ET4119 Electronic Power Conversion 2011/2012
Solutions 20 April 2012

1. Figure 1a shows a single-phase rectifier that is connected to a supply voltage v_s and a battery. The battery is represented by a DC load voltage V_d. The voltage v_s has a block-like shape (Figure 1b) that is produced by some HF inverter (not shown). The rectifier is intended to charge the battery. Depending on the charging state of the battery the voltage V_d may vary. The circuit specifications are as follows:

- $V_{d,nom}$=160V (nominal voltage of V_d)
- V_s=300V (amplitude of v_s as shown in Figure 1b)
- T_s=30µs (period of voltage v_s)
- f_s= 1/T_s=33.3 kHz (frequency of v_s)
- L_s=20 µH

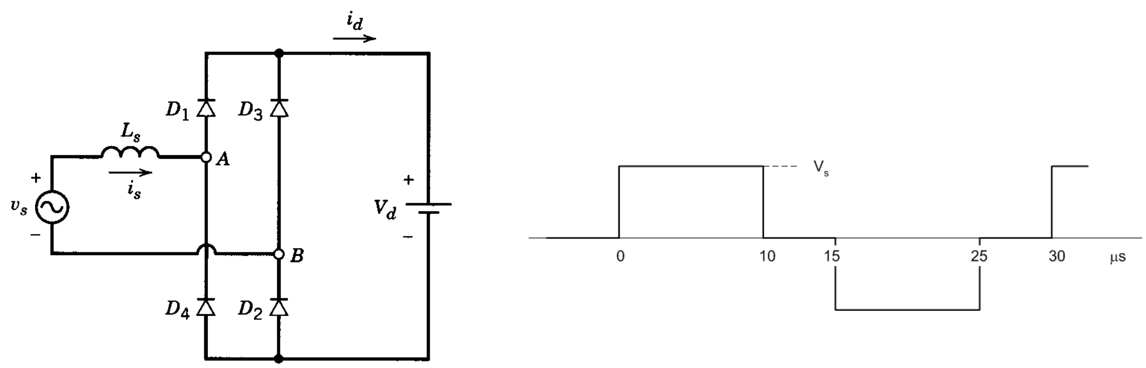


Figure 1 a. rectifier circuit b. input voltage waveform

No worked out solutions

2. Figure 2 shows a boost converter used in the Toyota Prius hybrid electric vehicle for stepping up the battery voltage from 150-250 V to 500 V. The converter's switching frequency is f_s= 20kHz.

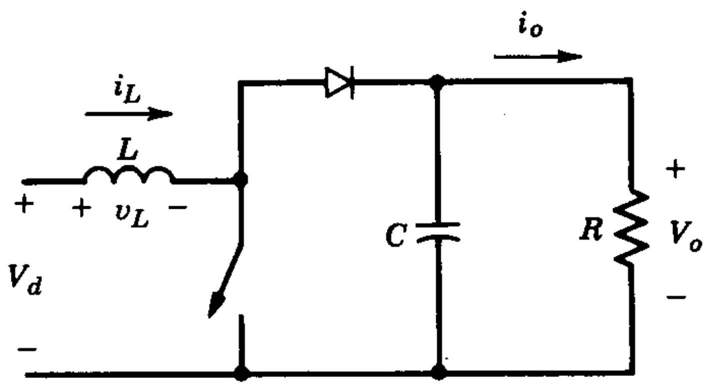


Figure 2 Boost converter

2.1.

$I_o := 10A$

$$L_{crit}(V_{in}) := \frac{V_o \cdot \left(1 - \frac{V_{in}}{V_o}\right) \cdot \left(\frac{V_{in}}{V_o}\right)^2}{2 \cdot I_o} \cdot T_s$$

$L_{crit}(V_{inmin}) = 78.75\mu H$

$L_{crit}(V_{inmax}) = 156.25\mu H$

2.2

$L_o := L_{crit}(V_{inmin})$

$I_{onom} := 4A$

$$D(V_{in}) := \sqrt{\frac{2}{1} \cdot \frac{I_{onom}}{\left(\frac{T_s}{L_o}\right) \cdot \frac{V_{in}^2}{V_o - V_{in}}}}$$

$D(V_{inmin}) = 0.443$

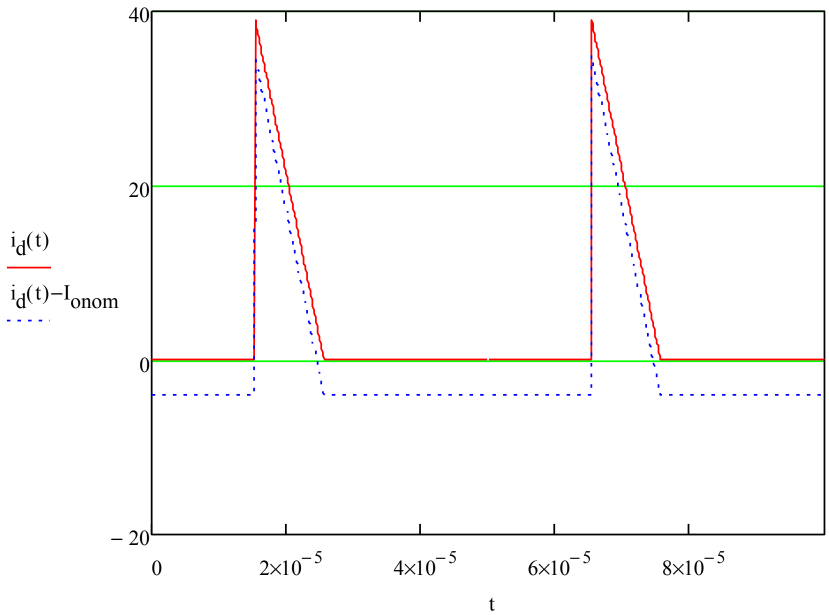
$D(V_{inmax}) = 0.224$

2.3

$$\Delta\left(V_{in}\right) := \frac{I_{onom}\cdot 2\cdot L_o}{T_s\cdot D\left(V_{in}\right)\cdot V_{in}}$$

$V_{in} := 200V$

$D_1 := D\left(V_{in}\right)$ $\quad\Delta_1 := \Delta\left(V_{in}\right)$ $\quad D_1 = 0.307$ $\quad\Delta_1 = 0.205$



$t_1 := D_1\cdot T_s$

$$t_2 := \frac{\frac{V_{in}}{L_o}\cdot D_1\cdot T_s - I_{onom} + \frac{V_o - V_{in}}{L_o}\cdot D_1\cdot T_s}{\left(\frac{V_o - V_{in}}{L_o}\right)}$$

$t_1 = 15.37\mu s$ $\quad t_2 = 24.567\mu s$

$$Q := \left[\int_{t_1}^{t_2}\left(i_d(t) - I_{onom}\right)dt\right]$$

$Q = 1.611\times 10^{-4}C$

$$C_{req} := \frac{Q}{2\%\cdot V_o}$$

$C_{req} = 16.111\mu F$

3. A switch-mode power supply is to be designed with the following specifications:

- V_d=48V±10%
- V_o=5V (regulated)
- f_s=100kHz
- P_{load}=15-50W

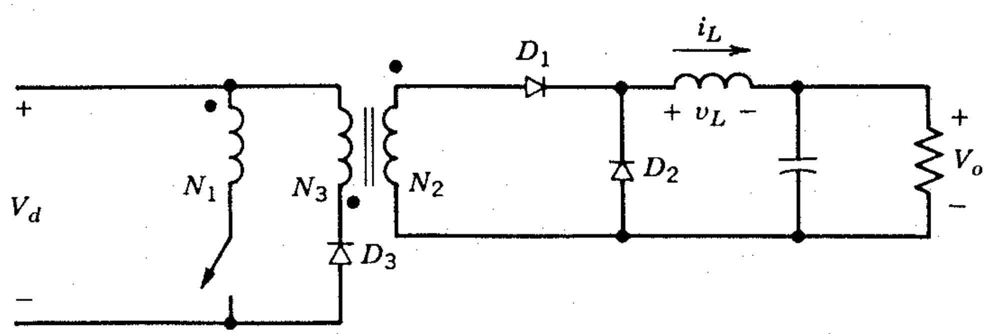


Figure 3 Forward converter

A forward converter topology shown in Figure 3 operating in a continuous conduction mode with a demagnetising winding (N_3=N_1) is chosen. Assume all components to be ideal except for the presence of transformer magnetising inductance.

3.1 See book, especially the chapter titled Forward Converter

3.2

Since $N_3 = N_1$, $D_{max} = 0.5$, $V_d = 43.2$ V to 52.8 V.

$$\frac{V_o}{V_d} = \frac{N_2}{N_1} D \quad \text{(continuous conduction)}$$

or,
$$\frac{N_2}{N_1} = V_o \frac{1}{(V_d)_{min} \cdot D_{max}} = \frac{5}{43.2 \times 0.5} = 0.232$$

The reason for using $(V_d)_{min}$ at the maximum allowable duty ratio is that at higher values of V_d, this converter can operate at lower values of D ($D < D_{max}$ of 0.5). For example, at $(V_d)_{max} = 52.8$ V with the above choice of $\frac{N_2}{N_1}$,

$$D = \left(\frac{5}{52.8}\right)/0.232 = 0.408.$$

3.3

At the boundary of cont./discont. conduction,

$$\frac{1}{2}\,\frac{(V_d\,\frac{N_2}{N_1} - V_o)}{L_{min}}\,t_{on} = I_{o,min}$$

or,
$$L_{min} = \frac{(V_d \cdot \frac{N_2}{N_1} - V_o)\,D}{2f_s\,I_{o,min}}$$

at $(V_d)_{min} = 43.2$ V, $D = 0.5$ $\therefore$ $L_{min1} = 4.18\ \mu H$

at $(V_d)_{max} = 52.8$ V, $D = 0.408$ $\therefore$ $L_{min2} = 4.93\ \mu H$

Therefore, $L_{min} = 4.93$ should be used.

4. Given is a single-phase full bridge dc/ac voltage source converter that is connected to a single phase induction motor with counter emf e_0, as shown in Figure 4. The output voltage v_0 of the inverter is obtained by bipolar voltage switching. To obtain a low distortion linear modulation is applied.

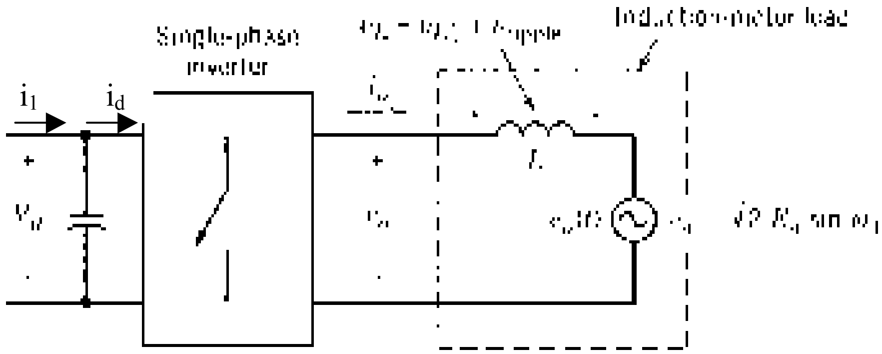


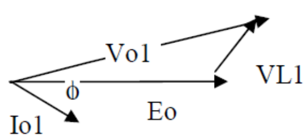
Figure 4 Full bridge inverter

Given is further:

- Vd = 350V (DC link voltage)
- $\omega_{1,nom}$ $=2\pi 60$ rad/s (nominal value of ω_1)
- $V_{01,nom}$ =230 V (nominal rms value of fundamental of v_0)
- L = 30 mH (inductance of machine)
- f_s=7.5 kHz (frequency of triangular carrier v_{tri})
- C_d=1 mF (capacitance of input filter)
- At nominal speed and nominal voltage the input power of the loaded drive is 1 kW at cos φ_1=0.8

4.1

$P_0 = V_0 I_0 \cos\phi_1$ or I_0=5.43 A . (so $\omega L_s I_0$=61.4V). Note that ϕ is the angle between V_o and I_o. The phasor diagram is like fig 8-18d.



4.2

$$m_a = \frac{\hat{V}_{control}}{\hat{V}_{tri}}; \qquad V_0\sqrt{2} = m_a \cdot V_d \quad \text{or} \quad m_a = 0.929.$$

4.3

$$p_0(t) = \sqrt{2}\, V_0 \sin\omega_1 t \cdot \sqrt{2} I_0 \sin(\omega_1 t - \phi) = V_0 I_0 \cos\phi - V_0 I_0 \cos(2\omega_1 t - \phi)\ .$$

4.4

For low frequencies: $p_d(t) = p_0(t)$ with $p_d(t) = V_d \cdot i_d$ (See Mohan fig 8-13) so

$$i_d(t) = \frac{V_0 I_0}{V_d}\cos\phi - \frac{V_0 I_0}{V_d}\cos(2\omega_1 t - \phi) = 2.85 - 3.57\cos(\omega_1 t - 36.9^0)$$

Amplitude of (sinusoidal) low frequency (120 Hz) current ripple:

$$\hat{i}_{ripple} = \frac{V_0 I_0}{V_d} = \frac{230 \cdot 5.43}{350} = 3.57A; \quad \rightarrow$$

$$\hat{V}_{d,ripple} = \frac{\ddot{i}_{ripple}}{2\omega_1 C_d} = \frac{3.57}{2 \cdot 120\pi \cdot 10^{-3}} = 4.73V;$$ Peak-to-peak

value: $\Delta V_d = 2\hat{V}_{d,ripple} = 9.46V$