ADVANTAGE OF BOOST VS. BUCK TOPOLOGY FOR MAXIMUM POWER POINT TRACKER IN PHOTOVOLTAIC SYSTEMS

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Abstract

Electrical systems employing solar cells as the energy source are designed to operated at the point of maximum power of the solar cells. To track this point as the solar radiation and temperature vary a Maximum-Power-Point-Tracker (MPPT) is used. Most MPPT are based on a DC to DC converter of the Buck or Boost types. In this article we compare the energy efficiency of these converters and show that an MPPT based on the Boost converter configuration results in higher output power, thus better utilizing of the solar cells.

1. INTRODUCTION

A photovoltaic (PV) energy conversion system may employ a DC to DC convertor. In many applications it is recommended to include a Maximum Power-Point-Tracker (MPPT) to transfer the maximum available energy from the PV array to the load.

An MPPT may be designed based on either the Buck or Boost topologies [1-5]. Buck converter is generally used to lower the output voltage and the Boost converter is used to obtain higher output voltages. In most cases the Buck converter is of higher efficiency. Another difference between these two configurations is that for the Buck converter there are times where current is not flowing into the input port, whereas for the Boost converter current flows constantly into the input port .

The difference between a conventional and a photovoltaic energy source is that while in a conventional energy source, energy which is not delivered to the load it is not consumed and remains in the source, in photovoltaic energy source the energy is wasted since it is available for free. Therefore, an MPPT is included in the PV system making it to operate at its maximum power output.

Inspite of the inherent higher efficiency of the Buck topology in systems with conventional power sources, the Boost topology may be more suitable for PV systems including an MPPT since the converter operates at continuos current mode extracting as much power as possible from the solar cells. Hence the energy efficiency of the Boost converter may be higher than for the Buck converter.

The present article deals with the analysis of an MPPT based on the Buck and Boost topologies and shows the advantage of the Boost topology for maximum energy transfer in photovoltaic systems.

2. BOOST CONVERTER

2.1 Basic Operation Principal of the Boost Converter

When switch S is closed (Fig-1) current flows through the inductor L from the power supply (solar cell array) thus charging the inductor. At the same time the load receives its power from the output capacitor C. When S is open, current flows from the power supply through the inductor and diode D to recharge the output capacitor, and simultaneously, to supply power to the load. Typical waveform can be seen in Fig-2.

To simplify the analysis we assume that:

(1) all elements are ideal,
(2) the load is pure ohamic, and

0-7803-3330-6/96/$5.00 1996-IEEE

(3) the switching time is much shorter then the electric time constant of the circuit, therefore a linear approximation is used.

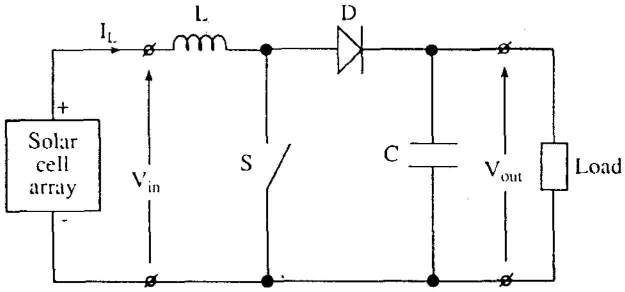

Fig. 1- Basic Boost Converter

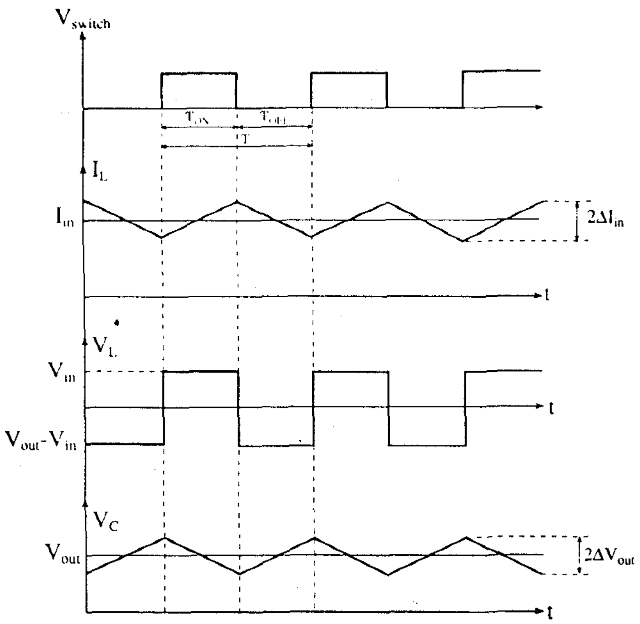

Fig. 2 - Typical Boost Converter Waveforms

2.2 Output Voltage Equation

At steady-state operation of the converter, the mean inductor voltage is zero over a full switching period T (i.e., the volt-second product is zero over the switching period T). From this we derive the output (load) voltage :

$$V_{out} = \frac{V_{in}}{1-D} \tag{1}$$

where :

V_{out} : is the output (load) voltage

V_{in} : is the input (solar cell array) voltage

D : is the duty-cycle ($D = \frac{T_{on}}{T}$)

T_{on} : is the on time, when the switch is closed.

2.3 Capacitor and Inductor Values

Based on the energy stored, energy discharge during Ton and Toff times and the required voltage and current ripples, we may calculate the required capacitor and inductor values:

$$C = \frac{V_{out} TD}{2\Delta V_{out} R_{load}} \tag{2}$$

$$L = \frac{2CV_{out}\Delta V_{out}}{2I_{in}\Delta I_{in}} \tag{3}$$

where

C : output capacitor
T : switching period
R_{load} : load resistance
ΔV_{out} : output voltage ripple
L : input inductance
ΔI_{in} : current ripple
I_{in} : input current

2.4 Load Resistance

The relation between the output and the input voltage depend on the duty-cycle. Assuming an efficiency of $\eta = 100\%$ meaning that the converter is a POPI type (Power out = Power in) we obtain the optimum load

$$R_{load} = \frac{V_{in}}{I_{in}(1-D)^2} \tag{4}$$

3. BUCK CONVERTER

3.1 Basic Operation Principal of the Buck Converter

The buck converter (Fig-3) consist of two parts :

(1) square wave generator with variable duty-cycle.
(2) low pass LC filter with a 40 dB/dec attenuation. The corner frequency $f_c = 1/2\pi\sqrt{LC}$ is designed to obtain a low output ripple .

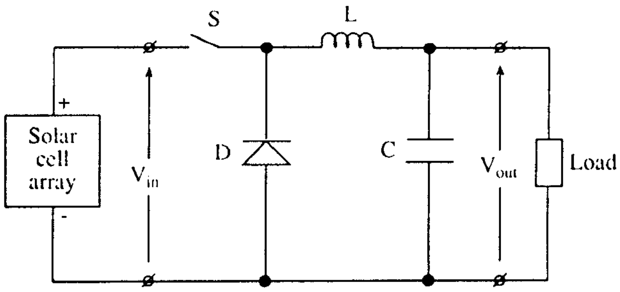

Fig. 3 - Basic Buck Converter

A good assumption of the converter operation is that the output ripple voltage is much smaller than the output voltage, therefore, we may take the load current to be constant, and the ripple current produced by the inductor flows into the capacitor from which the ripple voltage may be calculated. Typical voltage and current waveforms are shown in Fig. 4:

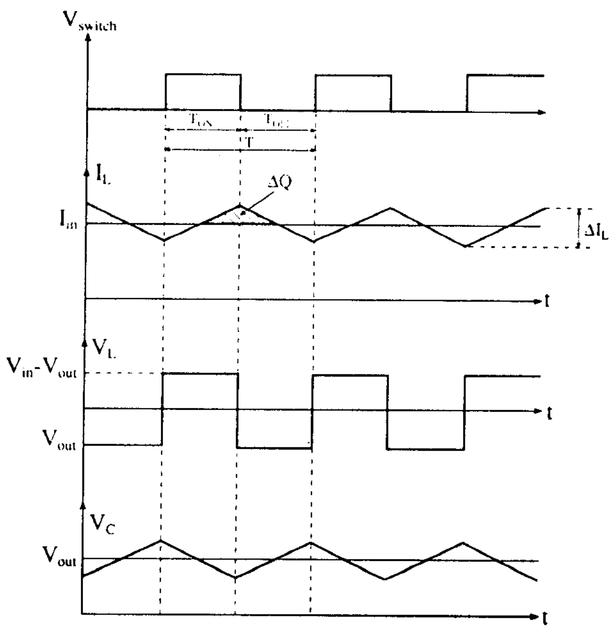

Fig. 4 - Typical Buck Waveforms

3.1 Output Voltage Equation

As in Boost converter analysis, the mean inductor voltage is zero over a full switching period T, thus we can write :

$$V_{out} = V_{in} D \tag{5}$$

3.2 Design Equation of the Capacitor and Inductor

Since the voltage across the inductor at any time can be calculated based on :

$$v_L = L\frac{dI_L}{dt} \tag{6}$$

the inductor value can be calculate from :

$$\Delta I_L = \frac{V_{out}(1-D)T}{L} \tag{7}$$

To calculate the capacitor value we can use the fact that the area under the inductor ripple current correspond to the stored charge ΔQ , and thus the capacitor can be calculate according to :

$$C = \frac{T\Delta I_L}{8C\Delta V_{out}} \tag{8}$$

3.3 Load Resistance

The relation between the output and the input voltage depends on the duty-cycle. Assuming an efficiency of $\eta = 100\%$ meaning that the converter is a POPI type, we obtain :

$$R_{load} = \frac{V_{in}}{I_{in}} D \tag{9}$$

4. MAXIMUM POWER POINT TRACKER (MPPT) CONSIDERATION

During steady-state operation the value of the output voltage is not of prime interest since the main purpose is to extract the maximum possible energy from the source and to deliver it to the output. Therefore, we would want to work with input voltages and currents close as possible to $V_{\max}$, $I_{\max}$ (maximum power voltage and current) of the solar cell array.

4.2 Converter Efficiency

The maximum power available from the solar cell array is:

$$P_{\max} = V_{\max} I_{\max} \tag{10}$$

and the power delivered by the converter is:

$$P_{converter} = \frac{1}{T}\int_T V_{in} I_{in} dt$$
$$\cong \frac{1}{T}\left(V_{in}(T_{on}) I_{in}(T_{on}) T_{on} + V_{in}\left(T_{off}\right) I_{in}\left(T_{off} T_{off}\right)\right) \quad (11)$$

The efficiency of the converter (neglecting all losses) is:

$$\eta_{converter} = P_{converter}/P_{max} \quad (12)$$

5. SIMULATION RESULTS

Simulation using "pspice" software was applied on both converter types varying the duty-cycle [6].

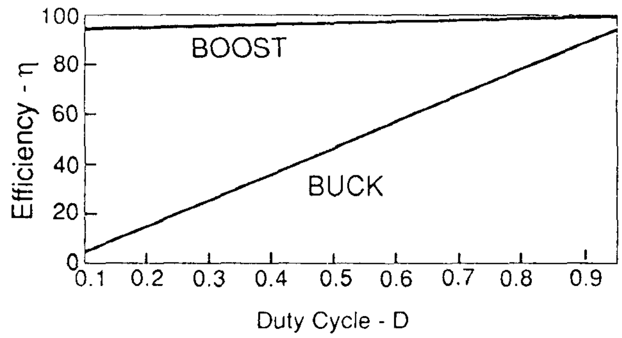

Fig. 5 Simulation Efficiency Results of Boost and Buck Converters

5.1 Solar array

Siemens M55 solar cells panels were used for the study.

5.2 Converter elements

The inductor and capacitor values were calculated based on eqs. (2), (3), (7) and (8), and the allowed current and voltage ripple of 1% . The converters switching frequency were chosen to be $50KHz$ taking into account the switching losses on one hand and the size of the inductor and capacitor on the other hand. A fast diode with low forward voltage drop and a switch with a low on time resistance were used.

6. CONCLUSIONS

An MPPT in a photovoltaic system may be based on Buck or Boost converters. The article shows that the Boost converter has higher energy efficiency than the Buck converter. The output voltage of a Buck converter is lower than the input voltage, conversely, the Boost converter steps up the input voltage. If the required voltage of the MPPT based on the Boost converter is higher than the desired output voltage one may use a Buck converter as the second stage to lower the voltage and still obtain a higher energy efficiency than for the case if the MPPT would be based on the Buck converter. Only for duty-cycles approaching 100% the Buck converter approaches the energy efficiency of the Boost converter. However in this case the control capability (controlling the duty-cycle) is very limited whereas for the Boost converter the energy efficiency varies slightly with the duty-cycle.

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