

Modeling and Simulation of Maximum Power Point Tracker in Ptolemy

Wei Cai and Leslie Lauren Gouveia

Abstract—This paper presents real time modeling of a simple efficient photovoltaic maximum power point tracker (MPPT) in Ptolemy. The MPPT consists of four components in Ptolemy: the PV component, the DC-DC component, the controller, and the battery. Based on the ambient temperature and solar irradiance, MATLAB results can predict when it is the optimal time to charge the battery. By modifying the PV angle, we can get the maximum solar power. So that's the real value we need for a real time simulation to see how much power we can get at the end by using Ptolemy software.

Index Terms—MPPT, photovoltaics, ptolemy, renewable energy.

I. INTRODUCTION

Photovoltaic's which generate electricity by using solar energy, are good candidates for renewable energy. Furthermore, it is a promising technology that may allow the generation of electrical power on a very large scale. Worldwide photovoltaic production was more than 5 GW in 2008, and is expected to rise above 20 GW by 2015 [2]. Because of shortage of energy, photovoltaics could thus make a considerable contribution to society in the next generation. The problem for solar cells is how to improve their efficiency.

In order to get the maximum photovoltaic system's output, the Maximum Power Point Tracking (MPPT) algorithm usually is used for the control system. The efficiency of the PV module is very low and output power depends on solar irradiation, ambient temperature, and solar temperature. Moreover, there is great loss due to the mismatch between the sources to the loads [4]. MPPT algorithms can provide the theoretical value to achieve the MPP of the solar panels, and can be implemented in hardware and software. In more detail, the MPPT can check the output of the PV module, compare it to the battery voltage then decide whether to charge the battery. It can also supply power to a DC load, which can directly charge to the battery. MTTP can be highly efficient in cloudy or hazy conditions, or when the battery is highly discharged. And here Ptolemy II can be used in real-time to see how much the, which can let the customer to optimize the power assumption.

It is possible to reduce the electric usage as much as we can by getting maximum power from solar power. If users can directly input all the parameters into the system, and the

system level simulation can finish quickly. That is what users need. Besides, users can observe how much power can get after modifying the PV angle, so the system needs the real time control. Real time control of power generation is important, so this paper mainly addresses this topic. Furthermore, all the power assumption and generation can be integrated and shown in the electronic device, and the device that has the RF transceiver can be directly accessible for the users, for example, apps at an I-phone. So it is possible for the user to monitor the power consumption at any time anywhere.

II. BACKGROUND

A. Solar Cell

Photovoltaic (PV) arrays consist of PV solar cells in series or parallel. The solar cell is a PN junction device converts the photon power into electrical power and delivers it to the load, as seen in Fig. 1. Moreover, the incident photon will create the electron-hole pairs in the space charge region, producing photocurrent as shown. The forward-bias voltage produces a forward-bias current. The net PN junction current is in the reverse-bias direction, as shown in Fig. 2 [1].

$$I = I_L - I_F = I_L - I_S \left[\exp\left(\frac{eV}{kT}\right) - 1 \right] \quad (1)$$

where e is electron charge, k is Boltzmann constant, T is absolute temperature.

There are two limiting cases of interest. The short-circuit condition occurs when $R=0$, so that $V=0$.

$$I = I_{sc} = I_L \quad (2)$$

The second condition happens when R is close to infinity.

$$V_{OC} = V_t \ln\left(1 + \frac{I_L}{I_S}\right) \quad (3)$$

A plot of the diode current I as function of the diode voltage V can be seen in Fig. 3.

B. Ptolemy II

The Ptolemy software can be used for heterogeneous modeling, simulation, and design of concurrent systems. A major concentration is on the application of the embedded systems. It can be designed for analog and digital electronics, hardware and software etc. Another major advantage is that Ptolemy can sense and combine all the different and complex operations, for example, networking, signal processing, feedback, and sequential decision making on the system level

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[4].

An actor is the basic component in Ptolemy II. Actors always have the ports, so they can communicate with other ports by ports interface. A definition for composite actor is an aggregation of actors and ports. So a composite actor always intercedes the signals among the actors. A director defines the communication mechanism and the execution order of the actors under its control. The director implements the communication among actors within a composite actor. A variety of models have been implemented in the Ptolemy II. Here the photovoltaic system is set up using this software [4].

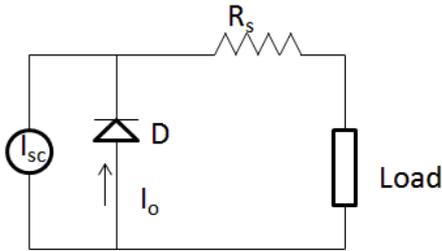


Fig. 1. Schematic of basic solar cell circuit configuration [3]

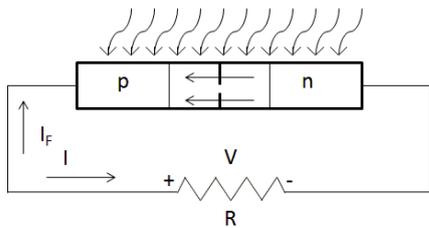


Fig. 2. PN junction at the reverse-bias condition [3]

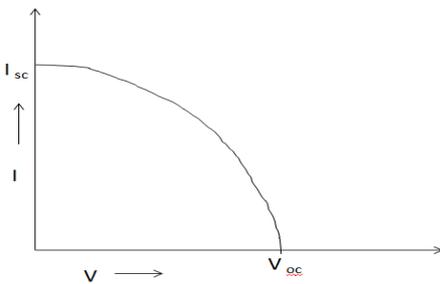


Fig. 3. IV curve of diode [3]

III. MODEL SETUP

MPPT is maximum power point tracking, which is the electronic device that using Photovoltaic modules to generate the energy to charge the battery. In order to charge a battery, PV module must apply a voltage that is higher than the threshold of the battery. If a PV module's V_{pp} is just slightly below the battery voltage, the PV module keeps charging the battery. The basic model can be seen in Fig. 4 and implements at the Ptolemy as seen in Fig. 5.

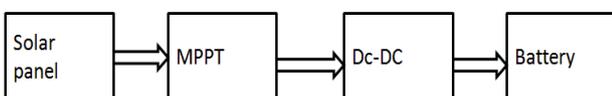


Fig. 4. Schematic of PV model

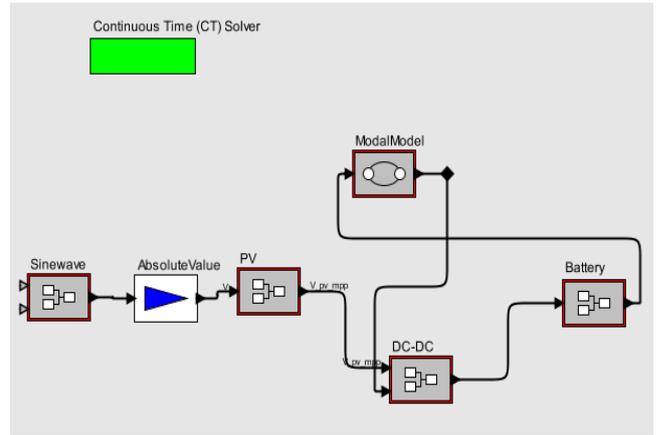


Fig. 5. Model implemented in Ptolemy II

A. PV Component

Based on the configuration, the first step is to build the PV component. As seen in Fig. 5, the typical voltage versus power and voltage versus current curve is like Fig. 6. So we first set up the kind of figure that looks like Fig. 6. After constructing the function of the P and V, and it plotting it in the MATLAB, as seen in Fig. 7, it looked close to Fig. 6. So the piecewise function can be modeled as the PV power.

The PV component models the solar panel (photovoltaic or PV) system, as seen in Fig. 7. The PV component is modeled as a Composite Actor containing two Composite

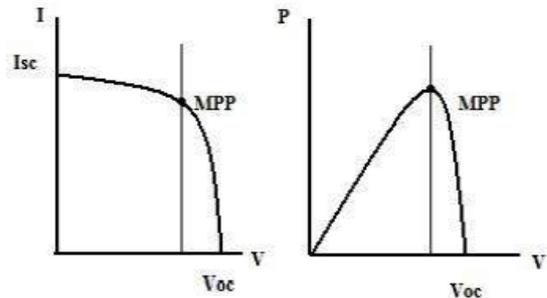


Fig. 6. Typical V vs I & P vs V characteristics of solar array [2].

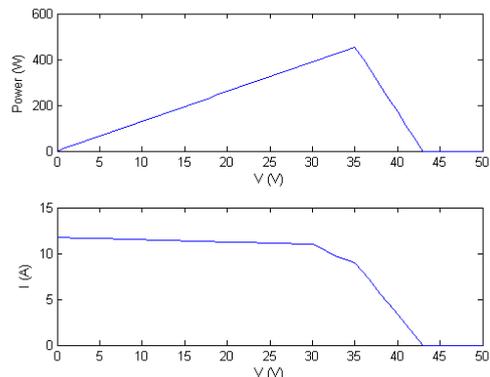


Fig. 7. Reconstructed Power vs voltage and current vs voltage in MATLAB.

Actors, P and I, modeling PV power and PV current, as seen in Fig. 8, and Fig.9. The PV component outputs V_{pv_mpp}(t), as seen in Fig. 9, where

$$V_{pv_mpp}(t) = \frac{P(V(t))}{I(V(t))} \quad (4)$$

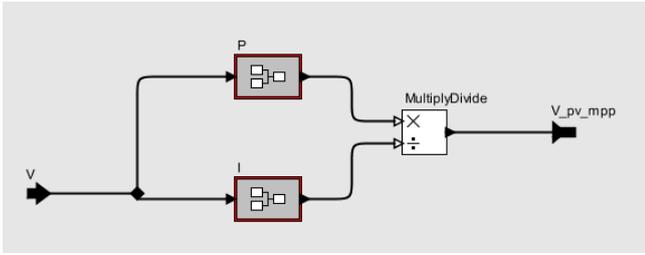


Fig. 8. Schematic for PV component in Ptolemy II



Fig. 9. Schematic for the PV power piecewise function in Ptolemy II

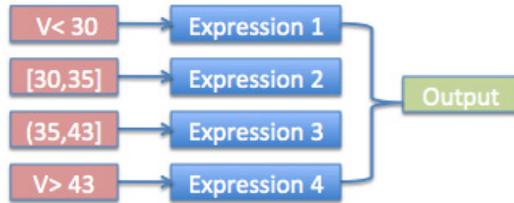


Fig. 10. Schematic for the PV voltage piecewise function in Ptolemy II

B. DC-DC Component

After finishing the configuration of the PV component, then the DC-DC component needs to be constructed. The DC-DC converter determines the voltage ratio at which the battery can be safely and maximally charged. The charge controller converts the DC PV output voltage to the DC battery charging voltage. Directly connecting the battery to the PV would limit the PV output voltage to the battery's max voltage. Using the intermediate charge controller allows the PV to generate its maximum power output. It also provides over-charge protection to the battery.

The DC-DC converter takes as input a control signal indicating if the battery should be charged off if the DC should be sent to a DC/AC inverter which connects directly to the AC grid, as seen in Fig. 11.

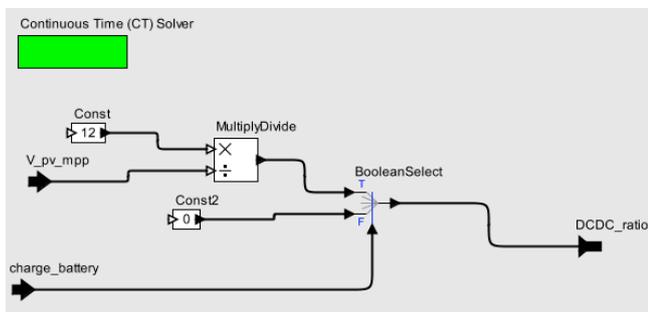


Fig. 11. Schematic for DC-DC converter

C. Controller Component

All the systems require a controller. Here the controller governs the charging of the battery and is implemented as a Finite State Machine, as shown in Fig. 12. The FSM has two states "Charge" or "Off" and takes $V_{batt}(t)$ as an input signal. If $V_{batt}(t) < V_{batt_max}$, where V_{batt_max} is the maximum voltage of the battery, the "Charge" signal is returned indicating that the battery should be charged. If

$V_{batt}(t) \geq V_{batt_max}$, the "Off" signal is returned indicating that the battery should not be charged.

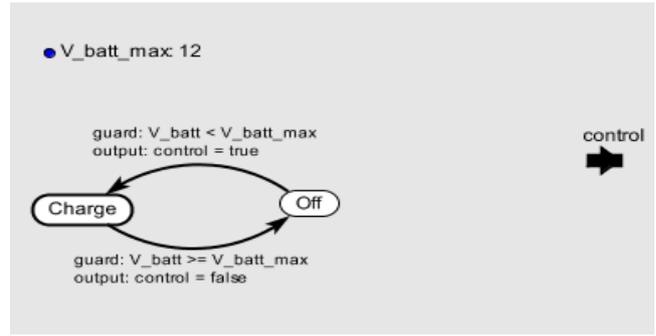


Fig. 12. Schematic for controller component

D. Battery Component

The Schematic of the battery is as seen as Fig. 13.

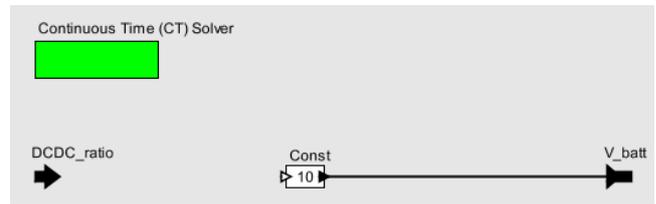


Fig. 13. Schematic for battery component

IV. CONCLUSION

This study presents that MPPT control algorithm can be implanted in the Ptolemy II for real time. The scope of the study was limited to those algorithms thought to be applicable to low-cost implementations. The MATLAB results show when the battery can be optimally charged based on the condition of the PV component, which is usually dependent on ambient temperature and solar irradiance. For future renewable energy, we can use some real data to conduct some experiments in order to see how much energy can be saved in real life.

V. FUTURE WORK

Systems level simulation can give the customer a blueprint about the power of the sun to the load. When solar cell behavior is understood, we can make the system-level simulation have more functions, and when the customers put more parameters, they can get more accurate results. Results can include minimization interconnect losses; evaluation of effects of environmental variation, such as light intensity and incidence angle, temperature variation, electrical environment and optimization power conversion.

The other significant part is how to improve the PV efficiencies; this is also a huge challenge for the electrical engineers and material scientists and chemists. These days the solar efficiency is low; the efficiency of the regular Si thin-film sub-module is 10%. However, the efficiency of the III - V material, for example GaAs, is likely 26%, but the cost is more than Si material. Therefore, there are possibilities for improving the PV efficiency.

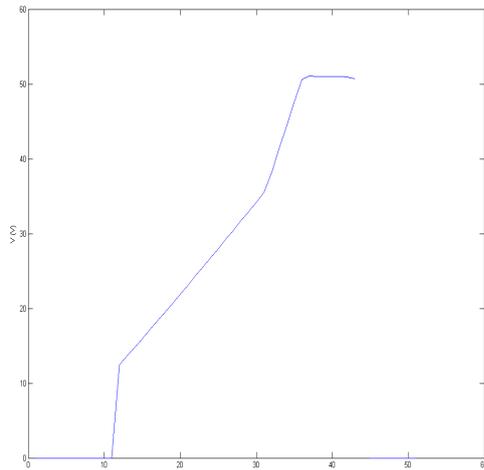


Fig. 14. Output function battery voltage vs PV voltage

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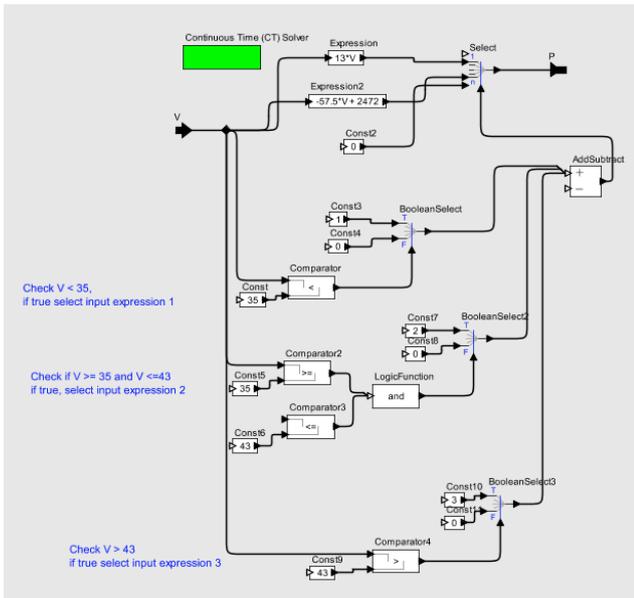


Fig. 15. Detailed schematic for the PV power piecewise function in Ptolemy II



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