Three level Boost Converter with MPPT Application

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***Abstract*—This report is about the design and implementation of a three-level boost converter(TLBC) for Maximum Power Point Tracking application in Photovoltaic cells.**

***Index Terms*—**

I. Introduction

The TLBC is an improved version of the traditional boost converter. It has better gain and can provide higher duty cycle than two level boost converter because it uses a combination of capacitors and diodes and has 4 stages of operation.

II. Literature survey

A. DC-DC boost converter

A traditional DC-DC boost converter is shown in figure 1. It consists of a capacitor,inductor and diode, with a switching transistor, a MOSFET. The output of boost converter is stepped up by a factor, which is dependent on the duty cycle(D) and the switching frequency(f_s) of the MOSFET. The MOSFET is turned on and off at a high frequency, because of which, the inductor charges and discharges. When the switch is turned on (T_{on}), the diode is reverse biased, hence, the circuit acts as two independent circuits, where the inductor charges and the capacitor discharges. When the switch is turned off (T_{off}), the diode conducts, hence the inductor discharges and capacitor charges. During this time, the output voltage is the voltage across the capacitor. The total time period, T_s or simply, T

$$T = T_{on} + T_{off} \tag{1}$$

Due to the high frequency of charging and discharging, we get an boosted output voltage across the load. The output voltage can be boosted to the the desired value only when the volt-second balance of the inductor and amp-second balance of the capacitor is maintained, i.e. the inductor and capacitor must have fully charged and discharged in a cycle.

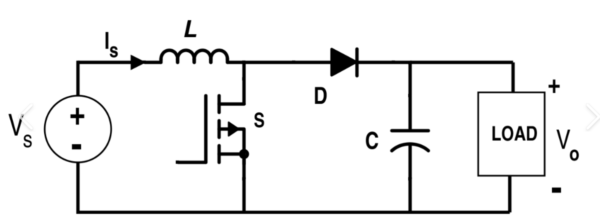

Fig 1: Boost converter

B. Duty cycle

The duty cycle(D) of the boost converter is defined as follows,

$$D = \frac{T_{on}}{T_{on} + T_{off}} = \frac{T_{on}}{T} \tag{2}$$

From this, we can say that,

$$T_{on} = DT \tag{3}$$

$$T_{off} = (1 - D)T \tag{4}$$

To derive the relation between input voltage, output voltage and duty cycle, we verify volt-sec balance across the inductor. When the switch is off, the voltage across inductor is the input voltage V_{in}. When the switch is on, the voltage across inductor is the difference of output and input voltage, i.e., V_{in} - V_o Applying volt-sec balance in a cycle,

$$V_{in}(T_{off}) + (V_{in} - V_o)(T_{on}) = 0 \tag{5}$$

Rewriting the equation in terms of Duty cycle,

$$V_o = \frac{V_{in}}{1 - D} \tag{6}$$

Hence, the output voltage of the boost converter can be controlled by the duty cycle of the converter.

This duty cycle also relates the input current,i.e., the inductor current(i_L), the capacitor current(i_C) and the output current(i_R). When the switch is on, the current through capacitor is the current through the load, i_R. When the switch is off, the current through capacitor is difference between load and inductor current, i_R - i_L Applying amp-sec balance in a cycle across capacitors,

$$i_R(DT) + (i_L - i_R)(1 - D)T = 0 \tag{7}$$

Therefore, the load current

$$i_R = \frac{i_L}{1 - D} \tag{8}$$

C. Voltage and current ripple

Due to the switching of the MOSFET, we see a ripple in the output current and voltage. In order to control the ripple, we need to select appropriate inductor(L) and capacitor values(C).

Current ripple is controlled by the value of inductor. Voltage across inductor when the switch is closed for a time, Δt = DT

$$V_{in} = L\frac{(\Delta i_L)_{closed}}{DT} \tag{9}$$

$$(\Delta i_L)_{closed} = \frac{V_{in}(DT)}{L} \tag{10}$$

Voltage across inductor when the switch is open for a time, Δt = (1-D)T

$$V_{in} - V_o = L\frac{(\Delta i_L)_{open}}{(1-D)T} \tag{11}$$

$$(\Delta i_L)_{open} = \frac{(V_{in} - V_o)(1-D)T}{L} \tag{12}$$

Since the inductor current controls the load current,the inductor value can be chosen according to the permissible amount of ripple for load current.

Voltage ripple is controlled by the value of the capacitor. The voltage ripple of output ΔV_R is equal to the voltage ripple across capacitor ΔV_c, since the load and capacitor are in parallel combination.

Current through capacitor i_c when the switch is closed for a time Δt = DT,

$$i_R = C\frac{(\Delta V_c)_{closed}}{DT} \tag{13}$$

$$(\Delta V_c)_{closed} = \frac{i_R(DT)}{C} \tag{14}$$

Current through capacitor i_c when the switch is open for a time Δt = (1-D)T,

$$i_L - i_R = C\frac{(\Delta V_c)_{open}}{(1-D)T} \tag{15}$$

$$(\Delta V_c)_{open} = \frac{(i_L - i_R)(1-D)T}{C} \tag{16}$$

Since the voltage across capacitor is the voltage across the load, the capacitor value can be chosen according to the permissible amount of ripple of output voltage.

III. Three level boost converter

The following image depicts a three-level boost converter. In this, a capacitor voltage divider is used in parallel with the load. To maintain the symmetry and balance of the converter, the capacitance of both capacitors must be equal(C_1=C_2), This in turn makes the center point voltage as $V_o/2$.

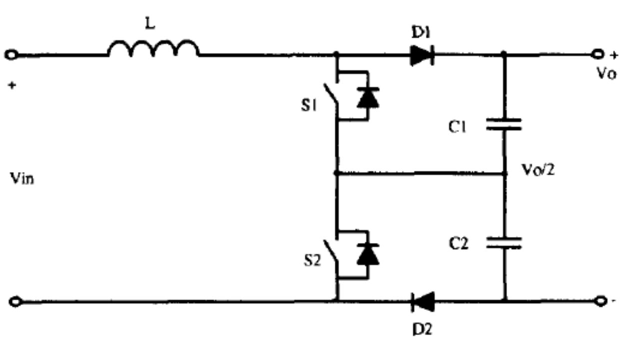

Fig 2: Three level Boost converter

The TLBC has four different states of operation, depending on which of the switches are on or off at a given time. This makes the TLBC more dynamic and can provide higher gain than a traditional boost converter.

A. Operating modes

TLBC has two different operating modes depending on the output required.

1) Region 1 - $V_{in} > V_o/2$: When the required output is less than twice the input voltage, then we apply the operating mode as shown in figure 3. In this operation mode, duty cycle $D < 0.5$

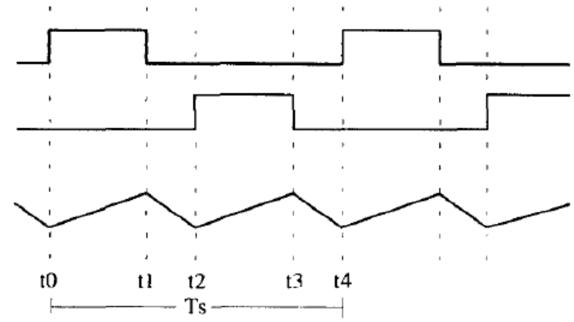

Fig 3: Operation waveform when $V_{in} > V_o/2$

The switch S1 is turned on for time DT and then turned off throughout the cycle. During this time, S2 is off. The switch S2 is turned on from T/2 to T/2 + DT.

In this operating mode, the expression for ripple current is given as follows. Voltage across inductor when switch S1 is closed is V_{in} - $V_o/2$

$$(\Delta i_L)_{closed} = \frac{(V_{in} - V_o/2)(DT)}{L} \tag{17}$$

Voltage across inductor when switch S1 is open is V_{in} - V_o

$$(\Delta i_L)_{open} = \frac{(V_{in} - V_o)(1-D)T}{L} \tag{18}$$

In this equation, the maximum current ripple occurs when D=0.5 and at the point where $\frac{\partial \Delta i}{\partial V_{in}} = 0$. This point is $V_{in} = 0.25V_o$. Hence the expression for maximum current ripple is for the output of the system is,

$$\Delta i = \frac{V_o T}{16L} \tag{19}$$

The voltage ripple can be written

2) Region 2 - $V_{in} < V_o/2$: When the required output is more than twice the input voltage, then we apply the operating mode as shown in figure 4. In this operation mode, duty cycle $D > 0.5$

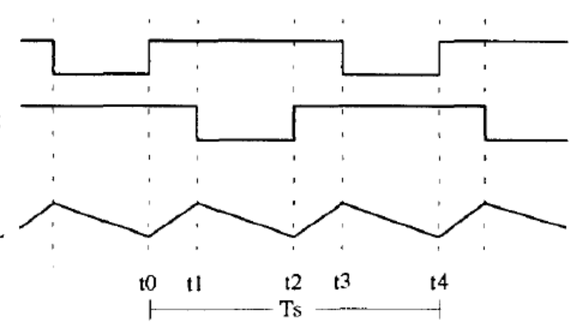

Fig 4: Operation waveform when $V_{in} < V_o/2$

The switch S1 is turned on for time DT and then turned off throughout the cycle. The switch S2 is turned on from T/2 to T/2 + DT. In this switching mode, both the switches are on for a short period of time, but the duty cycle of eacg switch remains the same.

In this operating mode, the expression for ripple current is given as follows. Voltage across inductor when one switch is closed is $V_o/2$ - V_{in}

$$(\Delta i_L)_1 = \frac{(V_o/2 - V_{in})(DT)}{L} \tag{20}$$

Voltage across inductor when both switches are closed is V_{in}

$$(\Delta i_L)_2 = \frac{(V_{in})(1-D)T}{L} \tag{21}$$

In this equation, the maximum current ripple occurs when D=0.5 and at the point where $\frac{\partial \Delta i}{\partial V_{in}} = 0$. This point is $V_{in} = 0.75V_o$. Hence the expression for maximum current ripple is for the output of the system is,

$$\Delta i = \frac{V_o T}{16L} \tag{22}$$

In both of these operation modes, the voltage ripple across the load(Δv_o) is split between the two capacitors, the voltage ripple across each capacitor, is $\Delta v_o/2$. Hence the expression for voltage ripple across the load,

$$\Delta V_o = 2i_o\frac{DT}{C} \tag{23}$$

IV. Maximum Power Point Tracking

A PV cell has a peculiar Current vs Voltage characteristic curve, as shown in figure 5. This curve shows the short circuit current and open circuit voltage of the solar cell. The point where the power is maximum in the curve is called the Maximum Power Point. The Power vs Voltage curve shows how the output power of a PV cell reaches a peak and then drops as the voltage varies from 0 to open circuit voltage. The PV cell will produce maximum power when operated at V_{mp}, i.e., the voltage at MPP. Usually, the maximum power point depends on the PV cell, irradiance, temperature and shading conditions.

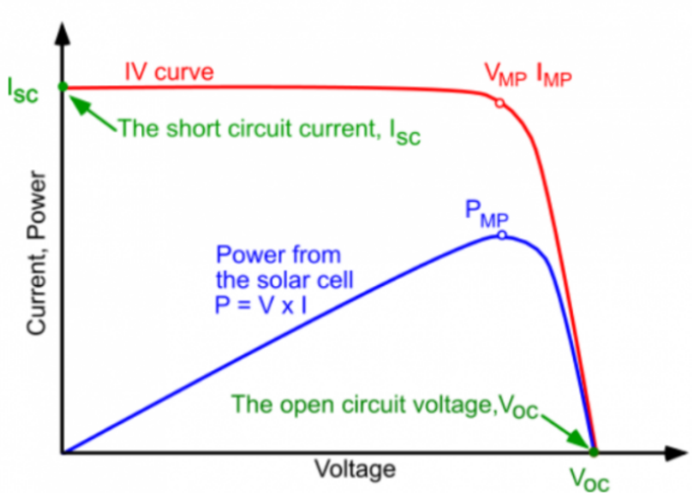

Fig 5: I-V and P-V Curve of a PV cell

A DC-DC converter is used as an MPP tracker for PV modules. The PV module is connected to the input of the DC-DC converter and the MPP tracking is done by controlling the duty cycle of the converter.

The two major MPP tracking methods are as follows:

A. Perturb and Observe(P O)

In this MPPT method, we disturb the voltage slightly and observe the change in the power output, and in turn, change the voltage accordingly to reach the MPP. If we perturb the voltage and the change in power is positive, we are moving towards the MPP, and we must perturb the voltage in the same direction. If the change in power is negative, then we are moving away from the MPP and we must perturb the voltage in the opposite direction.