LAB # 06

Analyzing and Understanding the Working of Buck-Boost Converter with PV Array

Objectives:

- To understand the working principle of buck-boost converter
- To learn how to calculate values of D (duty cycle), L (inductor) and C (capacitor) for buck-boost converter
- To analyze the working of buck-boost converter with PV array
- To observe input output characteristics (power, voltage & current) of buck converter by varying its duty cycle (greater or less than 50%)

Component required:

- PV Array
- Inductor
- Capacitors
- Constants
- PWM Generator
- IGBT (insulated Gate bipolar transistor)
- Diode
- Current Measurements
- Voltage Measurements
- Scope
- Display

Related Theory:

The buck–boost converter is a type of DC-to-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. It is equivalent to a fly back converter using a single inductor instead of a transformer.

The output voltage of the magnitude depends on the duty cycle. These converters are also known as the step up and step down transformers and these names are coming from the analogous step up and step down transformer. The input voltages are step up/down to some level of more than or less than the input voltage. By using the law of conservation of energy, the input power is equal to the output power. The following expression shows the low of a conversion.

$$\text{Input power } (P_{in}) = \text{Output power } (P_{out})$$

For the step-up mode, the input voltage is less than the output voltage ($V_{in} < V_{out}$). It shows that the output current is less than the input current. Hence the buck booster is a step-up mode.

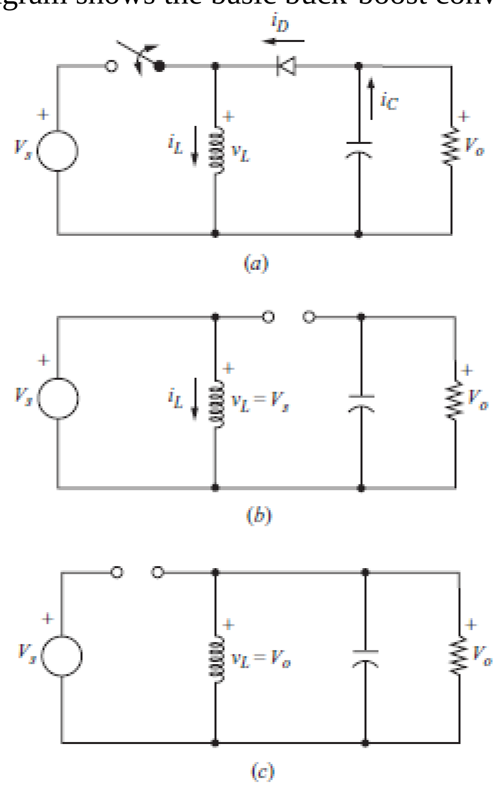
$$V_{in} < V_{out} \text{ and } I_{in} > I_{out}$$

In the step-down mode, the input voltage is greater than the output voltage (Vin > Vout). It follows that the output current is greater the input current. Hence the buck boost converter is a step-down mode.

$$V_{in} > V_{out} \text{ and } I_{in} < I_{out}$$

Working Principle of Buck-Boost Converter:

There are two types of converters in the buck-boost converter that are buck converter and the other one is boost converter. These converters can produce the range of output voltage than the input voltage. The following diagram shows the basic buck-boost converter.



<u>Generic Buck-Boost Converter</u>

Analysis for the Switch Closed:

When the switch is closed, the voltage across the inductor is

$$v_L = V_s = L\frac{di_L}{dt}$$

$$\frac{di_L}{dt} = \frac{V_s}{L}$$

Solving for Δi_L, when the switch is closed gives

$$(\Delta i_L)_{\text{closed}} = \frac{V_s DT}{L}$$

Analysis for the Switch Open:

When the switch is open, the current in the inductor cannot change instantaneously, resulting in a forward-biased diode and current into the resistor and capacitor. In this condition, the voltage across the inductor is

$$v_L = V_o = L\frac{di_L}{dt}$$

$$\frac{di_L}{dt} = \frac{V_o}{L}$$

Solving for Δi_L,

$$(\Delta i_L)_{\text{open}} = \frac{V_o(1-D)T}{L}$$

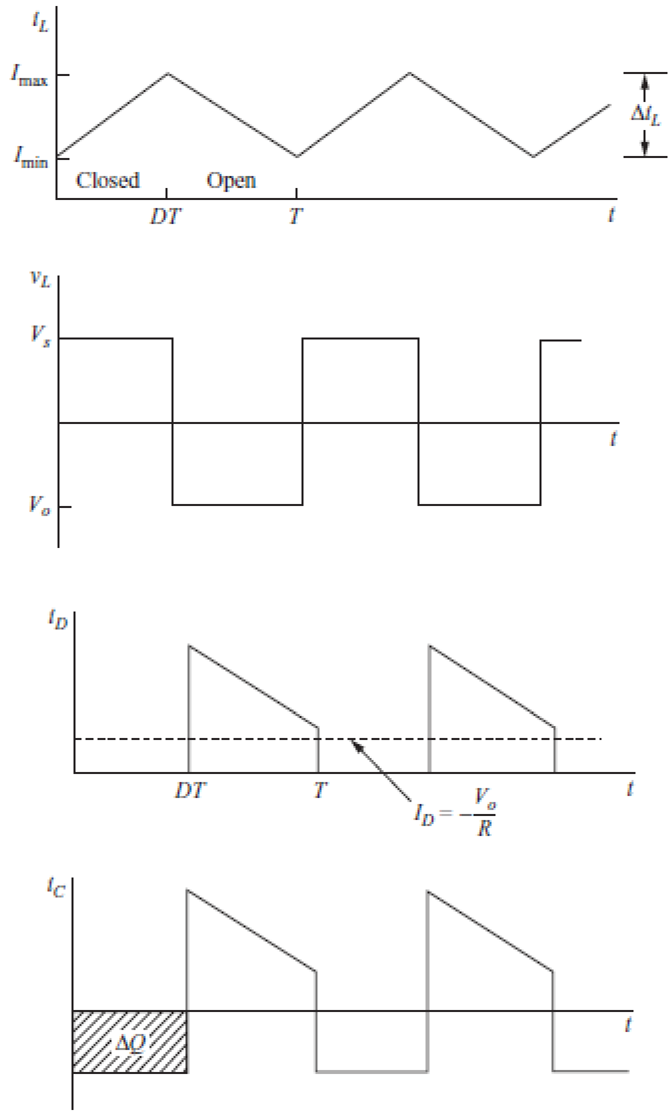
$$V_o = -V_s\left(\frac{D}{1-D}\right)$$

Above mentioned equations show that the output voltage has opposite polarity from the source voltage. Output voltage magnitude of the buck-boost converter can be less than that of the source or greater than the source, depending on the duty ratio of the switch.

If $D>0.5$, the output voltage is larger than the input; and if $D<0.5$, the output is smaller than the input. Therefore, this circuit combines the capabilities of the buck and boost converters. Polarity reversal on the output may be a disadvantage in some applications.

Note that the source is never connected directly to the load in the buck-boost converter. Energy is stored in the inductor when the switch is closed and transferred to the load when the switch is open. Hence, the buck-boost converter is also referred to as an indirect converter.

Voltage and current waveforms are shown below.



Average inductor current can be finding out through following expression:

$$I_L = \frac{V_o^2}{V_s R D} = \frac{P_o}{V_s D} = \frac{V_s D}{R(1 - D)^2}$$

Maximum and Minimum inductor current can be determined as following:

$$I_{\max} = I_L + \frac{\Delta i_L}{2} = \frac{V_s D}{R(1 - D)^2} + \frac{V_s D T}{2L}$$

$$I_{\min} = I_L - \frac{\Delta i_L}{2} = \frac{V_s D}{R(1 - D)^2} - \frac{V_s D T}{2L}$$

For continuous current, the inductor current must remain positive. Minimum value of inductor can be determined as following:

$$L_{\min} = \frac{(1-D)^2 R}{2f}$$

The output voltage ripple for the buck-boost converter is computed as following:

$$\frac{\Delta V_o}{V_o} = \frac{D}{RCf}$$

Buck-Boost Converter Design Calculations:

Design a buck-boost converter to produce an output voltage of 24V across a 5Ω load resistor. The output voltage ripple must not exceed 1 percent. The dc supply from PV array is 35V. Design for continuous inductor current. Specify the duty ratio, the switching frequency, the values of the inductor and capacitor. Assume ideal components.

Solution:

Simulation diagram:

Buck Mode of Operation with Duty Cycle < 50%:

Boost Mode of Operation with Duty Cycle > 50%

Scope Output of Different Parameter of PV Array with duty Cycle < 50%:

Scope Output of Different Parameter of PV Array with duty Cycle > 50%:

PWM Scope Output with Duty Cycle < 50%:

PWM Scope Output with Duty Cycle > 50%:

Output Waveforms of P_o, P_s, V_o, V_s and I_o, I_s with duty cycle < 50%:

Output Waveforms of P_o, P_s, V_o, V_s and I_o, I_s with duty cycle > 50%:

Conclusion and Comments: