Step-Down dc-dc Converter for Low Temperature Plasma

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Abstract. This paper presents a step down converter with a high speed rectifier and filter for Argon plasma torches. Buck circuit with a high frequency pulse width modulation control and very fast MOSFET transistor were used for switching. For Argon (Ar) gas Plasma Torches, and by increasing the pulse width, the average output voltage has modified from 80 V up to 100 V. The frequency of the designed step down converter was steady at 20 KHz.

Keywords. Step Down Converters, Buck Circuit, MOSFET, Filters, Argon Plasma

1. Introduction

The step down converter (Buck Converter) is used in SMPS circuits where the DC output voltage needs to be lower than the DC input voltage. The DC input can be derived from rectified AC or from any DC supply. It is useful where electrical isolation is not needed between the switching circuit and the output, but where the input is from a rectified AC source, isolation between the AC source and the rectifier could be provided by a mains isolating transformer. Fig. 1. shows the schematic of a step down converter [1-5].
2. Experimental Setup

Fig. 2. shows the schematic of Argon plasma power supply. The switching transistor between the input and output of the Buck Converter continually switches on and off at high frequency. To maintain a continuous output, the circuit uses the energy stored in the inductor $L$, during the on periods of the switching transistor, to continue supplying the load during the off periods. The circuit operation depends on what is sometimes also called a Flywheel Circuit ($L, C_{out}$). This is because the circuit acts rather like a mechanical flywheel that, given regularly spaced pulses of energy keeps spinning smoothly (outputting energy) at a steady rate.

![Schematic of Argon plasma power supply](image)

**Figure 2.** Schematic of Argon plasma power supply

Fig. 3. shows the typical plasma torches Volt-Ampere characteristics. The first region is the forward leakage, in this region the current is very little and no plasma emission. The second region is the reverse, in this region the current increases and the voltage decreases (negative load), for few gases there is a plasma emission. The third region is the forward conduction, in this region the current increases and the voltage increases too (positive load), this the case of argon gas which will be studied in this paper [6-23].

![Volt-Ampere characteristics](image)

**Figure 3.** Typical plasma torches Volt-Ampere characteristics

3. Results and discussion

The following three parameters are needed to calculate the power stage:
1. Input voltage range: $V_{IN(min)}$ and $V_{IN(max)}$
2. Nominal output voltage: $V_{out} = 100 \, V$
3. Maximum output current: \( I_{out(max)} \)
If these parameters are known, the power stage can be calculated.

**Calculate the Maximum Switch Current**
The first step to calculate the switch current is to determine the duty cycle \( D \), for the maximum input voltage. The maximum input voltage is used because this leads to the maximum switch current. 
\( \text{\( V_{IN(max)} \)} \) = maximum input voltage 350 V. 
\( V_{out} \) = output voltage 100 V.

Duty Cycle:

\[
D = \frac{V_{out}}{V_{IN(max)} \cdot \eta} = 0.32
\]

\( \eta \) = efficiency of the converter, e.g., estimated 90%

The next step in calculating the maximum switch current is to determine the inductor ripple current. 

\( V_{IN} \) = typical input voltage 310 V
\( V_{out} \) = desired output voltage 100 V
\( f_s \) = minimum switching frequency of the converter 20 KHz
\( \Delta I_L \) = estimated inductor ripple current, see the following:

A good estimation for the inductor ripple current is 20% to 40% of the output current.

\[
L = \frac{(V_{IN} - V_{out}) \cdot V_{out}}{\Delta I_L \cdot f_s \cdot V_{IN}} = 226 \ \mu H
\]

\( \Delta I_L \) = 0,3 \( I_{out(max)} \)

\( I_{out(max)} \) = maximum output current 50 A.

\( \Delta I_L \) = 15 A

**Rectifier Diode Selection**
To reduce losses, use Schottky diodes. The forward current rating needed is equal to the maximum output current:

\[
I_F = I_{out(max)} \cdot (1 - D) = 34 A
\]

\( I_F \) = average forward current of the rectifier diode
\( I_{out(max)} \) = maximum output current necessary in the application. Schottky diodes have a much higher peak current rating than average rating. Therefore the higher peak current in the system is not a problem.

The other parameter that has to be checked is the power dissipation of the diode.

\[
P_D = I_F \cdot V_F = 24 W
\]

\( I_F \) = average forward current of the receiver diode
\( V_F \) = forward voltage of the rectified diode.

**Output Capacitor Selection**
The best practice is to use low-ESR capacitors to minimize the ripple on the output voltage. Ceramic capacitors are a good choice if the dielectric material is X5R or better.
If the converter has external compensation, any capacitor value above the recommended minimum in the data sheet can be used, but the compensation has to be adjusted for the used output capacitance.

With internally compensated converters, the recommended inductor and capacitor values must be used, or the recommendations in the data sheet for adjusting the output capacitors to the application in the datasheet must be followed for the ratio of $L \times C$.

With external compensation, the following equations can be used to adjust the output capacitor values for a desired output voltage ripple:

$$C_{\text{out(min)}} = \frac{\Delta I}{8 \cdot f_s \cdot \Delta V_{\text{out}}} = 19 \mu F$$

- $C_{\text{out(min)}}$ = minimum output capacitance
- $\Delta I$ = estimated inductor ripple current
- $f_s$ = minimum switching frequency of the converter
- $\Delta V_{\text{out}}$ = desired output voltage ripple 5 V

Table 1 shows all the parameters of this converter.

| Parameters       | The value |
|------------------|-----------|
| $V_{IN}$         | 310 V     |
| $V_{IN(\text{max})}$ | 350 V   |
| $V_{IN(\text{min})}$ | 250 V   |
| $V_{out}$        | 100 V     |
| $I_{out(\text{max})}$ | 50 A    |
| $f_s$            | 20 KHz    |
| $\eta$           | 90%       |
| $D_{\text{max}}$ | 0.32      |
| $L$              | 226 $\mu H$ |
| $C_{\text{out(min)}}$ | 19 $\mu F$ |
| $L_F$            | 226 $\mu H$ |
| $I_F$            | 34 A      |

4. Conclusion

In short, the working region of the step down converter of the argon plasma torches can be only in the forward conduction region (Positive resistor). For argon gas plasma step down converter (Buck), and by increasing the Duty Cycle ($D$) from 25% up to 32% the average output voltage $V_{\text{out(ave)}}$ has modified from 70 V up to 100 V, and the average output current $I_{out(ave)}$ has modified from 40 A up to 50 A. The switching frequency of the step down converter $f_s$ was constant at the value 20 KHz.

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