Analysis of effect of magnetizing current on zero-voltage switching in the zero-voltage transition full-bridge converter. Figure 1 illustrates a full-bridge zero-voltage transition (ZVT) converter, with the magnetizing inductance $L_M$ and magnetizing current $i_M(t)$ explicitly identified. As noted in class, the magnetizing current can assist in the zero-voltage switching process, especially at light load, and a small air gap is often added to the transformer for this purpose.

(a) Sketch the waveforms of $v_M(t)$ and $i_M(t)$, along with the $v_2(t)$, $v_4(t)$, $v_s(t)$, and $i_c(t)$ waveforms, for all twelve intervals within a switching period. Label salient features. You may assume that the magnetizing inductance $L_M$ is large relative to the commutating inductance $L_c$, so that the magnetizing current $i_M(t)$ does not exhibit a significant resonant (ringing) component.

(b) Sketch the state-plane diagram ($j_c$ vs. $m_2$) for this converter. Label salient features.

(c) Show that the peak magnetizing current is given by:

$$I_{M_p} = \frac{VT_s}{4nL_M}$$

$$J_{M_p} = \frac{M\pi}{2F_L_{M}}$$

with $k_M = L_M/L_c$, and $M = V/nV$. Hence derive an expression that guarantees zero-voltage switching at no load. Also derive an expression for the conversion ratio $M$.

(d) Design a ZVT converter to meet the following specifications:

- $V_s = 385$ V
- Output: 28 V at 500 W
- Switching frequency: 500 kHz
- MOSFET output capacitances $C_{leg1}$ to $C_{leg4}$: 300 pF

Design for $M = 0.75$, and obtain zero-voltage switching at all load powers from 500 W to 0 W. You should specify:

- The phase shift $\phi$ at full load
- The required values of $L_c$ and $L_M$
- The turns ratio $n$
A flyback converter containing an active clamp snubber circuit is illustrated in Fig. 2 below. A transformer model containing a magnetizing inductance, leakage inductance, and an ideal transformer is illustrated. Elements \( C_s \), \( L_M \), and \( C_f \) are large in value, so that their switching ripples can be ignored. Element \( C_1 \), \( C_2 \), and \( L_l \) are relatively small in value, and constitute the resonant tank elements. The current \( i_l \) reverses in direction, leading to zero-voltage switching. Diode \( D_3 \) is ideal. The voltage \( V_s \) is slightly larger than \( V/n \).

Each switching period is composed of the following six subintervals:

1. **Subinterval 1:** \( Q_1 \) conducts. This interval ends when the controller turns \( Q_1 \) off.
2. **Subinterval 2:** all semiconductors are off.
3. **Subinterval 3:** Diode \( D_3 \) conducts
4. **Subinterval 4:** Conducting devices are \( D_3 \) and \( D_2/Q_2 \). \( Q_2 \) is turned on at zero voltage while \( D_2 \) conducts. This interval ends when \( Q_2 \) is turned off.
5. **Subinterval 5:** Diode \( D_3 \) conducts
6. **Subinterval 6:** Conducting devices are \( D_3 \) and \( D_1/Q_1 \). \( Q_1 \) is turned on at zero voltage while \( D_1 \) conducts. This interval ends when diode \( D_3 \) becomes reverse-biased.

The resonant intervals are subintervals 2, 3, 5, and 6. The converter operates with duty cycle control: the interval \( DT_s \) is composed of subintervals 5, 6, and 1.

(a) Sketch the waveforms of \( v_1(t) \) and \( i_l(t) \).

(b) Sketch the state-plane diagram for this converter, and label the six intervals described above.

(c) What are the conditions for zero-voltage switching of \( Q_2 \)? of \( Q_1 \)?

(d) Analysis: solve the state plane diagram of part (b) as appropriate, to write the equations describing each subinterval length and beginning/ending current or voltage.

(e) Sketch the waveforms of the clamp capacitor current \( i_s \) and the voltage across the magnetizing inductance \( v_M \). Apply volt-second or charge balance to these waveforms as appropriate. Hence, write a complete set of equations for this converter, that could be solved to find the steady-state solution of the converter. It is not necessary to solve your equations.