

Power Electronics Lab (EE39006)

Department of Electrical Engineering, IIT Kharagpur

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Title: STUDY OF AN ISOLATED FLYBACK CONVERTER.

Part A: Design an ideal Flyback converter with the following specifications:

Input voltage (V_{in}) = 15 - 20 V, rated output voltage (V_o) = 5 V, rated power (P_N) = 20 W, magnetizing inductance (L_M) = 250 μ H (referred to the high-voltage side), output capacitance (C_o) = 100 μ F, load resistance (R_o) = 1.25 – 25 Ω , and switching frequency (f_s) = 100 kHz. The switch can be operated at a maximum duty ratio of 50%. Choose the MOSFET and diode resistance as 1 $\mu\Omega$, and diode voltage drop as 0 V.

1. Choose the maximum turns ratio of the transformer ($N_p : N_s$) such that the converter is able to produce the rated output voltage for operating conditions. (Assume that the converter operates in CCM only).
2. Consider that the converter operates with an input voltage of 20 V, a duty ratio of 0.40, and a load resistance (R_o) of 1.50 Ω . Observe the following variables in steady-state: output voltage, switch current, diode current, switch voltage, and diode voltage. Plot these variables for 5 switching cycles.
3. Vary the input voltage from 15 V to 20 V (in steps of 1 V) with a fixed load resistance of 15 Ω , and a fixed duty ratio of 45%. Observe the relevant variables in steady-state.
4. The load resistance R_o is varied from 4 - 24 Ω (in steps 4 Ω). The input voltage is fixed at $V_{in} = 18$ V, and the converter operates with a fixed duty ratio of 45 %. Plot the output voltage, as a function of the load resistance.

Part B: Now, consider that the transformer has a leakage inductance of 450 nH (referred to the high-voltage side). Design an RCD clamp circuit with capacitance $C_d = 10$ nF, $R_d = 5$ k Ω ($V_{in} = 24$ V, duty ratio = 0.4, $R_o = 1$ Ω). Plot the steady state voltage across the switch (for 5 switching cycles). What is the average voltage across the snubber capacitor C_d ? Calculate the power dissipated in the snubber resistor R_d .

Part C: Implement a closed-loop control scheme for the Flyback converter, to regulate the output voltage and to limit the peak switch current. (neglect any leakage inductance of the transformer).

1. First design an inner control current loop to limit the peak switch current to 1.25 A. ($V_{in} = 20$ V, $R_o = 2\ \Omega$, simulate for $t = 10$ ms).
Hint: Sense the switch current and compare it with a constant value of 1.25. Connect the comparator output to reset pin of S-R latch. The S-R latch is set by a clock pulse, having the same frequency as the switching frequency. The output of the S-R latch acts as the gate pulse of the switch.
Verify whether the peak switch current is limited for different load conditions.
2. Now, the peak switch current reference is set as 1.0 A. The input voltage is fixed at 20 V, and the load resistance is $5\ \Omega$. What is the output voltage of the Flyback converter?
3. Plot the switch current and output voltage, when there is a step change in peak current reference, changing from 1.0 A to 0.50 A at time $t = 5$ ms. ($V_{in} = 20$ V, $R_o = 5\ \Omega$, plot from time $t = 4.9$ ms to $t = 5.3$ ms).
4. Now, make the voltage control loop using a PI controller to regulate the output voltage at 5 V (Hint: Sense the output voltage and compare it with a constant value of 5.0. Connect the comparator output to a PI controller, having the gains $K_p = 0.60$, $K_i = 5 \times 10^3$. The output of the PI controller is the reference in the inner current loop, instead of constant reference used in previous steps).
5. Now, apply a step change in the load resistance, changing from $2.5\ \Omega$ to $5\ \Omega$ (at time $t = 5$ ms). Verify that the output voltage remains at the desired reference. Plot the input current and the output voltage during this load transient (from time $t = 4.9$ ms to $t = 5.3$ ms).

Discussion Questions

1. What is the peak voltage stress on the switch and the diode in CCM and DCM operation of the converter? Obtain the expression in terms of V_{in} , D , $n (\triangleq N_s / N_p)$, and $k \left(\triangleq \frac{2 L_M}{R T_s} \right)$.
2. For the data given in **Part A**(4), find the critical value of R_o for which the converter operates in the boundary of CCM and DCM.
3. Consider the data given in **Part A**(1). What is the critical value of magnetizing inductance L_M (referred to the high-voltage side) so that the converter operates in CCM only (for the entire load range, at rated output voltage)?
4. In which quadrant of the B-H curve does the transformer operate in a Flyback converter?
5. What is the main advantage of a Flyback converter compared to a buck-boost converter?