Power Conditioning for Solar Panels

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ABSTRACT

In this work, simplified electrical models for solar panels are discussed and SPICE and SCILAB numerical simulations are proposed for a simple power conditioning system based on the perturbation and observation method, implementing a Maximum Power Point Tracker (MPPT) algorithm.

Keywords

Solar Cell, Solar Panel, Perturbation and Observation Method, Maximum Power Point Tracker (MPPT) Algorithm, SPICE, SCILAB.

1. INTRODUCTION

Currently, there is an increasingly large demand for alternative renewable energy sources that are environmentally friendly and may allow, in the future, cheap and reliable energy production in a sustainable manner. Some of the most promising proposals employ the direct conversion of sun light into electricity, through photovoltaic solar panels. However, in this process of converting solar photons into electrical energy, there are cost and efficiency issues that need to be tackled [1][2]. In order to extract as much energy as possible from solar panels, intelligent automatic controls must be employed to ensure that optimum operating conditions are maintained at all times. Some control strategies include Maximum Power Point Tracking (MMPT) algorithms. The power delivered by the solar panel is calculated as the product current x voltage observed at the panel's output terminals. To obtain maximum power extraction, for a given solar radiation condition, optimum current and voltage values must be set. In order to define that pair of optimum values, one must connect a specific electrical load to the solar panel. However, it must be assumed that for many applications the electrical load cannot be constant, as energy needs varies in time for specific users. In this context arises the obvious importance of having an intermediate process of power conditioning, so as to guarantee operation at a point of maximum efficiency for solar panels. Therefore, this work presents simulation results for a power conditioning system, obtained from SPICE [3] and SCILAB models. SCILAB software is free, and reproduces most functions and resources found in MATLAB. SCILAB has been developed since 1990 by researchers from INRIA and ENPC in France, and is maintained by The SCILAB Consortium since 2003 (www.scilab.org).

2. SOLAR PANEL ELECTRICAL MODEL

Usually, a classical solar cell consists of a sandwich of doped n-type and p-type semiconductor materials forming a PN junction, like a diode device. They capture light from the sun and transform it into electrical energy in a process called the photovoltaic effect. Solar Panels are constructed from the association of many solar cells, in series and in parallel. A very common electrical model circuit diagram for a Solar panel is presented, considering a uniform array of solar cells, associated in series and in parallel.
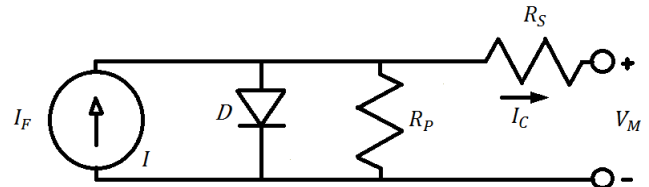

Figure 1. Electrical Model Diagram for a Solar Panel.

The equation that represents the behavior of the proposed solar panel [4] is as follows:

$$I_C = I_F - N_P I_0 \left[\exp \left(\frac{q \left(V_M + R_s \left(\frac{N_s}{N_p} \right) I_c \right)}{N_s n k T} \right) - 1 \right] - \frac{V_M + R_s \left(\frac{N_s}{N_p} \right) I_c}{R_P \left(\frac{N_s}{N_p} \right)} \quad (1)$$

With:

$I_C = Current\ at\ the\ terminals\ of\ the\ photovoltaic\ panel$

$V_M = $ Voltage at the terminals of the photovoltaic panel

$I_F = Short-circuit\ photovoltaic\ panel\ current$

$N_p = Number\ of\ cells\ in\ parallel$

$N_s = Number\ of\ cells\ in\ series$

$I_0 = Saturation\ current\ of\ the\ diode\ (\sim 1x10^{-12}\ A)$

$R_s = Series\ resistance\ of\ the\ panel$

$R_P = Resistance\ in\ parallel\ panel$

$q = Elementary\ charge\ of\ the\ electron\ (\ 1.602x10^{-19} C\ )$

$k = Boltzmann\ constant\ (\ 1.381x10^{-23}\ J/K\ )$

$T = Temperature\ (\ K\ )$

$n = Constant\ of\ diode\ ideality\ (\sim 1)$

However, for the purpose of capturing only the essential behavior of solar panels, in the simulations of the power conditioning system proposed, the R_s and R_p resistances may be ignored. Therefore, the simplified model adopted is presented in Figure 2. The corresponding mathematical expression for the panel's output voltage and current is presented in Equation 2.

$$I_c = I_F - N_p I_0 \left[\exp\left(\frac{q V_M}{N_s n k T} \right) - 1 \right] \quad (2)$$
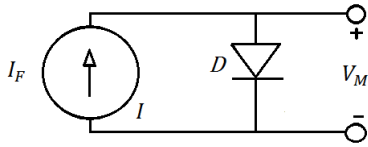

Figure 2. Simplified Electric Diagram for a Solar Panel.

In the SPICE simulations, the electrical characteristics of a commercial solar panel were used. The panel considered is Kyocera's KC50T [5], which has a total of 36 solar cells, with parameters shown on Table 1, below.

Table 1. Parameters of Kyocera's KC50T Solar Panel

Parameter	Value
Maximum Power (P_{max})	54 W
Maximum Power Voltage(V_{mpv})	17.4 V
Maximum Power Current (I_{mpc})	3.11 A
Open Circuit Voltage (V_{oc})	21.7 V
Short Circuit Current (I_{sc})	3.31 A
Conversion Efficiency	16 %
Area	0.42 m²

Below (Figure 3), the simulations' graphical results are presented, showing the nonlinear IxV curves obtained for the commercial solar panel, with constant temperature (300 K), under to different levels of solar irradiation, ranging from 200 to 1000 watts/m².
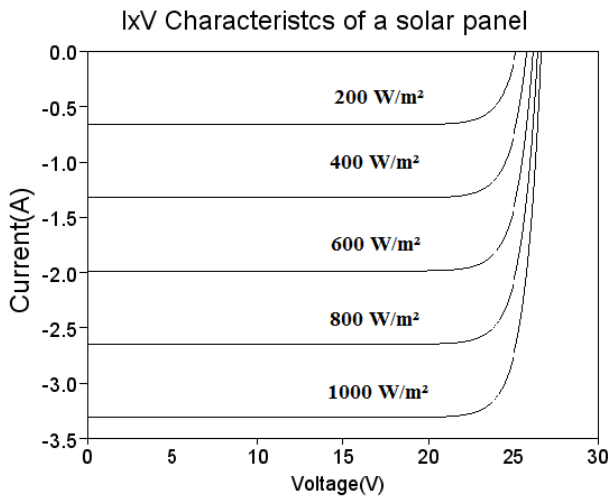

Figure 3. IxV Curve Characteristics for the Solar Panel.

3. MPPT ALGORITHM

A solar panel is not a constant source of electrical power, since the captured solar radiation, which may be converted by the photovoltaic effect, varies with weather conditions such as cloud cover and rain, and is available only during the day, in a 24 hours period. Therefore, in a given period of time, the electrical power that may be supplied by the panel varies both in a deterministic as well as in a stochastic way. Therefore, the power conditioning system must adjust the load seen by the solar panel so that it always operates at optimum points (voltage and current) with a maximum power generated. There are several ways to program the MPPT algorithm, among them, the most common and easy to implement is the method of perturbation and observation. For these reasons, this method was chosen for the present work. Its operation is quite simple: The instantaneous output voltage and current values are sampled at time **t** and the instantaneous electrical power is calculate. Then the loading conditions are changed (perturbed), by a different duty-cycle in the Pulse-width Modulation (PWM), defining a characteristic power curve as shown in Figure 4, which was obtained from a switching control circuit SPICE simulation, shown in Figure 5. Suppose the equilibrium average voltage in the capacitor is reduced, because the switch is now in the on-state longer than in the previous condition. Later, at a time **t+Δt**, the sampling and calculation process is repeated, and the resulting values compared with the previous result. The decision process is as follows. If the instantaneous power observed at time **t+Δt** is greater than at time **t**, a better condition of operation was found, and the next perturbation should proceed in the same direction. If the opposite occurs, the strategy must be reversed, and the next move should be an increase in the capacitor voltage, keeping the switch in the off-state a little longer. Eventually, the algorithm will converge to the optimum point of operation, with maximum power generation.
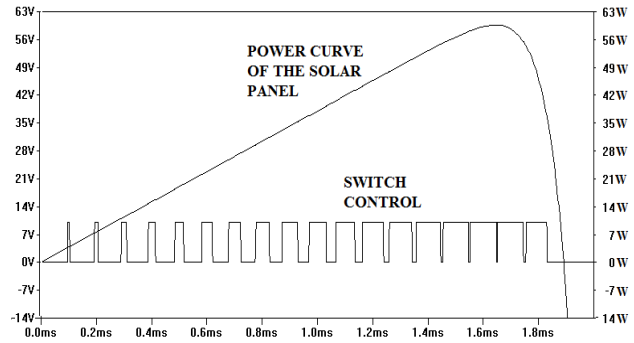

Figure 4. Solar Panel Power Curve Simulation.

4. POWER CONDITIONING SYSTEM

The simplest power conditioning case is considered below with a constant resistive load and a capacitor voltage controlled by a single ideal switch with a PWM switching scheme.
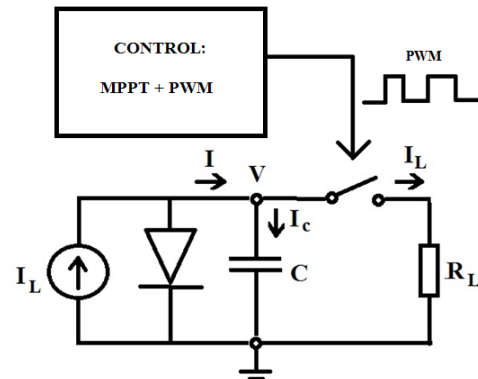

Figure 5. Switching System for Power Conditioning.

Where I_L is approximately equal to the panel's short-circuit current (I_{SC}), and I is the current supplied; I_C is the current in the capacitor, and C=10 μF is the capacitor's value; R_L is the resistive

load, which must be less than V_{OC}/I_L, so the capacitor voltage may be controlled (V_{OC} = Open Circuit Panel Voltage).

The average equilibrium voltage V in the capacitor C is adjusted as a function of the PWM switching duty-cycle, controlled by the MPPT algorithm, which constantly probes for better operating conditions.

In a SCILAB simulation of a hypothetical solar panel, with a power conditioning circuit as described in Figure 5. The following parameters were defined and the simulation's numerical results are as shown in Table 2. The panel has a 10 x 10 array of silicon cells ($N_s = 10$, $N_p = 10$). The short circuit current $I_{SC} = 3$ A, and was arbitrarily chosen, not considering a conversion efficiency factor nor an effective capture area. The reverse saturation current $I_0 = 1\text{x}10^{-12}$ A, which is typical value for silicon solar cells. Constant load resistance $R_L = 0.5$ Ω. Notice that the maximum power that may be extracted from the solar panel $P_{max} < V_{OC}$ x I_{SC}. That is true for any real solar panel.

Table 2. Hypothetical Solar Panel Simulation Results

Parameter	Value
Maximum Power (P_{max})	18.1 W
Maximum Power Voltage (V_{mpv})	6.28 V
Maximum Power Current (I_{mpc})	2.87 A
Open Circuit Voltage (V_{OC})	7.08 V
Short Circuit Current (I_{SC})	3.0 A

5. CONCLUSIONS
A simplified electrical model for solar panels was proposed for the evaluation of power conditioning strategies, in order to capture their essential behavior.

Both SCILAB and SPICE simulations were carried out to evaluate the performance of solar panels with and without power conditioning systems. It is demonstrated that maximum power generation may be achieved with MPPT algorithms, in a simple PWM switching control system, with the addition of a single capacitor.

6. FUTURE WORK
To analyze and evaluate techniques, such as the MPPT algorithm, and to improve operating efficiency and to maximize energy generated by real photovoltaic panels, it is necessary to refine electrical models as much as possible, including features such as parasitic resistance and reactance, and any additional surge protection and filtering circuits that may be employed in practical systems. The influence of buck-boost switching converters, which are commonly used in conditioning and regulating power delivered to different kinds of loads must also be considered in future simulations of complete conditioning systems. Switching noise must be kept to a minimum and filtering strategies must be developed and evaluated. Switching dynamics may be improved with alternative techniques, such as Pulse Density Modulation (PDM). Transient analysis of all possible scenarios, such as short-circuits or significant fluctuations of incident solar radiation and load, must be considered in the overall system's design. Maximum power generation may be obtained with alternative methods, with more robust and adaptive schemes, including the use of many different artificial intelligence techniques that are available, such as Fuzzy Logic, Neural Networks and Genetic and Evolutionary Algorithms. Intelligent integrated control schemes may allow more efficient association to other alternative energy sources and to battery banks, for reliable energy distribution and storage.

7. REFERENCES
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