Principle document of A simple low power DC-DC boost converter

Very often a low power boost converter used to convert some low voltage to a higher voltage is required in a system. This build exercise is to learn to build one such simple converter, using an open loop. Open loop implies that we will not use output voltage as feedback, as it gives fixed voltage.

Let us take a 5V DC input and lets us assume we need a 12V DC output, say up to 1Amp output current as shown in Fig1

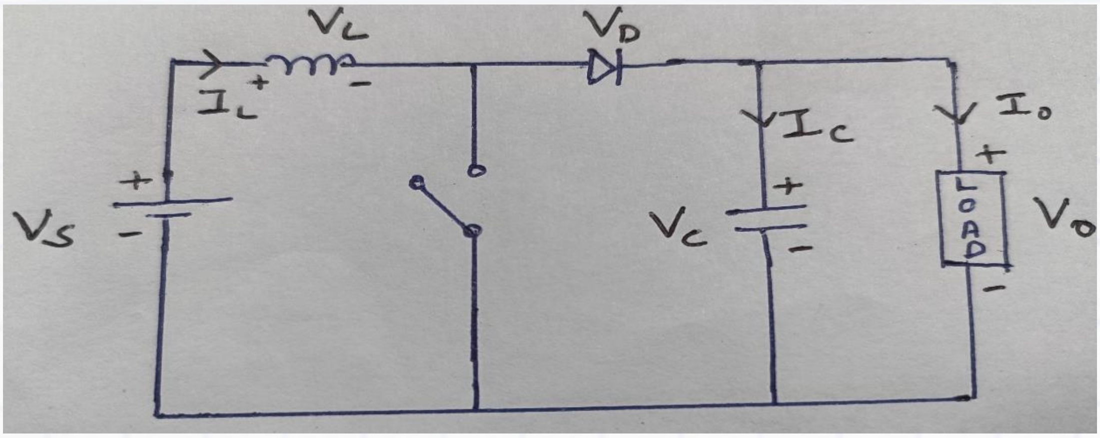

Fig1

The circuit consists of an inductor, a MOSFET (switch), a diode (D) and a capacitor(C). The MOSFET switch is turned ON and OFF at higher frequency, say at 20 KHz. Two more parameters are required to build the circuit, Let the output voltage be Vo and the output current be Io, the output will have ripples, which is ΔVo and ΔIo respectively.

Thus, the specification of the converter is:

V_s = Input supply voltage, say 5V

V_o = Output voltage, say 12V

I_o = Output current, say 1Amp

$\triangle Io$ = Output ripple current, say 10% of Io

$\triangle Vo$ = Output ripple voltage, say 10% of Vo

V_L = Inductor voltage

I_L = Inductor current

$\triangle I_L$ = 10% of Inductor current

F_m = Frequency

T =Total period

Po = output power

Pin = input power

A circuit to build a converter is shown in fig. 2. As mentioned, MOSFET will be switched ON and OFF at frequency F_m, with on time Ton and off time Toff.

Thus, Ton+Toff = $\frac{1}{Fm}$

And duty cycle D = $\frac{Ton}{Ton+Toff}$

One must obtain the values of D, L and C to need the desired specs.

How does a converter work?

1. <u>During MOSFET ON period</u>, the circuit required is in Fig2. The diode represents two circuits, with Vs discharging through inductor and MOSFET as one and the capacitor discharging through load as another.

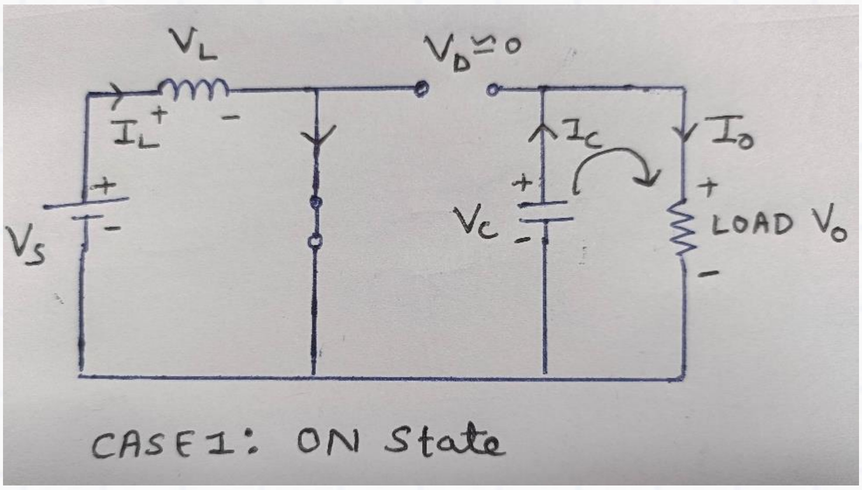

Fig2: V_S Discharged through inductor during MOSFET on

We get,

$V_L = V_S,$ and

$L\frac{di_l}{dt} = V_S$ or

$di_l = \frac{V_S}{L}dt$

Integrating both side

$\Delta I_L = \frac{V_s}{L}\int_0^{Ton} dt$

$\Delta I_L = \frac{V_S}{L}\text{Ton}$ …………eqn (1)

As Ton = DT, and T= $\frac{1}{\mathrm{F_m}}$

$\Delta I_L = \frac{\mathrm{V_S D}}{\mathrm{L\,F_m}}$ …………eqn (2)

As, Po = Pin

power supplied by the source must be the same as the power absorbed by the load. Hence

Vo Io = Vs I_L

$\mathrm{I_L} = \frac{\mathrm{Vo\ Io}}{\mathrm{Vs}}$

Assume that it is not desirable to have ΔI_L higher than ΔI_o, which is 10% of Io. With that assumption, we are taking $\triangle \mathrm{I_L}$ is 10% of $\mathrm{I_L}$.

Now using eqn(2) we can compute L

$\mathrm{L} = \frac{\mathrm{DV_S}}{\mathrm{F_m \Delta I_L}}$

Let us now look at capacitor discharged through load, R

The discharge is Q= Io×Ton = $\frac{\mathrm{Vo \times Ton}}{\mathrm{R}}$

Where R is load resistance. Thus, the voltage Vo will drop

$\Delta Vo = \frac{Q}{C}$ or $\frac{\mathrm{Vo \times Ton}}{\mathrm{RC}}$ or $\frac{\mathrm{Vo \times DT}}{\mathrm{RC}}$, or

$\Delta Vo = \frac{\mathrm{Vo \times D}}{\mathrm{RCF_m}}$ = output ripple voltage………eqn (3)

In otherwards,

$\Delta Io \times R = \frac{\mathrm{Io \times D}}{\mathrm{CF_m}}$ or,

$$\Delta Io = \frac{Io \times D}{RCF_m} = \text{output ripple current} \ldots\ldots\ldots \text{ eqn (4)}$$

From eqn (2),

$$\frac{\Delta Vo}{Vo} = \frac{D}{RCF_m}$$

From maximum load, we can compute C:

$$C = \frac{Vo \times D}{\Delta VoRF_m}$$

For, higher load (lower output pulse), ripple will always be less.

2. <u>During MOSFET OFF:</u> The circuit is given by Fig.3 the current I_L now will fall as shown in Fig.4 - 4(b).

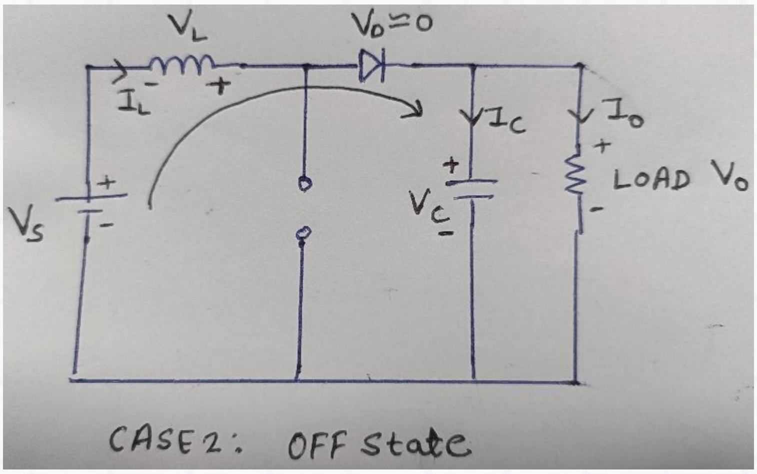

Fig.3

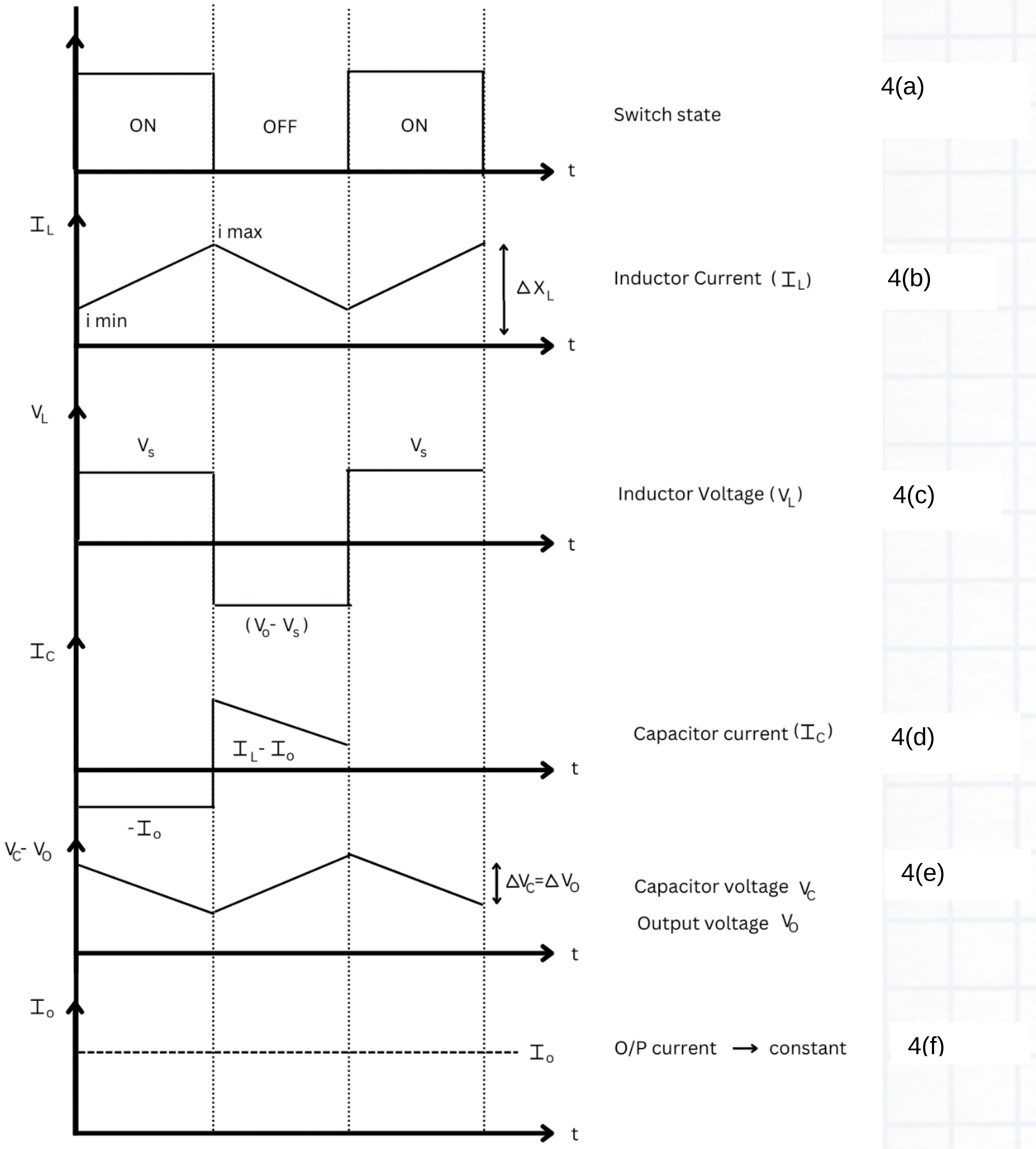

Fig.4 Waveforms

The Voltage across inductor, as shown as 4(c)

$V_L = (V_o\text{-}V_S)$, or

$$L\frac{di_L}{dt} = (Vo - Vs) \text{ ....eqn (5),}$$

$$\Delta I_L = \frac{(V_o - V_S)}{L}\int_{Ton}^{Ton+Toff} dt$$

$$\Delta I_L = \frac{(V_o - V_S)Toff}{L} \text{ ....eqn (6),}$$

During steady state, the fall ΔI_L given in eqn (6), must be same as the rise ΔI_L during ON period given in eqn (1). Thus

$$\frac{(V_o - V_S)Toff}{L} = \frac{V_S Ton}{L}$$

$(V_o - V_S)Toff = V_s Ton,$

As Ton = DT, and

Toff = T - Ton = T – DT,

By substituting We get,

$(V_o - V_S)(T - DT) = Vs\ DT,$

$(Vo - Vs)(1 - D) = Vs\ D,$

or $V_o = \frac{V_S}{1-D}$............. eqn (7)

This can be used to compute D required to obtain the required output voltage.

Summarizing all the formulas:

$$Vo = \frac{V_S}{1-D}$$

$$L = \frac{DV_S}{F_m \Delta I_L}$$

$$C = \frac{VoD}{\Delta VoRF_m}$$

Calculations: According to the specs of the converter, calculating D, L and C

$$D = 1 - \frac{5}{12} = 0.58 = 58\ \%$$

$$L = \frac{0.58 \times 5}{20\ KHZ \times 0.24} = 0.6\text{mH}$$

$$C = \frac{12 \times 0.58}{12 \times 1.2 \times 20\text{khz}} = 24.16\mu\text{F}$$

<u>Losses</u>

There are four types of losses:

a. Switching loss

b. Conduction loss

c. Inductor loss

d. Diode loss

Thus, the specification for calculating losses is:

t_r = rise time of MOSFET, says 98ns

t_f = fall time of MOSFET, says 21ns

R_{DS} = drain to source resistance of MOSFET, says 3.7milli ohm

R_L= internal Inductor resistance, says 3 mH

P_o= output power, says 12 watts

V_f = forward voltage of diode, says 0.7V

$P_{total\ losses}$ = sum of all losses

Note: These parameters depend on components datasheet.

$$P_{switching\ loss} = \frac{V_L\ I_L(t_r+t_f)F_m}{6}$$

$$P_{conduction\ loss} = {I_L}^2 R_{DS}\ D$$

$$P_{inductor\ loss} = {I_L}^2 R_L\ D$$

$$P_{Diode\ loss} = V_f\ \ I_L(1 - D)$$

$$\text{Efficiency} = \frac{P_o}{P_o+P_{Total\ losses}} \times 100\%$$

Steps for designing boost converter with the help of Dexter Board

1. Design a Boost converter circuit on zero dot board.
2. Drive the switching device (MOSFET) with the help of the Dexter board.
3. Use STM32CUBE IDE for generating PWM.
4. Supply voltage = 5Volt, Supply frequency = 20kHZ