Power Electronics Lab (EE39006)

Department of Electrical Engineering, IIT Kharagpur

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Title: STUDY OF AN ISOLATED FLYBACK CONVERTER.

Part A: Simulate an ideal Flyback converter in open-loop using following parameters: Input voltage (V_{in}) = 20 - 32 V, transformer turns ratio ($N_p : N_s$) = 5 : 2, output capacitance (C_o) = 100 μF, magnetizing inductance (L_M) = 20 μH (referred to the high-voltage side), and switching frequency (f_s) = 100 kHz. Choose the MOSFET and diode resistance as 1 $\mu\,\Omega$, and diode voltage drop as 0 V.

1. 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 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.

2. Now set R_o = 2.50 Ω, and vary the input voltage from 20 - 32 V (in steps of 2 V) with a fixed duty ratio of 0.40. Observe the relavent variables in steady-state. Does the converter operate in Continuous Conduction Mode (CCM), or Discontinuous Conduction Mode (DCM)?

3. Vary the duty ratio from 0.25 to 0.50 (in steps of 0.05) with a fixed load resistance of 1.5 Ω, and fixed input voltage of 32 V. Again, observe the relavent variables in steady-state.

4. The load resistance R_o is varied from 1 - 3.50 Ω (in steps of 0.50 Ω). The input voltage is fixed at V_{in} = 24 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 125 nH (referred to the high-voltage side). Design an RCD clamp circuit with capacitance C_d = 50 nF, R_d = 5 kΩ (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 current control loop to limit the peak switch current to 7.5 A. (V_{in} = 24 V, R_o = 1 Ω, simulate for t = 10 ms).
   Hint: Sense the switch current and compare it with a constant value of 7.50. 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 5.0 A. The input voltage is fixed at 24 V, and the load resistance is 1 Ω. 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 5.0 A to 10.0 A at time t = 5 ms. (V_{in} = 24 V, R_o = 1 Ω, 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 $K_p = 2.50$, $K_i = 100 \times 10^3$. 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 1 Ω to 2 Ω (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 $k\left(\triangleq \dfrac{2\,L_M}{R\,T_s}\right)$.

2. For the data given in **Part A**(3), calculate the duty ratio above which the converter operates in CCM.

3. Consider 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.

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?