Homework 8

Page 156, Chinese textbook Question 8.1

Try to analyze the maximum voltage, maximum current and average current of the switch and the rectifier diode in forward circuit and flyback circuit during operation.

Question 8.2

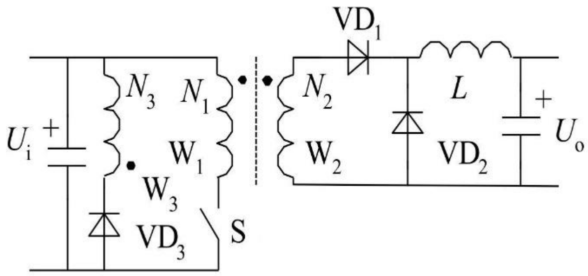
Try to analyze the maximum voltage, maximum current and average current of the switch and the rectifier diode in full-bridge, half-bridge and push-pull circuit during operation.

Question 8.3

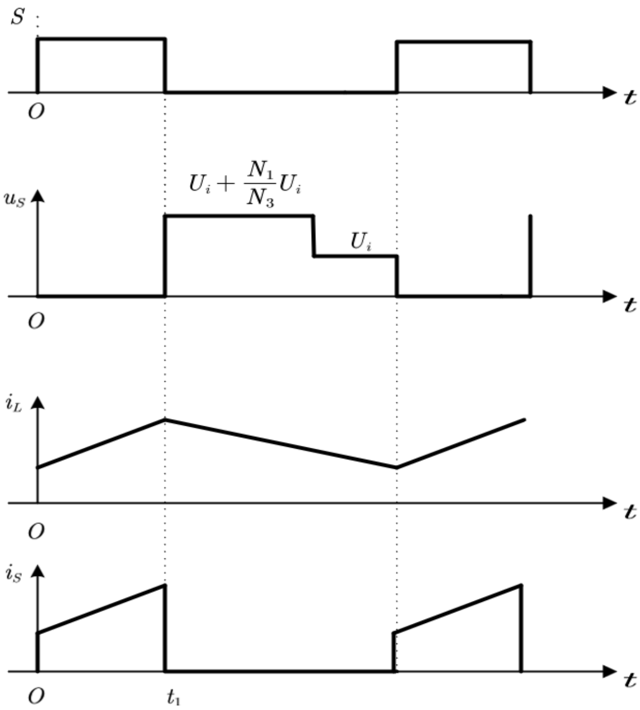
Try to analyze the relationship between the transmission power and the phase angle difference between the two bridges in the dual active circuit

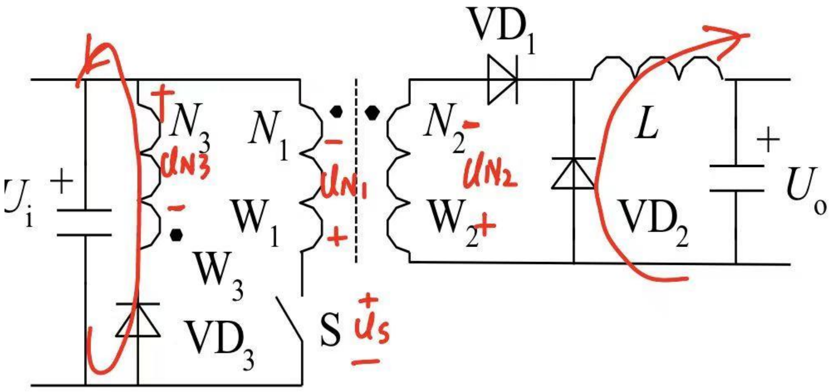
Answer 8.1

1) Forward circuit:



The waveform of this circuit is shown as below:

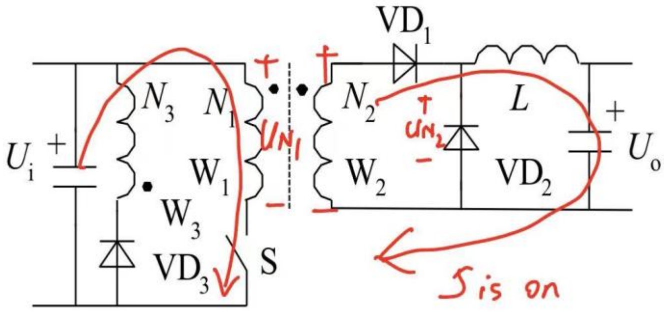




The magnetic core begins to reset through N3 and VD3 when the switch is off. Therefore, the voltage across the switch S equals to $U_{N1}+U_{N3}$. For U_{N3} equals to U_i, we can see that the maximum voltage of the switch is:

$$U_{S\max}=\left(1+\frac{N_1}{N_3}\right)U_i$$

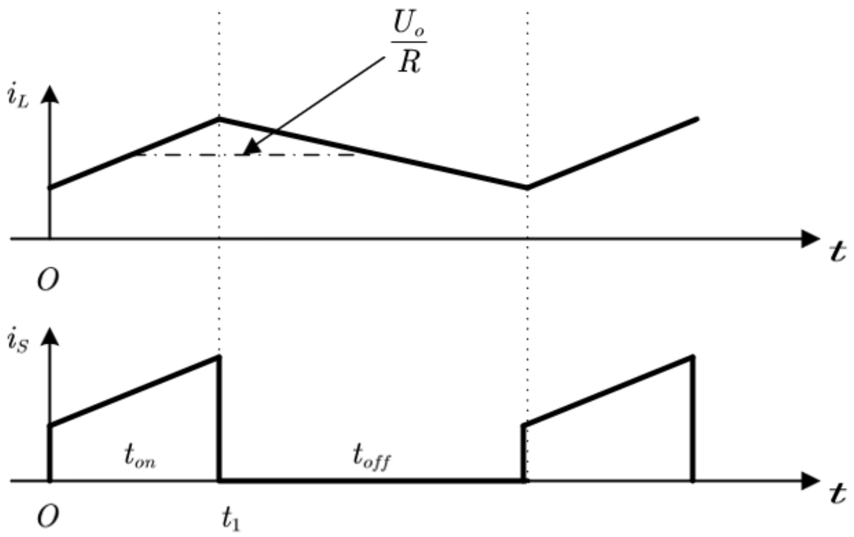
When S is on, VD1 is conducting. For VD2:



$$U_{VD2\max}=\frac{N_2}{N_1}U_i$$

When S is off, VD2 is conducting. For VD1:

$$U_{VD1\max}=\frac{N_2}{N_3}U_i$$



From the figure above, we can see the current reaches the maximum for both two rectifier diodes and the switch S when it is at t_1, and due to the relationships between primary side and secondary side of the transformer:

$$I_{S\max} = \frac{N_2}{N_1} I_{VD\max} = \frac{N_2}{N_1} I_{L\max}$$

From t_1, the inductor begins to discharge towards the load, and the voltage across the inductor equals to U_o. Then we can know the slope of the i_L is $-U_0/L$. Furthermore, we can see:

$$I_{VD1\max} = I_{VD2\max} = I_{L\max} = \frac{U_o}{R} + \frac{U_o}{L}\frac{t_{off}}{2}$$

$$I_{S\max} = \frac{N_2 U_o}{N_1 R} + \frac{N_2 U_o}{N_1 L}\frac{t_{off}}{2}$$

Where $I_o = U_o/R$ is the average value of inductor current.

Then it is easy to calculate the average value of current flowing through the diode with I_o.

$$I_{VD1} = \frac{t_{on}}{T_s} I_o = DI_o$$

$$I_{VD2} = \frac{t_{off}}{T_S} I_o = (1-D) I_o$$

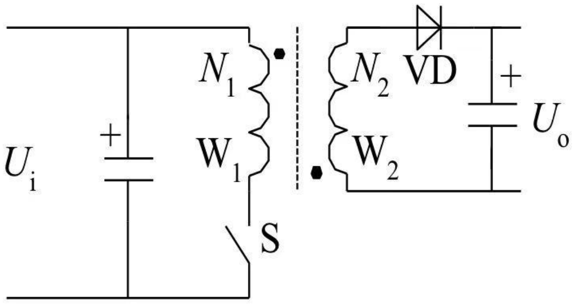
$$I_S = \frac{N_2}{N_1} I_{VD1} = \frac{N_2}{N_1} DI_o$$

Where

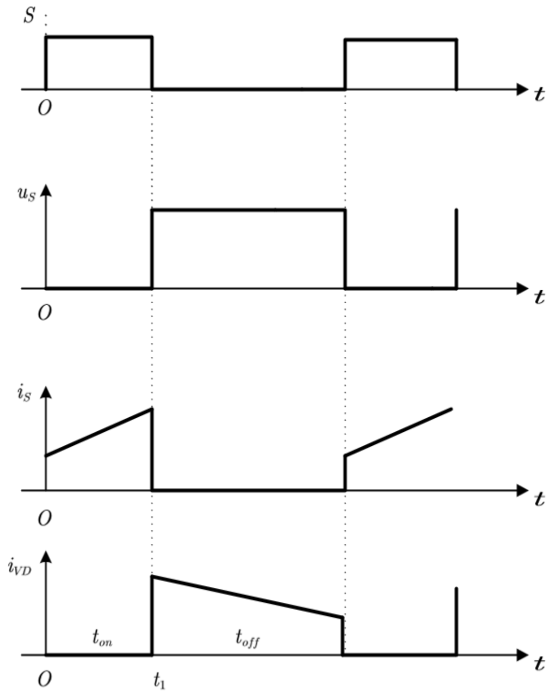
$$I_o = U_o/R$$

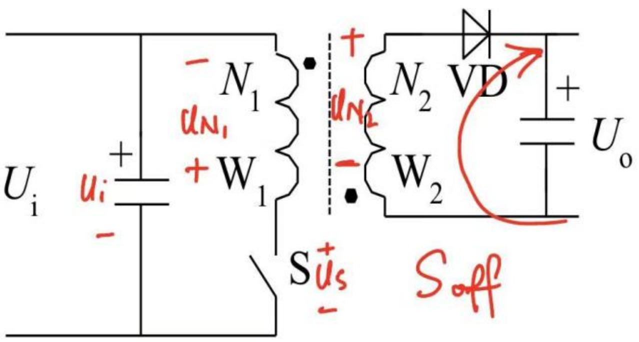
$$U_o = \frac{N_2}{N_1} DU_i.$$

2) Flyback circuit:



The waveform (CCM) of this circuit is shown as below:





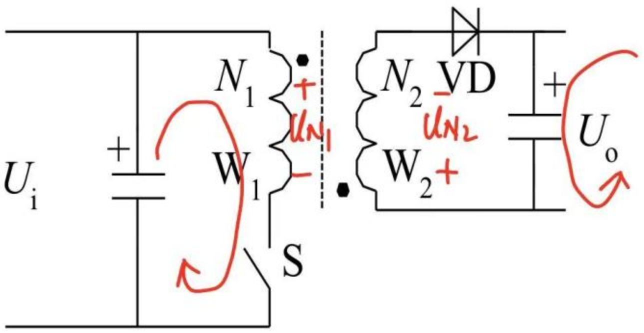
When the switch is off, we can calculate the maximum voltage:

$$U_{S\max} = U_i + U_{N1} = U_i + \frac{N1}{N2} U_o$$

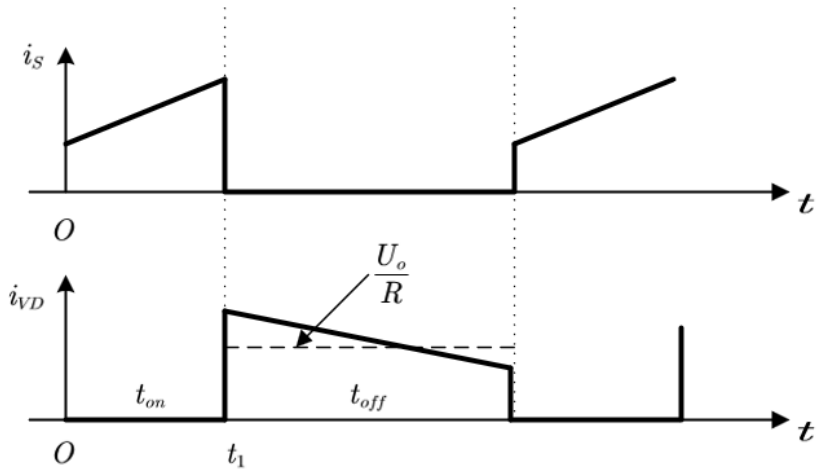
Where $U_o = \dfrac{N_2}{N_1} \dfrac{D}{1-D} U_i$.

$$U_{S\max} = \frac{1}{1-D} U_i$$

$$U_{VD\max} = U_{N2} + U_o = \frac{N_2}{N_1} U_i + \frac{N_2}{N_1} \frac{D}{1-D} U_i = \frac{N_2}{N_1} \frac{1}{1-D} U_i$$



Similarly, we can analyze the current through discharging process of inductor.



The average value of the current through the secondary side equals to $\frac{U_o}{R}$. Because the voltage across inductor of the secondary side is U_o, we can calculate:

$$I_{VD\max} = \frac{U_o}{R} + \frac{1}{2} \frac{U_o}{L} t_{off}$$

$$I_{S\max} = \frac{N_2}{N_1} I_{VD\max}$$

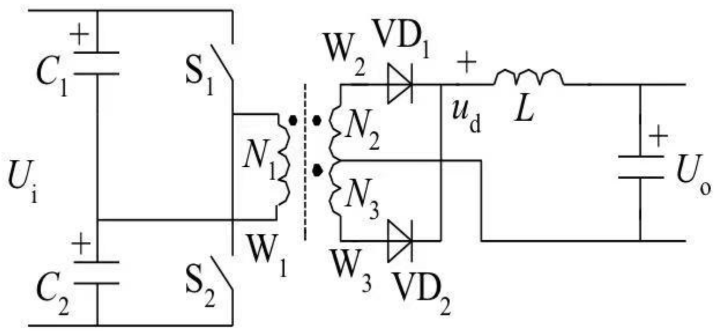
$$I_{VD} = \frac{t_{off}}{T_S} \frac{U_o}{R} = (1-D) \frac{U_o}{R}$$

$$I_S = \frac{N_2}{N_1} \frac{t_{on}}{T_S} \frac{U_o}{R} = \frac{N_2}{N_1} D \frac{U_o}{R}$$

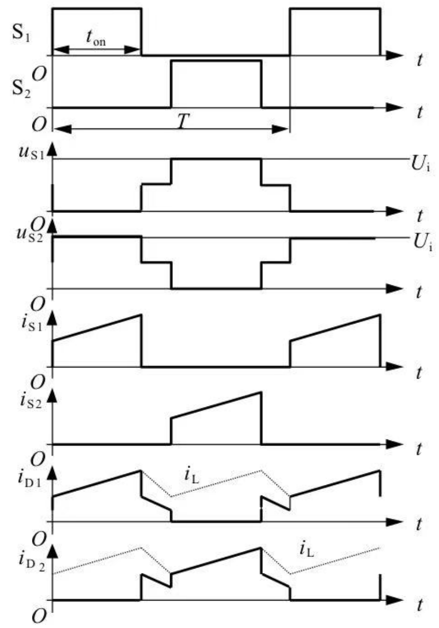
Where $U_o = \frac{N_2}{N_1} \frac{D}{1-D} U_i$.

Answer 8.2

1) Half bridge:

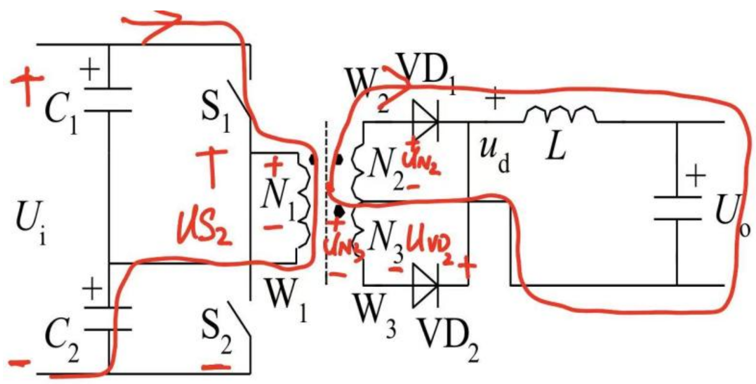


The waveform of this circuit is shown as below:



Because of the symmetrical structure, the value of upper device and lower device should be the same.

When S1 is on, S2 is off:



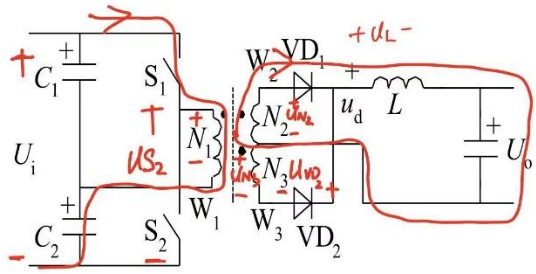
We can see:

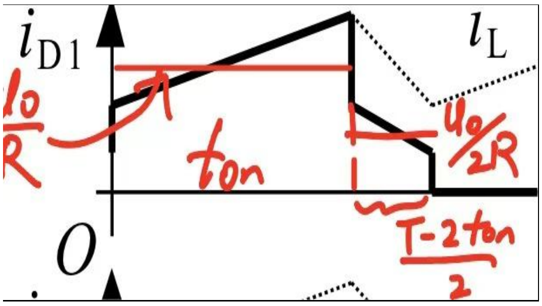
$$U_{S2\max} = U_{S\max} = U_i$$

During this period, VD1 is conducting while VD2 is blocked:

$$U_{VD2\max} = U_{VD\max} = U_{N3} + U_{N2} = \frac{N_3 + N_2}{N_1}\frac{U_i}{2}$$

The analysis of the current is still similar to previous questions:





When S1 is on, S2 is off. The inductor is being charged.

$$U_L = U_{N2} - U_o = \frac{N_2}{N_1}\frac{U_i}{2} - \frac{N_2}{N_1}DU_i = \frac{N_2}{N_1}(0.5 - D)U_i$$

$$I_{VD1\max} = \frac{U_o}{R} + \frac{t_{on}}{2}\frac{U_L}{L}$$

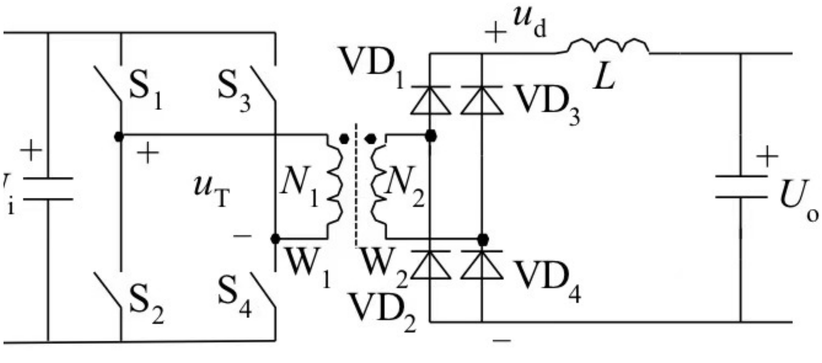
$$I_{VD1} = \frac{U_o}{R}\frac{t_{on}}{T_S/2} + \frac{1}{2}\frac{U_o}{R}\frac{T_s - 2t_{on}}{2}$$

Correspondingly,

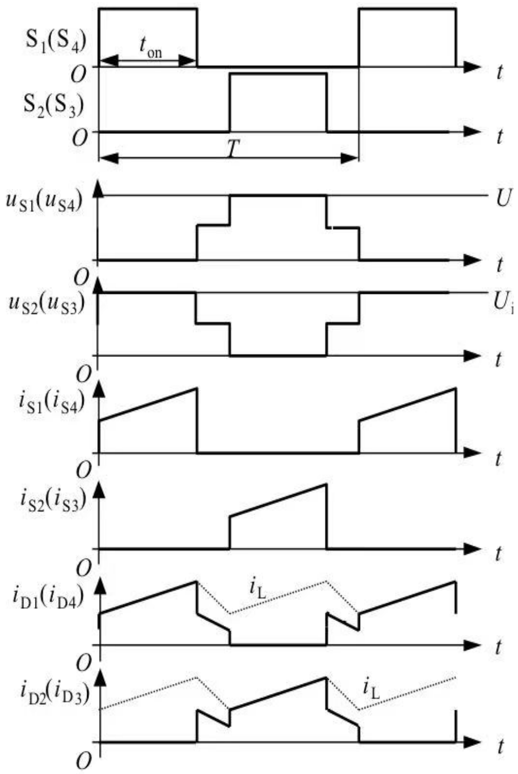
$$I_{S1\max} = \frac{N_2}{N_1}I_{VD1\max}$$

$$I_{S1} = \frac{N_2}{N_1}\frac{U_o}{R}\frac{t_{on}}{T_S/2} = \frac{2U_o}{R}\frac{N_2}{N_1}D$$

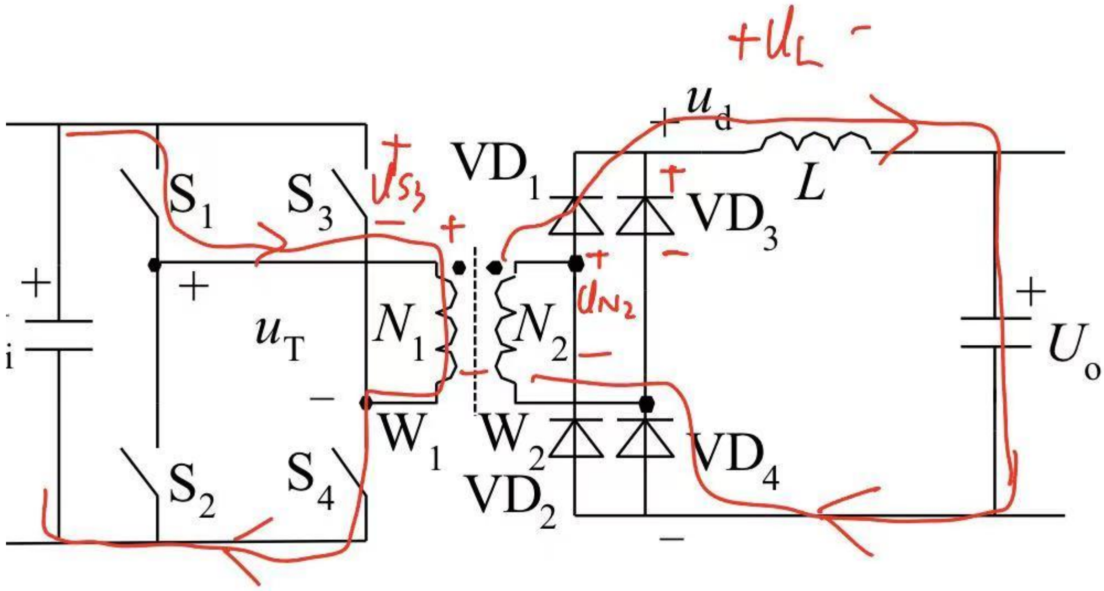
2) Full bridge



The waveform of this circuit is shown as below:



When S1 and S4 are on:



$$U_{S\max} = U_i$$

$$U_{D\max} = U_{N2} = \frac{N_2}{N_1} U_i$$

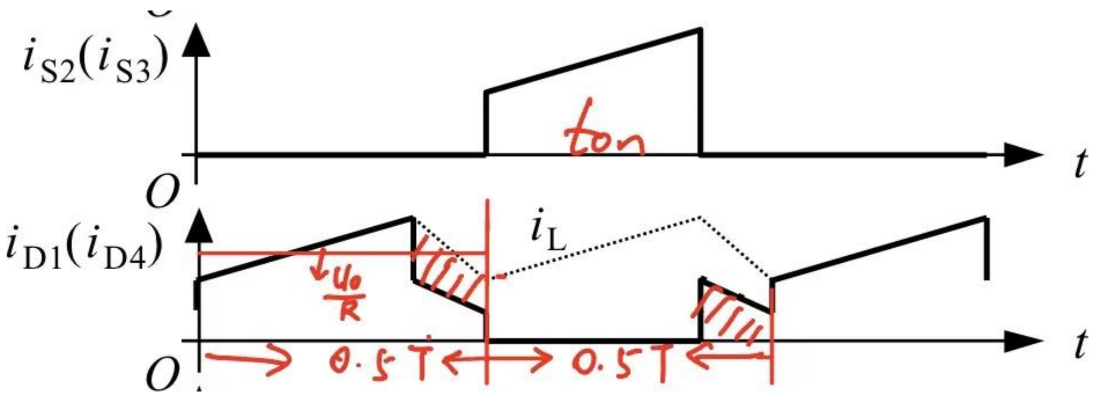
$$U_L = U_{N2} - U_o$$

Where

$$U_o = 2\frac{N_2}{N_1} D U_i$$

Thus,

$$U_L = \frac{N_2}{N_1} U_i (1 - 2D)$$



From the figure above, we can see that:

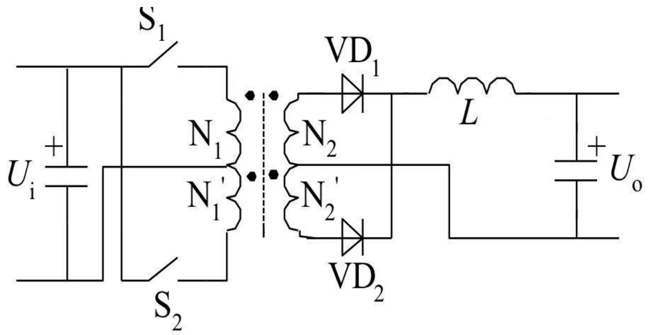
$$I_{D\max} = \frac{U_o}{R} + \frac{U_L}{L} \frac{t_{on}}{2}$$

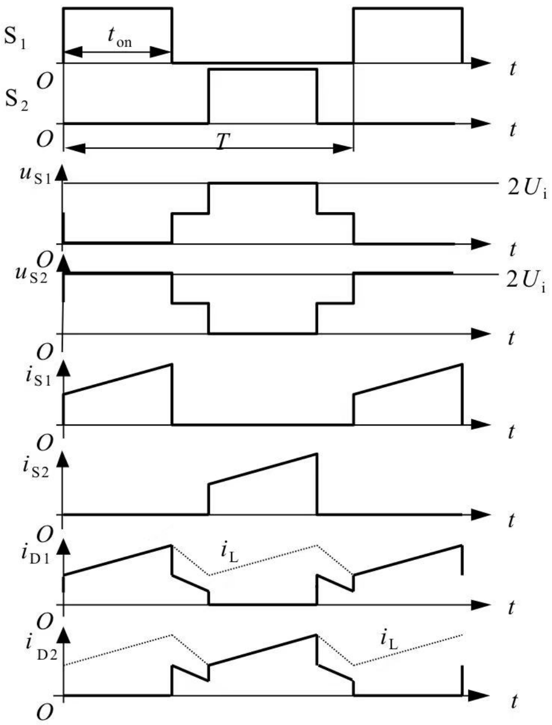
$$I_D = \frac{U_o}{R} \frac{0.5T}{T} = \frac{U_o}{2R}$$

$$I_S = \frac{U_o}{R} \frac{t_{on}}{T/2} = 2 \frac{DU_o}{R}$$

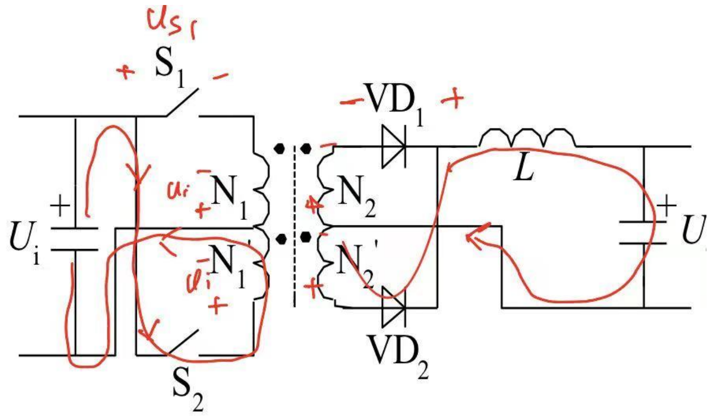
$$I_{S\max} = \frac{N_2}{N_1} I_{D\max}$$

3) Push-pull circuit:





When S2 is on:



$$U_{S\max} = 2U_i$$

$$U_{D\max} = 2U_{N2} = \frac{2N_2}{N_1}U_i$$

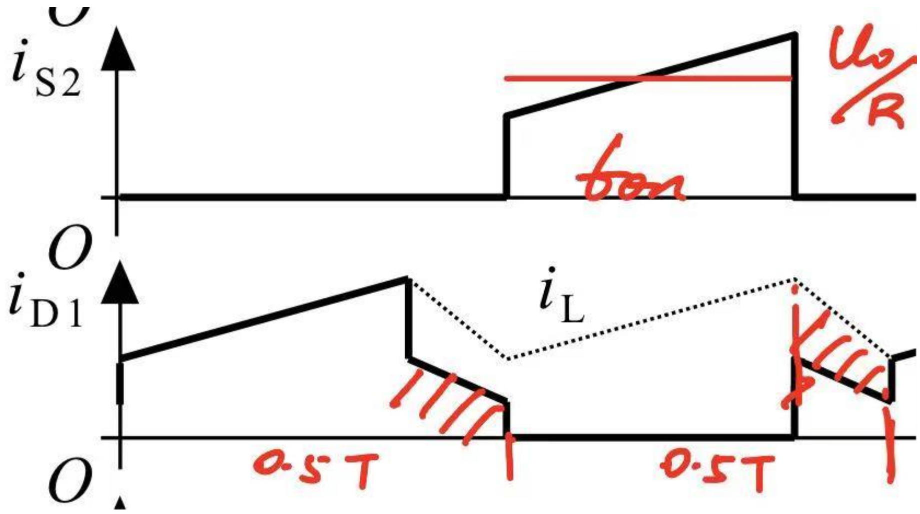
$$U_L = U_{N2} - U_o$$

Where

$$U_o = 2\frac{N_2}{N_1}DU_i$$

Thus,

$$U_L = \frac{N_2}{N_1}U_i(1-2D)$$



From the figure above, we can see that:

$$I_{D\max} = \frac{U_o}{R} + \frac{U_L}{L}\frac{t_{on}}{2}$$

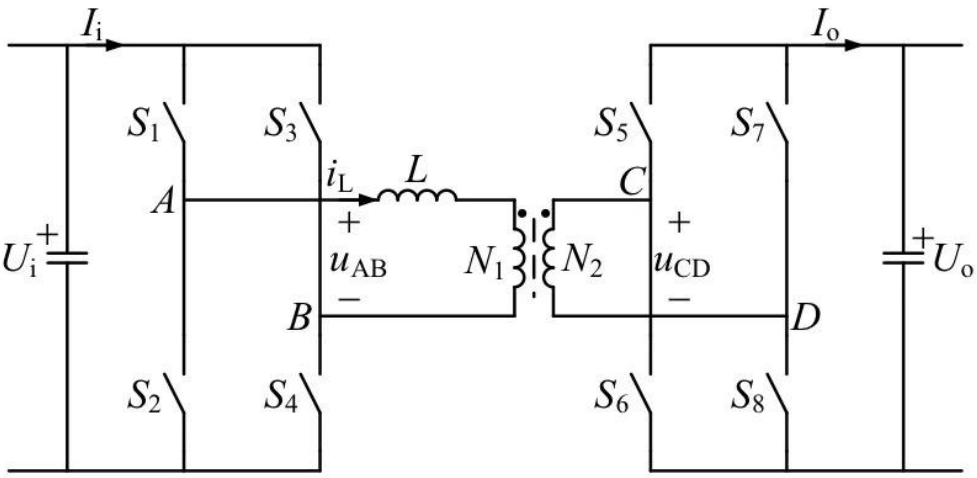
$$I_D = \frac{U_o}{R}\frac{0.5T}{T} = \frac{U_o}{2R}$$

$$I_S = \frac{U_o}{R}\frac{t_{on}}{T/2} = 2\frac{DU_o}{R}$$

$$I_{S\max} = \frac{N_2}{N_1} I_{D\max}$$

Answer 8.3

1) We can adjust the magnitude of transmission power and output voltage through changing phase angle difference.
2) The direction of transmission power can be changed with phase angle difference varying.



If waveform of S5 is leading S1 by φ, which means U_{CD} is leading U_{AB} by φ, power will be transmitted from secondary side to primary side. If U_{CD} is lagging U_{AB}, power will be transmitted from primary side to secondary side.