $C_x=14.3\text{mF}$, $T_{s1s}=5\text{ms}$, $T_{s1d}=10\text{ms}$, $T_{s2s}=70\text{ms}$, $T_{s2d}=75\text{ms}$, $T_{s3s}=85\text{ms}$, $T_{s3d}=90\text{ms}$, $T_{s4s}=95\text{ms}$, $T_{s4d}=100\text{ms}$.

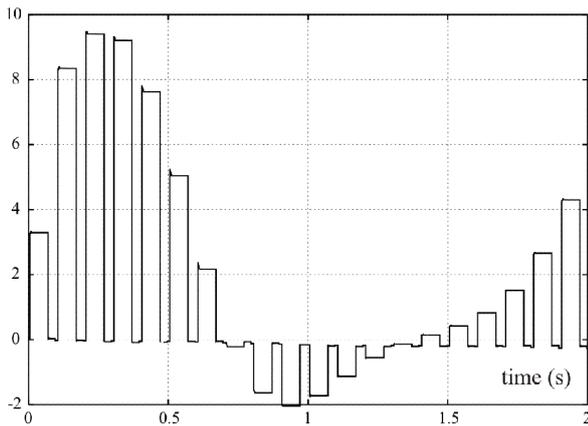


Fig. 7. The product $Q=(p_2-p_1)(v_1-v_2)$

To illustrate the implementation of the algorithm an example will be shown. Instead of getting the signals directly from the PV panel, for verification purposes, we created two signals as follows:

$$v(t)=2+\sin(2\pi \cdot 50000 \cdot t)+\sin(2\pi \cdot 0.5 \cdot t) \text{ [V]} \quad (1a)$$

$$i(t)=0.6+\sin(2\pi \cdot 50000 \cdot t)+\sin(2\pi \cdot 0.5 \cdot t+\pi/2) \text{ [A]}. \quad (1b)$$

These were used as excitation for the circuit of Fig. 6. Fig. 7. depicts the signal Q of Fig. 6. Finally, Fig. 8 illustrates the dependence of the duty cycle at the output of the circuit of Fig. 6. It is clear that it follows the shape of Q .

It also implements the new version of the MPPT algorithm promoted in Fig. 5.

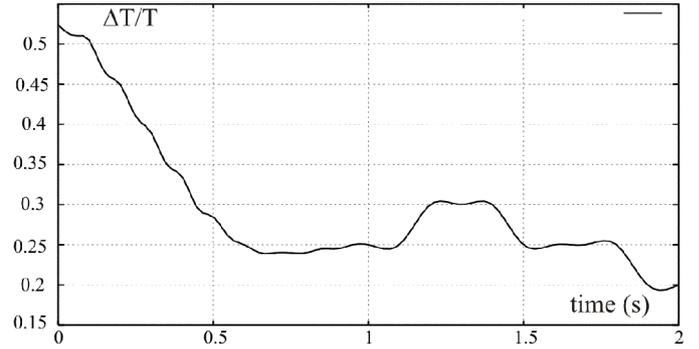


Fig. 8. Dependence of the duty cycle at the output of the circuit of Fig. 6

IV. CONCLUSION

An attempt was demonstrated to improve the MPPT algorithm and to simulate it by an electronic circuit in SPICE.

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