1. Dc-Dc Converter

A DC–DC converter converts a fixed DC voltage into a variable DC voltage, functioning like a transformer that can step up or step down voltage. They are widely used in applications such as electric vehicles, trolley cars, forklifts, and marine hoists to provide smooth acceleration, high efficiency, and fast response. DC converters also enable regenerative braking in DC motors to save energy, are used in voltage regulators, and can work with inductors to generate a DC current source for current source inverters.

2. Performance Parameters of DC–DC Converters

Both the input and output voltages of a dc–dc converter are dc. This type of converter can produce a fixed or variable dc output voltage from a fixed or variable dc voltage as shown in Figure A. The output voltage and the input current should ideally be a pure dc, but the output voltage and the input current of a practical dc–dc converter contain harmonics or ripples as shown in Figure B. The converter draws current from the dc source only when the converter connects the load to the supply source and the input current is discontinuous.

The dc output power is

$$P_{dc} = I_a V_a$$

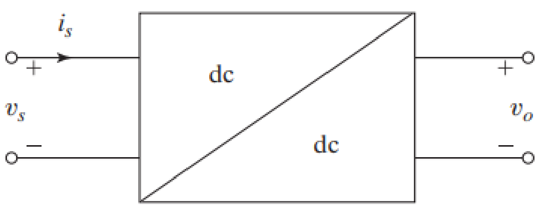
where V_a and I_a are the average load voltage and load current.

The ac output power is

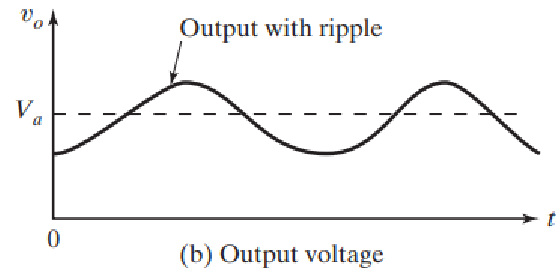
$$P_{ac} = I_o V_o$$

where V_o and I_o are the rms load voltage and load current.

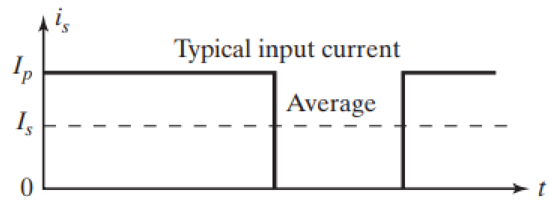
The converter efficiency (not the power efficiency) is



(a) Block diagram



(b) Output voltage



(c) Input current

$$\eta_c = \frac{P_{dc}}{P_{ac}}$$

The rms ripple content of the output voltage is

$$V_r = \sqrt{V_o^2 - V_a^2}$$

The rms ripple content of the input current is

$$I_r = \sqrt{I_i^2 - I_s^2}$$

where I_i and I_s are the rms and average values of the dc supply current.

The ripple factor of the output voltage is

$$RF_o = \frac{V_r}{V_a}$$

The ripple factor of the input current is

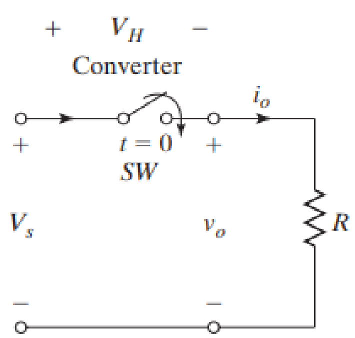
$$RF_s = \frac{I_r}{I_s}$$

The power efficiency, which is the ratio of the output power to the input power, will depend on the switching losses, which in turn depend on the switching frequency of the converter.

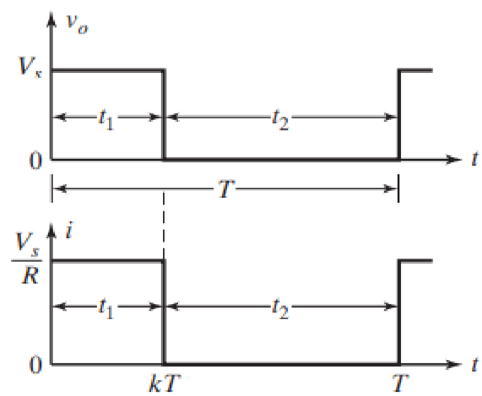
The switching frequency f should be high to reduce the values and sizes of capacitances and inductances. The designer has to compromise on these conflicting requirements. In general, fs is higher than the audio frequency of 18 kHz.

3. Principle of Step-Down Operation

The principle of operation can be explained by Figure A. When switch SW, known as the chopper, is closed for a time t1, the input voltage Vs appears across the load. If the switch remains off for a time t2, the voltage across the load is zero. The waveforms for the output voltage and load current are also shown in Figure B



(a) Circuit



(b) Waveforms

The average output voltage is given by

$$V_a = \frac{1}{T}\int_0^{t_1} v_0\, dt = \frac{t_1}{T}V_s = ft_1 V_s = kV_s$$

and the average load current, $I_a = V_a/R = kV_s/R$,

where T is the chopping period;
$k = t_1/T$ is the duty cycle of chopper;
f is the chopping frequency.

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The rms value of output voltage is found from

$$V_o = \left(\frac{1}{T}\int_0^{kT} v_0^2\,dt\right)^{1/2} = \sqrt{k}\,V_s$$

Assuming a lossless converter, the input power to the converter is the same as the output power and is given by

$$P_i = \frac{1}{T}\int_0^{kT} v_0 i\,dt = \frac{1}{T}\int_0^{kT}\frac{v_0^2}{R}dt = k\frac{V_s^2}{R}$$

The effective input resistance seen by the source is

$$R_i = \frac{V_s}{I_a} = \frac{V_s}{kV_s/R} = \frac{R}{k}$$

Example.1: Finding the Performances of a Dc–Dc Converter

The dc converter in Figure has a resistive load of R = 10 Ω and the input voltage is Vs = 220V. When the converter switch remains on, its voltage drop is vch = 2V and the chopping frequency is f = 1kHz. If the duty cycle is 50%, determine (a) the average output voltage Va, (b) the rms output voltage Vo, (c) the converter efficiency, (d) the effective input resistance Ri of the converter, (e) the ripple factor of the output voltage RFo, and (f) the rms value of the fundamental component of output harmonic voltage.

Solution

$V_s = 220\,\text{V}$, $k = 0.5$, $R = 10\,\Omega$, and $v_{ch} = 2\,\text{V}$.

a. From Eq. (5.8), $V_a = 0.5 \times (220 - 2) = 109\,\text{V}$.
b. From Eq. (5.9), $V_o = \sqrt{0.5} \times (220 - 2) = 154.15\,\text{V}$.
c. The output power can be found from

$$P_o = \frac{1}{T}\int_0^{kT}\frac{v_0^2}{R}dt = \frac{1}{T}\int_0^{kT}\frac{(V_s - v_{ch})^2}{R}dt = k\frac{(V_s - v_{ch})^2}{R}$$

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$$= 0.5 \times \frac{(220 - 2)^2}{10} = 2376.2\,\text{W}$$

The input power to the converter can be found from

$$P_i = \frac{1}{T}\int_0^{kT} V_s i \, dt = \frac{1}{T}\int_0^{kT} \frac{V_s(V_s - v_{ch})}{R} dt = k\frac{V_s(V_s - v_{ch})}{R} \tag{5.13}$$

$$= 0.5 \times 220 \times \frac{220 - 2}{10} = 2398\,\text{W}$$

The converter efficiency is

$$\frac{P_o}{P_i} = \frac{2376.2}{2398} = 99.09\%$$

d. From Eq. (5.11),

$$R_i = V_s/I_a = V_s(V_a/R) = 220 \times (109/10) = 20.18\,\Omega$$

e. Substituting V_a from Eq. (5.8) and V_o from Eq. (5.9) into Eq. (5.6) gives the ripple factor as

$$\text{RF}_o = \frac{V_r}{V_a} = \sqrt{\frac{1}{k} - 1} \tag{5.14}$$

$$= \sqrt{1/0.5 - 1} = 100\,\%$$

f. The output voltage as shown in Figure 5.2b can be expressed in a Fourier series as

$$v_o(t) = kV_s + \sum_{n=1}^{\infty} \frac{V_s}{n\pi} \sin 2n\pi k \cos 2n\pi ft + \frac{V_s}{n\pi}\sum_{n=1}^{\infty}(1 - \cos 2n\pi k) \sin 2n\pi ft \tag{5.15}$$

The fundamental component (for $n = 1$) of output voltage harmonic can be determined from Eq. (5.15) as

$$v_1(t) = \frac{(V_s - v_{ch})}{\pi}[\sin 2\pi k \cos 2\pi ft + (1 - \cos 2\pi k)\sin 2\pi ft] \tag{5.16}$$

$$= \frac{(220 - 2) \times 2}{\pi} \sin(2\pi \times 1000t) = 138.78 \sin(6283.2t)$$

and its root-mean-square (rms) value is $V_1 = 138.78/\sqrt{2} = 98.13\,\text{V}$.