9.7 Power electronics introduction

Name: _____ Class: _____ Date: _____ **Total: 24 marks**

KEY WORDS buck converter

Objective

Design buck and boost converters: duty cycle, current ripple, component choice and the efficiency accounting that decides the topology.

1 Key knowledge and worked examples

■ The two canonical converters

Buck: $V_{out} = D \cdot V_{in}$. Boost: $V_{out} = V_{in}/(1 - D)$. Continuous conduction needs the inductor current to stay positive: $\Delta I_L/2 < I_{load}$.

■ Ripple

$\Delta I_L = V_{out}(1 - D)/(L \cdot f)$ (buck); output ripple $\Delta V = \Delta I/(8Cf)$. Ripple sets L and C; the switch sets f – tens to hundreds of kHz.

■ Worked example: where the loss goes

20 V at 2 A out (40 W): switch 1.2 W, diode 0.8 W, control 0.3 W $\rightarrow \eta = 40/42.3 =$ 94.6%. A synchronous rectifier (MOSFET replacing the diode) recovers most of the diode term – the reason mid-90s efficiency is routine.

2 Practice

2.1 A buck converter drops 24 V to 9 V at 100 kHz with L = 150 µH. Compute D and the ripple current. [3]

2.2 A boost converter must raise 12 V to 48 V. Compute the duty cycle. [3]

2.3 A 20 V, 2 A supply dissipates 1.2 W in the switch, 0.8 W in the diode and 0.3 W in the control. Compute the efficiency. [3]

3 Exam-style questions

3.1 Design a buck converter: 24 V input, 5 V at 2 A output, switching at 200 kHz, target ripple current 20% of the load.

Compute the duty cycle. Choose L for the ripple target. Verify continuous conduction. Compute the output voltage ripple with C = 220 µF, and state one consequence of halving the switching frequency. [8]

3.2 A boost converter feeds 60 W into a 30 V load from a 12 V source; L = 100 µH, f = 100 kHz, efficiency 95%.

Compute the duty cycle and the input current. Compute the inductor ripple current and the peak switch current. Recompute the input current at 95% efficiency and state where the extra 3.2 W goes. [7]

Solutions

2.1

- $D = 9/24 = 0.375$.
- $\Delta I = 9 \times 0.625/(150\mu \times 100k) = 0.375A$.

2.2

- $1 - D = 12/48 \rightarrow D = 0.75$.

2.3

- $\eta = 40/(40 + 2.3) = 94.6\%$.

3.1

- $D = 5/24 = 0.208$.
- $L = V_{out}(1 - D)/(\Delta I \cdot f) = 5 \times 0.792/(0.4 \times 200k) = 49.5\mu H$.
- $\Delta I/2 = 0.2$ A against a 2 A load – deep in continuous conduction ✓.
- $\Delta V = \Delta I/(8Cf) = 0.4/(8 \times 220\mu \times 200k) = 1.1mV$.
- Halving f doubles ΔI (L unchanged) – or needs 2× the inductance for the same ripple; smaller f eases switching loss but grows L, C and the magnetics.

3.2

- $D = 1 - 12/30 = 0.60$.
- $I_{in} = P/V_{in} = 60/12 = 5.0A$ (ideal).
- $\Delta I = V_{in} \cdot D/(Lf) = 12 \times 0.6/(100\mu \times 100k) = 0.72A$.
- $I_{pk} = I_{in} + \Delta I/2 = 5.36A$ – the switch must carry it.
- At 95%: $P_{in} = 60/0.95 = 63.2W \rightarrow I_{in} = 5.26A$.
- The extra 3.2 W is conduction and switching loss in the MOSFET and diode (plus a little in copper) – heat that the package must dump.