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**Solar Car 1 MPPT Design**

**Starting 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>
* MPPT Charge Controller Reference Design for 12-V, 24-V and 48-V Solar Panels: <https://www.ti.com/lit/ug/tiduej8a/tiduej8a.pdf?ts=1635705495282&ref_url=https%253A%252F%252Fwww.google.de%252F>

**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?*

* 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/designed for:
  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. If the solar array is automatically “brought down” to the battery voltage, MPPT will be moot and we will just have a charger. Due to the rectifying diode or FET with dead-time on a boost converter, the output of the converter should always be >= battery voltage, and the solar array voltage will not be dictated by the battery.
  2. We design a **hardware** (NOT SOFTWARE) failsafe shutoff of converter if battery voltage is above certain threshold is implemented
     + Consider 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 different output voltage than the battery voltage? If operating at maximum power point, is the output power fundamentally “capped” by the ideal voltage source that is the battery?*

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). At first thought, one might think that if the MPP yields an output voltage at the inductor that is greater than the battery voltage, there is some loss in the difference between the inductor output and the battery when the inductor voltage is “brought down” after passing through the rectifying diode to the battery voltage.

**Diagram

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

The answer to this question is best answered by reviewing the fundamentals of inductors. Inductors will do whatever it takes to keep the current flowing in it from changing – creating a voltage across the inductor as necessary to do so. Given this, the inductor will only output as high of a voltage as necessary to keep the current that was flowing in the inductor “charge” state into the battery. There is no “excess voltage” that is being lost due to a duty cycle that would yield a higher voltage if a resistive load was connected.

**Simulation**:

In order to answer some of the above questions and get a better understanding of the operation of an MPPT boost converter, a characteristic simulation will be made of a solar array & converter 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

Description automatically generatedExample:

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:

**Boost converter simulation:**

Hooking up the solar array model to a boost converter topology as shown below is helpful to understand the working principles and waveforms on various nodes of the MPPT. The actual “Maximum Power-point Tracking” would be a function of the output current of this model (to the battery and load). The dependent variable is the duty cycle of the MOSFET gate drive signal, simulated by V1 here.

**Graphical user interface, application

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**Boost Converter Design**

**Helpful links:**

* Multiphase (&single phase) boost converter design: <https://www.ti.com/seclit/wp/slup323/slup323.pdf>
* MOSFET Losses in Switching Power supplies: <https://fscdn.rohm.com/en/products/databook/applinote/ic/power/switching_regulator/power_loss_appli-e.pdf>
* Boost converter design & power losses: <https://www.powerelectronicsnews.com/the-dc-dc-boost-converter-part-2-power-supply-design-tutorial-section-5-2/>
* System Design considerations for battery operated system: <https://www.ti.com/download/trng/docs/seminar/Topic%206%20-%20DC-DC%20Power%20Conversion%20and%20System%20Design%20Considerations%20for%20Battery%20Operated%20System.pdf>

**Solar array and battery specs:**

* Pack nominal voltage: 96V
* Pack max voltage: 107V
* Solar array open circuit voltage: 57.12V
* Solar array mpp voltage: 48.72
* Solar array open circuit current: 3 strings \* 6.34A = 19.02A
* Solar array mpp current: 3 strings \* 6A = 18A

**Initial design goals**

Due to the high output power (876.96W) of this array, the first solar car will need to use 3 Elmar MPPT devices to handle all the current, as each device has a max array current rating of 7A. The goal of this design will be to:

1. Consolidate these 3 MPPT devices into one sleeker, cheaper, simpler solution.
2. Achieve an efficiency of 97% or greater in design & ideal test conditions.
3. Learn about and implement fundamentals of power conversion and control in the context of a large embedded system.

**Multiphase boost converter**

In order to turn the functionality of three MPPT’s into one while retaining high efficiency, a multiphase boost converter design will be pursued. Per TI, “When considering higher output currents, a multiphase boost converter provides many advantages over a single-phase option for higher power boost converters. Advantages are seen in efficiency, thermal performance and size”.

This is accomplished by the following means:

1. Efficiency: