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**Solar Car 1 MPPT Design**

**Helpful links:**

* Solar cell equivalent circuit: <https://www.allaboutcircuits.com/technical-articles/circuit-designer-guide-to-photovoltaic-cells-solar-powered-devices/>
* Boost converter MPPT simulation: <https://www.youtube.com/watch?v=o9BOrAHH5E4>
* Discussion on MPPT vs charge controlling: <https://electronics.stackexchange.com/questions/519900/understanding-working-of-mppt-charger>
* Complete open source buck MPPT design: <https://www.instructables.com/DIY-1kW-MPPT-Solar-Charge-Controller/>
* Boost converter power stage: <https://www.ti.com/lit/an/slva372c/slva372c.pdf>

**Preliminary Questions:**

Buck or boost converter?

* Contingent on motor voltage: if > 100V or so, want boost, if less consider boost
  + The reason for this is we want to be able to use integrated buck converter IC’s on the board for peripheral voltages (i.e. 12V, 3.3V) and these packages rarely are rated for VIN > 80V or so.

How does altering duty cycle of these converters move you along the solar IV curve?

*Key concept:* ImpedanceConverter ~= Vapplied/CurrentDelivered

* Buck:
  + Increasing duty cycle approaches short circuit (I increases)
  + Decreasing duty cycle approaches open circuit (I decreases)
* Boost:
  + Increasing duty cycle approaches short circuit (I increases)
  + Decreasing duty cycle approaches open circuit (I decreases)

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*Decreasing duty cycle*

*Pictured: Relationship between duty cycle and position on IV curve. Applies to both buck/boost.*

Can MPPT buck/boost converter be the same as the charge controller or do we need two with a DC link (large capacitor between the two)?

* In order to ideally use one controller as both, three things must be true:
  1. Can accurately do pure current control (NOT MPPT) when battery is charging
     + Must be able to distinguish Iload from Icharge
     + Develop charge algorithm to take over MPPT when Iload < Iarray
       - Two scenarios:
         * Iarray – Iload < ideal charge current for current SOC

Continue MPPT

* + - * + Iarray – Iload > ideal charge current for current SOC

Current control necessary

* + - * To get charging current to decrease, the converter will have to increase the impedance of the converter by altering duty cycle (*­­­­­decrease* on buck converter, *decrease* on boost converter) to utilize the decaying nature of current as voltage increases on the IV curve)
        + Must size pack to have max voltage to the voltage to where the minimum desired charging current lies on IV curve (or just max solar array voltage, as voltage is pretty constant at end of the IV curve).



*Pictured: Increasing array voltage will decrease input current in a charging scenario*.

* 1. MPP on the solar array side remains unaffected regardless of what the battery voltage is. This is unknown and will be answered by the question “What happens if the maximum power point impedance/duty cycle yields a higher output voltage than the battery voltage? If the solar array is automatically “brought down” to the battery voltage, MPPT will be moot and we will just have a charger.
  2. We design a **hardware** (NOT SOFTWARE) failsafe shutoff of converter if battery voltage is above certain threshold is implemented
     + Maybe a comparator comparing battery voltage to reference voltage that turns off control FET
       - Needs to take into account battery voltage drop under load so battery doesn’t charge when at full SOC, but voltage appears lower because discharging : VBat = VBatNominal – (Iout\*PackInternalResistance).
       - Potentially set this cutoff threshold to not charge above VBat = VBatNominal – IMaxExpected\*PackInternalResistance.

What happens if the maximum power point impedance/duty cycle yields a higher output voltage than the battery voltage?

This is a question because typically with buck and boost converters with a voltage source Vin, Vout = Vin \*(D) and Vout = Vin( 1/(1-D)) respectively. (D = duty cycle).

**Diagram

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*Pictured: Ideal buck and boost output voltage transfer functions with voltage src Vin*

* My initial intuition is because solar cells are effectively a current source, logic that would apply for a voltage regulator does not apply. Rather, this is a current regulator that has voltage implications depending on how much current is being drawn. Preliminary simulations will inform this intuition more.

**Characterize following scenarios:**

Buck converter:

* MPP duty cycle output is > in voltage than battery
  1. Iload > Ipanels
  2. Iload < Ipanels (charging)

Boost converter:

* MPP duty cycle output is > in voltage than battery
  1. Iload > Ipanels
  2. Iload < Ipanels (charging)

**Simulation**:

In order to answer some of the above questions, a characteristic simulation will be made of a solar array that can be modified to fit desired array parameters.

Links referenced:

* <https://www.youtube.com/watch?v=MZ-3HDjwPWw>
* <https://electronics.stackexchange.com/questions/257253/modeling-a-solar-panel-for-simulations>
* <http://www.intusoft.com/nlhtm/nl78.htm#The_Solar_Cell_SPICE_Model>

**Parameters for modeling custom solar array:**

*Voc* = *open circuit array voltage*

*Isc = short circuit array current*

*I0* = *saturation current* (of single cell). Hard to derive – informs open circuit voltage. Solar cell saturation current on the order of magnitude of 1e-10. Best derived from test data.

**Derived parameters for modeling custom solar array:**

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*N = emission coefficient*



*XTI = exponent temperature coefficient*

*IS = saturation current*



*EG = energy gap*

To put these in the equivalent circuit for a solar cell, add a generic diode in the proper location as D1 below:

Diagram

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Graphical user interface, application

Description automatically generated CTRL + Right click on the diode to bring up this menu:

Change the “value” Parameter to the custom name you’d like to call the diode – “DiodeSolarCell here:

Graphical user interface, text, application

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Add a spice directive with the following form to attribute calculated parameters to this diode:

*.model <name\_you\_gave\_diode> D LEVEL=1 IS=<calculated IS> N=<calculated\_N> EG=<calculated\_EG> XTI=calculated\_XTI*

Diagram, schematic

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Graphical user interface, application

Description automatically generatedThis should result in an I=V curve with the following shape when a dc sweep is ran on the model: