제 6 장 직류변환장치

DC to DC Converter
DC → DC

6.1 개요

- AC의 전력변환: 변압기을 사용 쉽게 가능함
- DC의 전력변환: 변압기로는 어려움
- DC-DC Converter를 사용하면 가능
- 종류
  - 강압 초퍼(Buck chopper)
  - 승압 초퍼(Boost chopper)
  - 강압 및 승압 초퍼(Buck & Boost chopper)

6.2 Basic Switching Converter

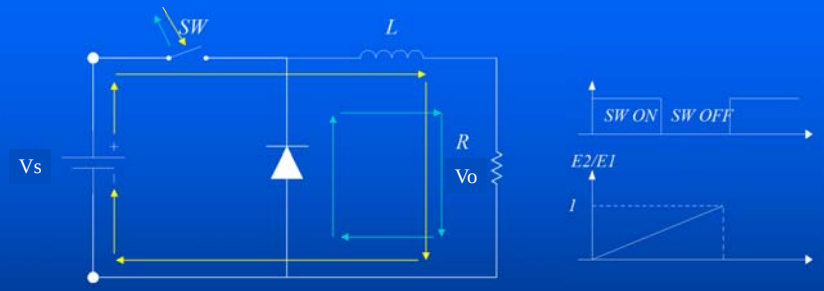
- Switching 방식에 의한 DC 제어

$$V_0 = \frac{1}{T}\int_0^T v_0(t)dt = \frac{1}{T}\int_0^{DT} V_S(t)dt$$

$$= \frac{V_S}{T}\int_0^{DT} 1dt = \frac{V_S}{T}\left[t\right]_0^{DT} = \frac{V_S}{T}(DT-0) = V_S D$$

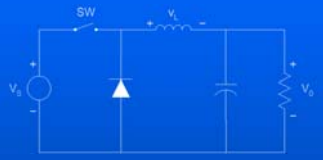
- Duty Cycle(D)=Switch On 시간(DT)/주기(T)

6.3 강압: Buck Converter(Step-down)



- 입력(Vs) 보다 출력(Vo) 이 작음

6.3 Buck Converter: 전압



- Switch On

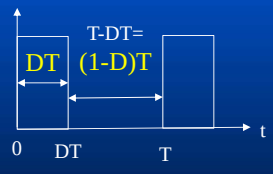
$$v_L = V_S - V_0 = L\frac{di_L}{dt} = L\frac{\Delta i_L}{\Delta t} = L\frac{\Delta i_L}{DT}$$

$$\therefore \Delta i_L = \frac{1}{L}(V_S - V_0)DT$$

- Switch Off

$$v_L = -V_0 = L\frac{di_L}{dt} = L\frac{\Delta i_L}{\Delta t} = L\frac{\Delta i_L}{(1-D)T}$$

$$\therefore \Delta i_L = -\frac{1}{L}V_0(1-D)T$$



- 충전전류+방전전류=0

$$\frac{1}{L}(V_S - V_0)DT - \frac{1}{L}V_0(1-D)T = 0$$

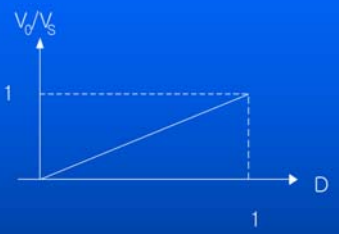
$$V_S D - V_0 D - V_0 + V_0 D = 0 \quad \therefore V_0 = V_S D$$

6.3 Buck Converter: 출력

- 충전전류+방전전류=0

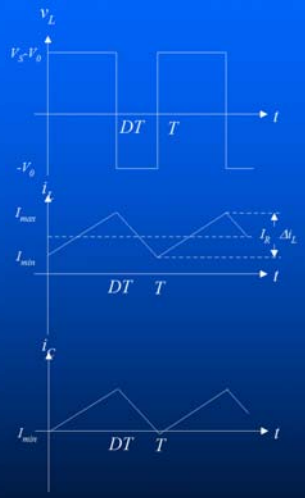
$$D \le 1, \quad V_0 = V_S D, \quad \therefore \frac{V_0}{V_S} = D$$

D	출력/입력(V_0/V_S)
0	0
0.2	0.2
0.5	0.5
0.8	0.8
1.0	1.0



- 강압(Step-down)
- 입력 대비 출력이 낮음

6.3 Buck Converter: 리플



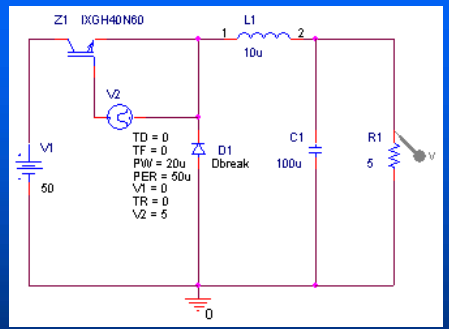
- Ripple

$$v_L = -V_0 = L\frac{di_L}{dt}$$

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-D)T} = -\frac{1}{L}V_0$$

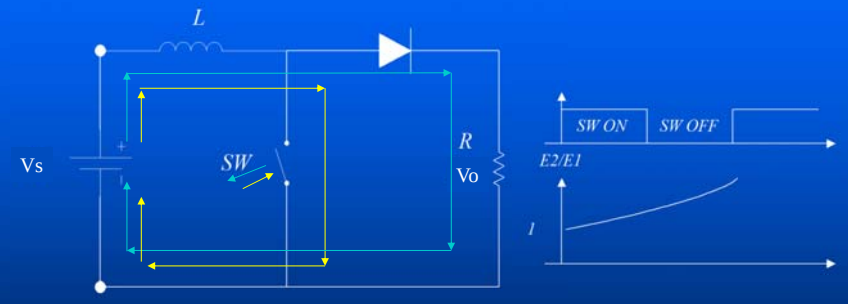
$$\Delta i_L = (1-D)T\left(-\frac{1}{L}V_0\right)$$

예제 6-1 벅 변환기



- *Parameter*
  - ✓ V_S=50 V
  - ✓ L=10 μH
  - ✓ C=100 μF
  - ✓ f=20 kHz(T=50 μs)
  - ✓ D=0.4(T=20 μs)
  - ✓ R=20 ohm
  - ✓ Step =0 1 ms
- *Find*
  - ✓ 출력전압
  - ✓ 전류 최대, 최소값

6.5 승압: Boost Converter(Step-up)



■입력(Vs) 보다 출력(Vo) 이 커짐

6.3 Boost Converter: 전압

- Switch On

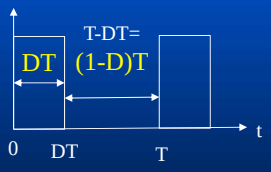
$$v_L = V_S = L\frac{di_L}{dt} = L\frac{\Delta i_L}{\Delta t} = L\frac{\Delta i_L}{DT}$$

$$\therefore \Delta i_L = \frac{1}{L}V_S DT$$

- Switch Off

$$v_L = V_S - V_0 = L\frac{di_L}{dt} = L\frac{\Delta i_L}{\Delta t} = L\frac{\Delta i_L}{(1-D)T}$$

$$\therefore \Delta i_L = \frac{1}{L}(V_S - V_0)(1-D)T$$



- 충전전류+방전전류=0

$$\frac{1}{L}V_S DT + \frac{1}{L}(V_S - V_0)(1-D)T = 0$$

$$V_S D + V_S - V_S D - V_0 + V_0 D = 0$$

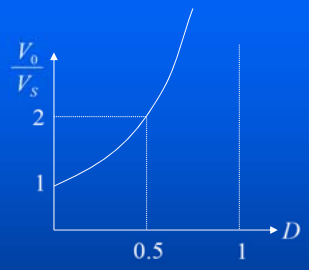
$$\therefore V_0 = \frac{V_S}{(1-D)}$$

6.5 Boost Converter: 출력

- 충전전류+방전전류=0

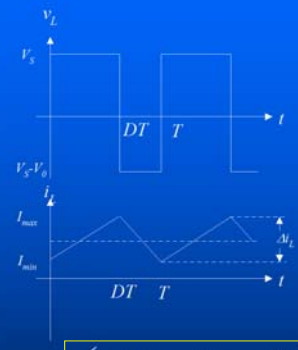
$$D \le 1,\ V_0 = \frac{V_S}{(1-D)},\ \therefore \frac{V_0}{V_S} = \frac{1}{(1-D)}$$

D	출력/입력	(V_0/V_S)
0	1/(1−0)	1
0.2	1/(1−0.2)	1.25
0.5	1/(1−0.5)	2.0
0.8	1/(1−0.8)	5.0
1.0	1/(1−1)	∞



- 승압(Step-up)
- 입력 대비 출력이 높음

6.5 Boost Converter: 인덕터전류



- 인덕터의 평균전류

$$V_S I_L = \frac{V_0^2}{R} = \frac{\left(\frac{V_0}{(1-D)}\right)^2}{R} = \frac{V_S^2}{(1-D)^2 R}$$

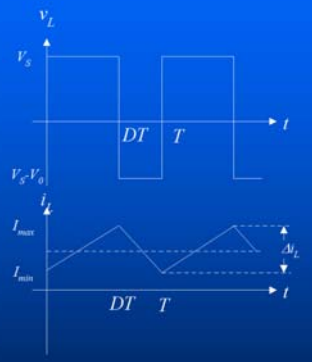
$$\therefore I_L = \frac{V_S}{(1-D)^2 R}$$

- 인덕터의 전류 최소, 최대값

$$\left(\because \frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT} = \frac{V_S}{L}\right) \rightarrow I_{\max} = I_L + \frac{\Delta i_L}{2} = \frac{V_S}{(1-D)^2 R} + \frac{V_S DT}{2L}$$

$$I_{\min} = I_L - \frac{\Delta i_L}{2} = \frac{V_S}{(1-D)^2 R} - \frac{V_S DT}{2L}$$

6.5 Boost Converter: 스위칭 주파수



- 전류의 연속조건: 최소 값이 0 보다 커야함

$$I_{\min} = 0 = \frac{V_S}{(1-D)^2 R} - \frac{V_S DT}{2L}$$

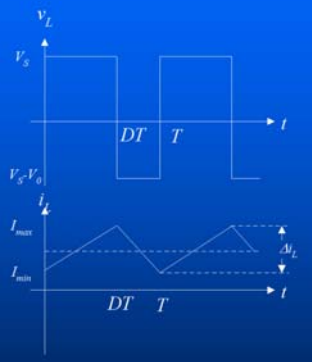
$$\frac{V_S}{(1-D)^2 R} = \frac{V_S DT}{2L} = \frac{V_S D}{2Lf}$$

- 인덕터 및 스위치의 조합

$$(Lf)_{\min} = \frac{D(1-D)^2 R}{2}$$

$$\therefore L_{\min} = \frac{D(1-D)^2 R}{2f}$$

6.5 Boost Converter: 전압의 맥동



- 커패시터 전하 변화량

$$|\Delta Q| = \left(\frac{V_0}{R}\right) DT = C\Delta V_0$$

- 맥동

$$\Delta V_0 = \frac{V_0 DT}{RC} = \frac{V_0 D}{RCf}$$

$$\frac{\Delta V_0}{V_0} = \frac{DT}{RC} = \frac{D}{RCf}$$

예제 6-3 부스트 변환기의 설계

- 12V→30V로 승압, 맥동율: 1% 미만, R=50ohm
- Duty 비

$$\frac{V_0}{V_S} = \frac{1}{(1-D)}, \quad D = 1 - \frac{V_0}{V_S} = 1 - \frac{12}{30}$$

- 인덕터 최소값: f=25kHz로 함(가청주파수 보다 높게)

$$L_{\min} = \frac{D(1-D)^2 R}{2f} = \frac{0.6(1-0.6)^2 50}{2(25000)} = 96\mu H$$

예제 6-3 부스트 변환기의 설계(2)

- 인덕터 전류

$$I_L = \frac{V_S}{(1-D)^2 R} = \frac{12}{(1-0.6)^2 50} = 1.5\,A$$

$$\frac{\Delta i_L}{2} = \frac{V_S D}{2Lf} = \frac{(12)(0.6)}{2(120\times10^{-6})(25000)} = 1.2\,A$$

$$I_{\max} = 1.5 + 1.2 = 2.7\,A$$

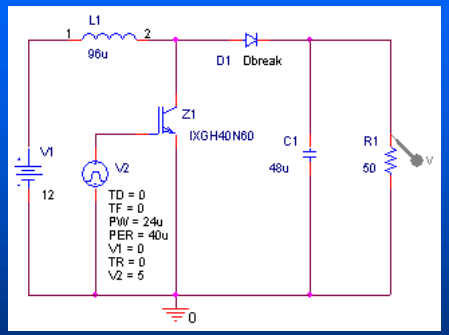
$$I_{\min} = 1.5 - 1.2 = 0.3\,A$$

- 인덕터 전류

$$\frac{\Delta V_0}{V_0} < 1\%$$

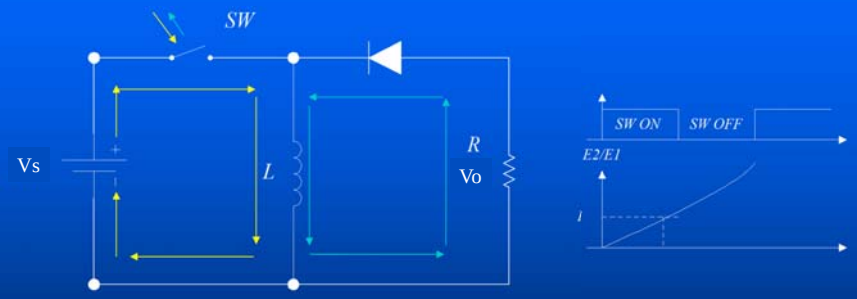
$$C >= \frac{D}{Rf(\Delta V_0 / V_0)} = \frac{0.6}{(50)(25\times10^3)(0.01)} = 48\mu F$$

예제 6-3 부스트 변환기(Pspice 해)



- *Parameter*
  - ✓ V_S=12 V
  - ✓ L=96 μH
  - ✓ C=48 μF
  - ✓ f=25 kHz(T=40 μS)
  - ✓ D=0.6 (D=24 μS)
  - ✓ R=50 ohm
  - ✓ Step =0 1 ms
- *Find*
  - ✓ 출력전압
  - ✓ 전류 최대, 최소값

6.6 강압 및 승압: Buck-Boost Converter



■입력(Vs) 보다 출력(Vo) 이 D=0.5이상이면 커짐

6.3 Buck-Boost Converter: 전압

- Switch On

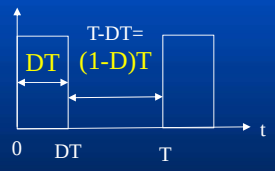
$$v_L = V_S = L\frac{di_L}{dt} = L\frac{\Delta i_L}{\Delta t} = L\frac{\Delta i_L}{DT}$$

$$\therefore \Delta i_L = \frac{1}{L}V_S DT$$

- Switch Off

$$v_L = -V_0 = L\frac{di_L}{dt} = L\frac{\Delta i_L}{\Delta t} = L\frac{\Delta i_L}{(1-D)T}$$

$$\therefore \Delta i_L = -\frac{1}{L}V_0(1-D)T$$



- 충전전류+방전전류=0

$$\frac{1}{L}V_S DT - \frac{1}{L}V_0(1-D)T = 0$$

$$V_S D - V_0 + V_0 D = 0$$

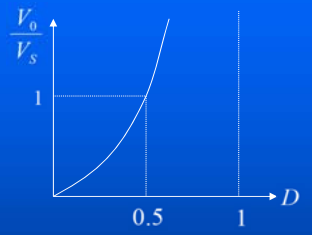
$$\therefore V_0 = \frac{V_S D}{(1-D)}$$

6.6 Buck-Boost Converter: 출력

- 충전전류+방전전류=0

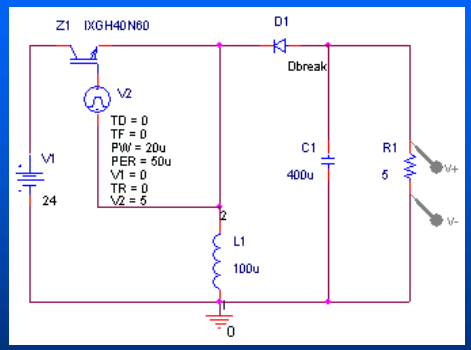
$$D \le 1, \quad V_0 = V_S\frac{D}{(1-D)}, \qquad \therefore \frac{V_0}{V_S} = \frac{D}{(1-D)}$$

D	출력/입력	(V_0/V_S)
0	0/(1-0)	0
0.2	0.2/(1-0.2)	0.25
0.5	0.5/(1-0.5)	1.0
0.8	0.8/(1-0.8)	4.0
1.0	1/(1-1)	∞



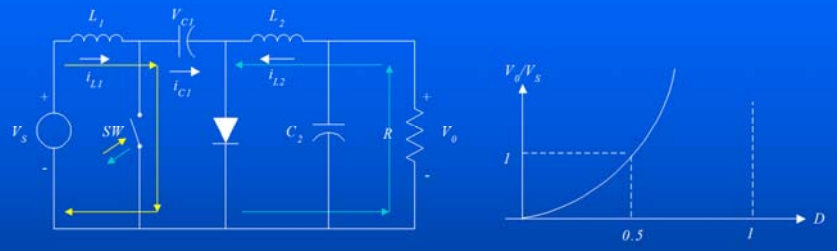
- 강압 및 승압 (Step-up & down)
- 입력 대비 출력이 낮거나 높음

예제 6-4 벅-부스트 변환기(Pspice 해)



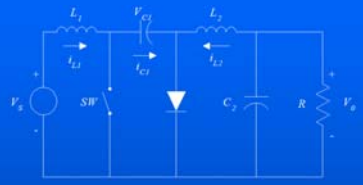
- *Parameter*
  - ✓ V_S=24 V
  - ✓ R=5 ohm
  - ✓ L=100 μH
  - ✓ C=400 μF
  - ✓ f=25 kHz(T=40 μS)
  - ✓ D=0.6 (D=24 μS)
  - ✓ Step
    =0 0.5 ms
- *Find*
  - ✓ 출력전압
  - ✓ 전류 최대, 최소값

6.6 Cuk Converter



- 입력(E_1) VS 출력(E_2) 이 적거나 커짐

6.7 Cuk Converter: 전압



- Switch On

$$V_{C1} = V_S - V_0$$

$$(i_{C1})_{closed} = -I_{L2}$$

- Switch Off

$$(i_{C1})_{open} = I_{L1}$$

- 충전전류+방전전류=0

$$-i_{L2}DT + i_{L1}(1-D)T = 0, \quad \frac{i_{L1}}{i_{L2}} = \frac{D}{(1-D)}$$

6.7 Cuk Converter: 출력

- 공급전력=소모전력

$$P_S = P_0$$

$$V_S i_{L1} = -V_0 i_{L2}, \quad \frac{i_{L1}}{i_{L2}} = \frac{-V_0}{V_S}$$

$$\therefore \frac{V_0}{V_S} = -\frac{D}{(1-D)}, \quad \left(\because \frac{i_{L1}}{i_{L2}} = \frac{D}{(1-D)}\right)$$

Switching Frequency

- Audio frequency(가청주파수)을 벗어나는 20kHz 이상의 초음파(ultra sonic) 영역에서 스위칭)

DC-DC Converter 종합

- Buck: 강압

- Boost : 승압

- Buck-boost: 승압/강압

- Cuk: 승압/강압