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Maximum Power Point Tracking of Photovoltaic Systems

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The need for alternative energy sources has increased dramatically over the past 10 years. The demand for oil is higher than ever with emerging economies such as China and India. In addition, there is great concern about the emission of carbon dioxide. It is of utmost importance to create and develop renewable energy sources. Solar energy has been in the forefront of such a demand. However, there is much more research to be conducted from both theoretical and practical viewpoints to make alternative energy sources cost-effective and efficient. In this presentation, the power optimization of solar panels is investigated. Power optimization is extremely important in trying to receive the most energy from any renewable energy source. Photovoltaic cells (solar panels) in particular offer an interesting challenge due to how the weather conditions (irradiation/temperature/shading) constantly change the operating power for a fixed electrical load. Also, different electrical loads will result in different current/voltage outputs for the same weather conditions. In order to optimize the output, DC-DC converters using Maximum Power Point Tracking (MPPT) algorithms are placed between the photovoltaic array and the electrical load. The author has been working on the integration of a complete solar system that optimizes the output power. Progress has been made with both the theory and implementation, and this is what will be shown.

Maximizing the output of a solar panel using Maximum Power Point Tracking

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Introduction:

Solar panels, like batteries or fuel cells, may be operated at a number of different voltage/current points on their current -voltage (IV) curve. However, there is only one point where the power is maximum, called the Maximum Power Point (MPP). Since the IV curve of a solar panel changes based on sunlight and temperature, the MPP constantly changes. The purpose of this work is to track this point during changing conditions, so that the system is always operating at this point. This is called Maximum Power Point Tracking (MPPT)

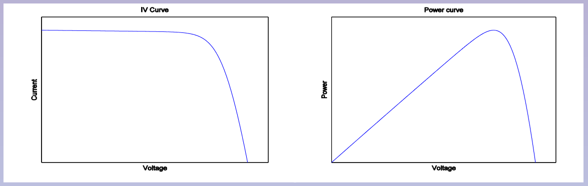

Figure 1: IV and power curves of typical solar panel

Objectives:

- Compare various solar panel models and see if a simpler model is appropriate for use in a typical MPPT converter system.
- Compare this model in the context of different converter topologies
- Use developed solar panel/converter model for testing MPPT control algorithms
- Improve on MPPT control techniques
- Test this model in a more realistic system (include system losses). Modify control parameters as necessary.
- Implement a circuit to test the modeling and MPPT algorithm that has been developed.

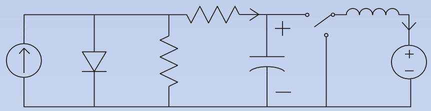

Figure 2: Circuit model for PV panel attached to buck converter

Modeling of solar panel and converter:

It is first necessary to find a model for the solar panel, as well as a converter that will be used for the MPPT algorithm. Since this is a feedback system, the model for the solar panel needn't be too complex. In particular, the typical model is an implicit function which makes analysis difficult. First, work was done on solving for model parameters based on solar panel spec sheets. Once various models were tested, and solved for, for some given solar panels, these models were compared in the context of various DC/DC converters.

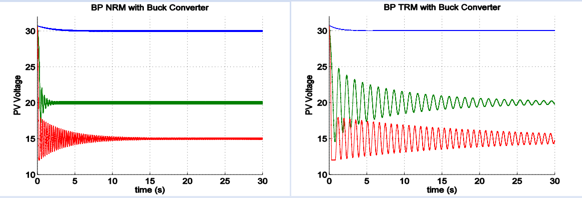

Figure 3: Results for two different PV models using buck converter.

MPPT Control:

Once the PV model and converter are selected, some typical MPPT algorithms were tested. The test was done using a standard input that represents sunlight changing in both step and ramp fashions (typical control system inputs for finding system type). Afterwards, a different algorithm was proposed. Analysis was done, and many control experiments ran, in order to find out the values that should be used for some of the control parameters. This was done in a way to keep the results as general as possible, to allow for a range of solar panels to work properly.

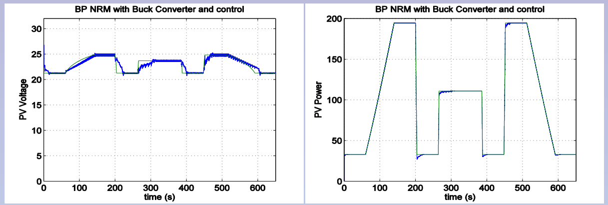

Figure 4: The voltage (left) and power (right) outputs to the proposed MPPT algorithm tracking changing irradiation.

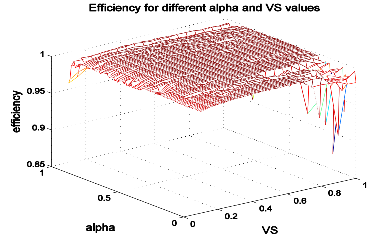

Figure 5: This shows the effects of two parameters on the efficiency of the control algorithm for a given PV panel. These results were used to verify that the method for selecting these parameters work, as well as that these values are robust: meaning a slight change in these parameters barely effect efficiency.

Incorporating System Losses:

Incorporating typical circuit losses, like transistor and inductor resistance, as well as the diode forward voltage drop, necessitated some changes in some of the equations.

Ideal relationship between voltage and duty cycle:

$$v = \frac{v_{out}}{d}$$

Realistic relationship between voltage and duty cycle:

$$v = \frac{v_{out}}{d} + \frac{1-d}{d}V_f + \frac{iR_t}{d} + \frac{iR_i}{d^2}$$

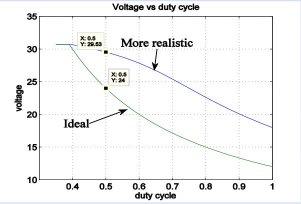

Figure 6: Relationship between voltage and duty cycle of converter for control purposes.

Circuit Implementation:

To test the system, a simple buck converter was built . Data Acquisition equipment was used to measure and control the circuit via software written in Labview. Results were first tested inside to make sure everything was working correctly. Numerous lights were used in order to get approximately half the intensity of the sun at solar noon. Experiments were then done outside during clear days. Only step type input were tested in the actual circuit, as implementing gradual changes was more difficult.

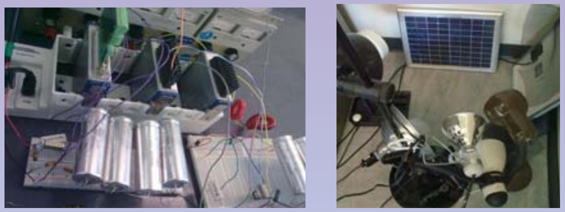

Figure 7 The circuit (left) and the solar panel (right) that were used for testing. In-doors many lights had to be used to get enough power out of the solar panel.

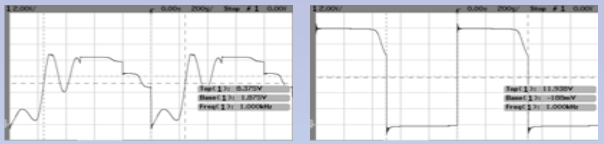

Figure 8: Hard switching (left) of the MOSFET greatly affected the diode voltage in the circuit. A simple capacitor and resistor fixed the problem (right).

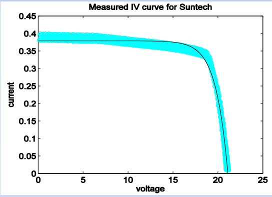

Figure 9: Measured IV curve, as well as a fitted IV curve, verifying the solar panel model.

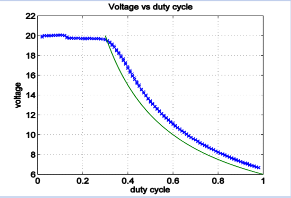

Figure 10: Measured relationship between voltage versus duty cycle, as well as ideal.

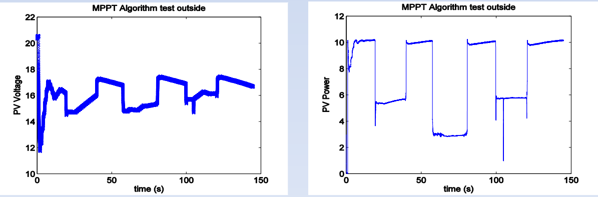

Figure 11: Tracking of voltage (left) and power (right) of 10 watt panel for different irradiation conditions (caused by shading with a screen).

Conclusions:

The components of an MPPT system were built, and an MPPT algorithm implemented. Preliminary results from the tested circuit seems to confirm much of the theory.