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EE4001 Quiz 2: Power Electronics

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PROBLEM 1: The system parameters of a permanent-magnet dc motor supplied by a switch-mode PWM dc-dc H-bridge converter are as follows: armature resistance $R_a = 0.35\,\Omega$, armature inductance $L_a = 1.5$ mH, motor moment of inertia 0.02 kg m^2, motor torque constant $k = 0.5$ Nm/A, converter dc bus voltage $V_d = 200$ V, switching frequency $f = 25$ kHz, and amplitude of triangular waveform control voltage $V_{tri} = 3$ V. The motor is spinning in a forward direction at a speed of 1500 RPM, supplying a load torque of 10 Nm.

Calculate the following: (a) the applied armature voltage Vab; (b) the duty ratio for the overall converter; (c) the peak-to-peak ripple on the armature current.

$R_a = 0.35\,\Omega$ $\quad V_d = 200V$ $\quad N = 1500 rpm$

$L_a = 1.5 mH$ $\quad f_{sw} = 25 kHz$ $\quad \omega = 50\pi\, rpm$

$K = 0.5\, Nm/A$ $\quad V_{tri} = 3V$ $\quad T_L = 10\, Nm$

a) $V_{ab} = E + I_a R_a$

$= k\omega + \frac{T}{k} R_a$

$= 85.54\, V$

b) i) $d = \frac{V_{ab}}{V_d} = 0.428$

ii) $d_A = \frac{1}{2} + \frac{1}{2} d = 0.714$

iii) $d_B = \frac{1}{2} - \frac{1}{2} d = 0.286$

c) $\Delta I_{p-p} = \frac{V_L d T_s}{2 L_a} = \frac{(V_d - V_{ab}) d}{2 f_{sw} L_a}$

$= 0.653 A$

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PROBLEM 2: The 2043 Toyota Prius uses a 20 kW bidirectional converter to generate a 500 V dc link voltage from the 200 V NiMH battery. The bidirectional converter has an inductance of 435 uH and switches at 10 kHz. The above vehicle is operating in motoring mode and the bi-directional converter is required to act as a **boost** and provide full power. Calculate the average and rms currents in the switch and diode.

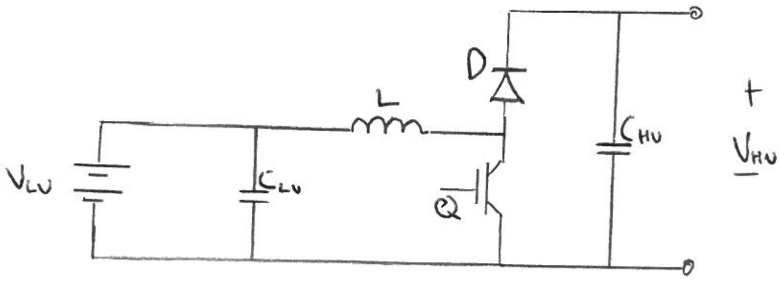
Boost: $\frac{V_o}{V_i} = \frac{1}{1-d} \Rightarrow d = 0.6$

$P = 20kW$

$f_{sw} = 10KHz$

$L = 435\mu H$

$I_i = \frac{P}{V_i} = 100A$



$$\Delta I_{p-p} = \frac{(V_{HU} - V_{LU})(1-d)}{f_{sw} L_a}$$

$$= 27.59A$$

$$i_{CLU} = \frac{\Delta I_{p-p}}{\sqrt{12}} = 7.96A$$

$$I_L = \sqrt{I_i^2 + i_{CLU}^2}$$

$$= 100.3A$$

$$I_{Q rms} = \sqrt{d}\, I_L = 77.7A$$

$$I_{Q AVG} = d I_L = 60.18A$$

$$I_{D rms} = \sqrt{1-d}\, I_L = 63.44A$$

$$I_{D AVG} = (1-d) I_L = 40.12A$$

$$i_{CHU} = \sqrt{I_{D rms}^2 - I_{D AVG}^2} = 49.2A$$

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PROBLEM 3: In a flyback converter, $V_I = 30$ V, $N_1 = 30$ turns, $N_2 = 15$ turns. The self-inductance of winding 1 is 50 μH and $f_s = 200$ kHz. The output voltage is regulated at 9V and full power is 27 W. Assume ideal components with no parasitics. Determine the switch duty cycle and the maximum voltage across the switch. Estimate the peak current in the switch at full load.

$$\frac{V_o}{V_i} = n\frac{d}{1-d} \Rightarrow d = \frac{V_o}{V_o + nV_i}$$

$V_1 = 30V$, $N_1 = 30$

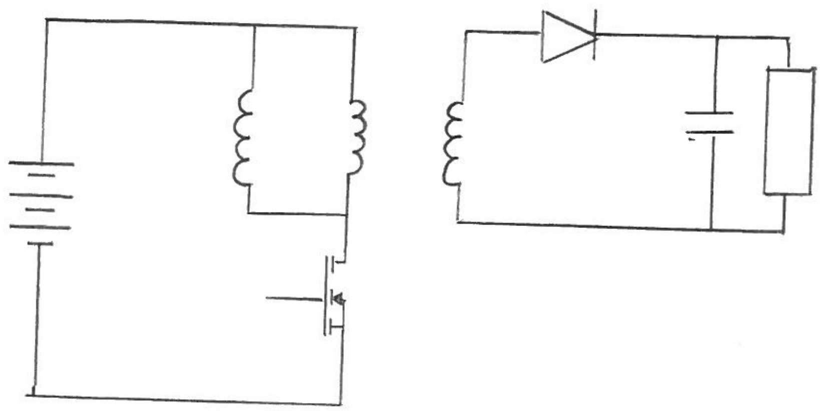
$V_o = 9V$, $N_2 = 15$

$f_s = 200kHz$

$P = 27W$

$n = 0.5$

$L = 50\mu H$



$$d = \frac{9}{9+15} = 0.375 \qquad V_{sw} = V_i + \frac{V_o}{n} = 48V$$

$$\Delta I_{p-p} = \frac{V_i\, d\, T_s}{L} = 1.125A$$

$$I_i = \frac{P}{V_i} = 0.9A$$

$$I_{QAVG} = \frac{I_i}{d} = 2.4A$$

$$I_{Qmin} = I_{QAVG} - \frac{\Delta I_{p-p}}{2} = 1.8375A$$

$$I_{Qmax} = I_{QAVG} + \frac{\Delta I_{p-p}}{2} = 2.9625A$$

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