Introduction to Electrical Engineering

Course Code: EE 103

Department: Electrical Engineering

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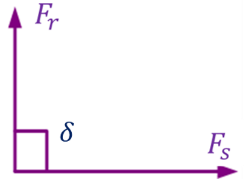
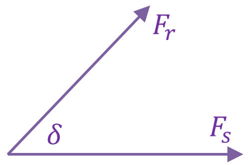
Review:

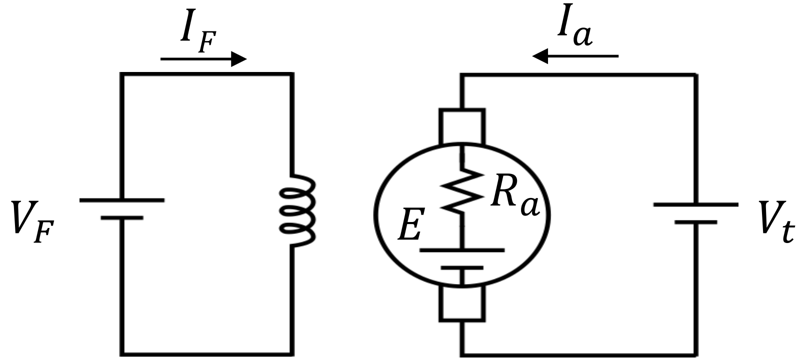
DC machines:

$$EI_a = V_t I_a - I_a^2 R_a$$

$$T = \frac{EI_a}{\omega} = \frac{(K\phi\omega)I_a}{\omega} = K\phi I_a$$







- In DC machine → Stator field is 'time-invariant'
  → Stator winding is concentrated and connected to a DC supply

Induction(Asynchronous) machines:

- The result of displacing 3 windings by 120° in space and displacing the winding 'I' by 120° in time phase is a single revolving field of constant magnitude
- For a given winding arrangement, speed of rotation is determined by supply frequency of the input alone
- This speed of rotation of field is called 'synchronous speed' and it is denoted by N_s

$$N_s = \frac{120f}{P}$$

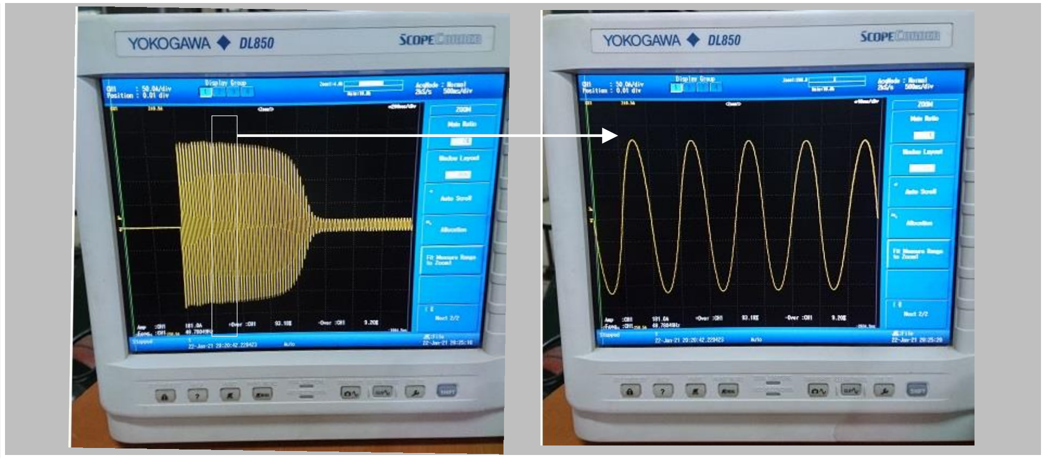
- N_r can not be = N_s because at $N_r = N_s$, relative speed between rotor (conductor) and stator field is zero
  → no emf, and therefore, no 'I' and no force or torque
- $N_s - N_r$ → slip speed

Slip: $s = \frac{N_s - N_r}{N_s}$

Review (cont.):

- At starting, relative speed between field and conductor (rotor) is maximum,
  → induced emf, and therefore, rotor 'I' is maximum.
- Now, for any current in rotor there is an equivalent 'I' in stator

∴ if an IM is started at rated 'V' & 'f', a high 'I' will be drawn from the source



Induction motor started at rated 'V' & 'f'

→ This high 'I' could be ≅ (6 - 7) times the rated current of motor

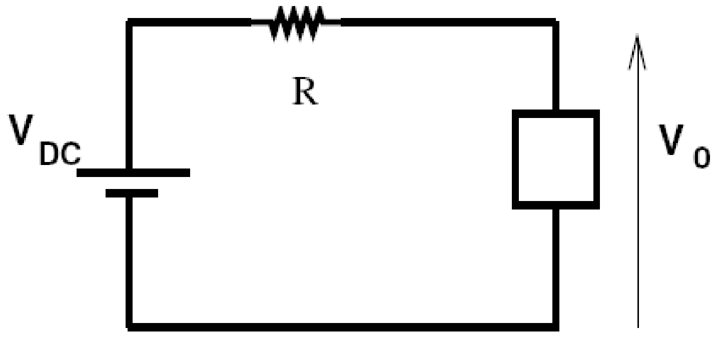
- At steady state, $T_e = T_L$ (neglecting friction)
- N_s can be changed by changing the supply frequency.
- To reduce the speed, 'f' ↓ Recall that: $V = 4.44 f \phi_m N_{\text{turns}}$
- If the 'V' is kept constant and 'f' is reduced, ϕ_m tries to ↑ → this should not be done
- Instead, ϕ_m is kept constant. This can be done by keeping $\frac{V}{f} = \text{constant}$ ⇒ both, 'V' and 'f' are changed

DC – DC conversion

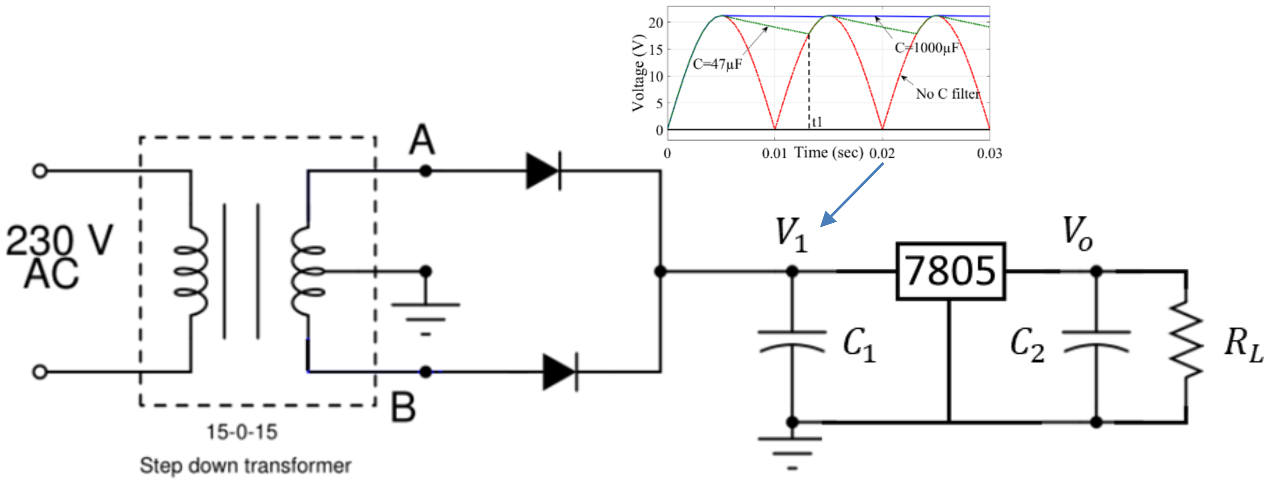
DC-DC Conversion

How to convert dc input of 30 V to 5 V output?

→ Use potential divider



→ Use a linear voltage regulator ‘7805’



V_1 can range from 7 to 35 V

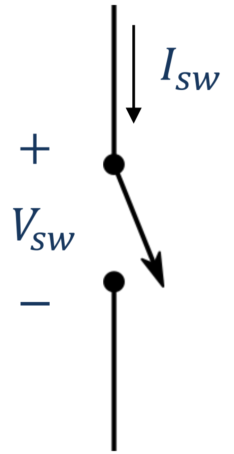
But, unnecessary power losses in R and in the ‘7805’ IC

Can this be avoided?

DC-DC Conversion

How can a circuit change the voltage level, yet dissipate low power?

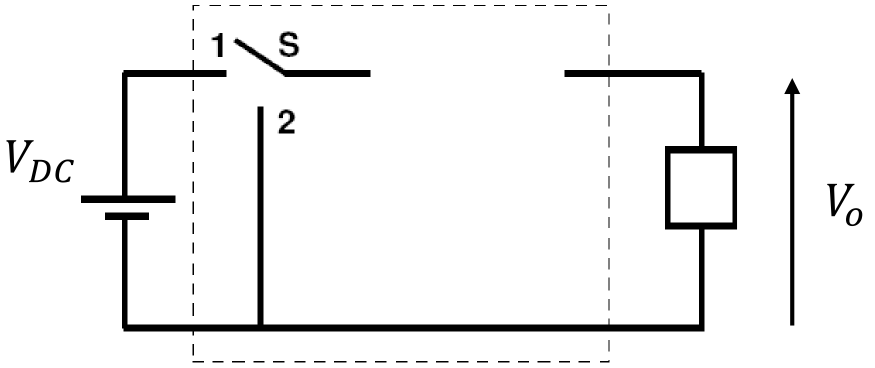
- Circuit elements → R, L, C → Passive
- ~~L & C → do not consume power~~
- Power loss in a 'switch' = $V_{sw} \times I_{sw}$
  - When switch is open, I_{sw} = 0
  - When switch is closed, V_{sw} → Very low
  - Power loss ≈ 0



- Resistor results in power dissipation
- For high efficiency, a power switch with low on-state voltage drop must be used
- In addition, use only L & C elements

DC-DC Conversion

How can a circuit change the voltage level, yet dissipate low power?

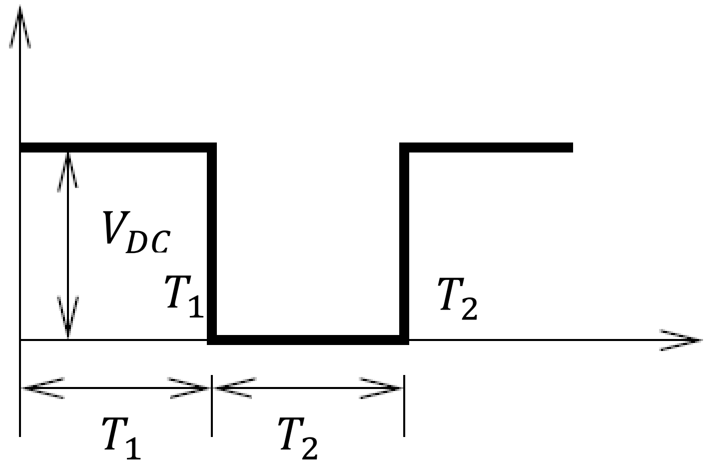


Operate the switch as follows

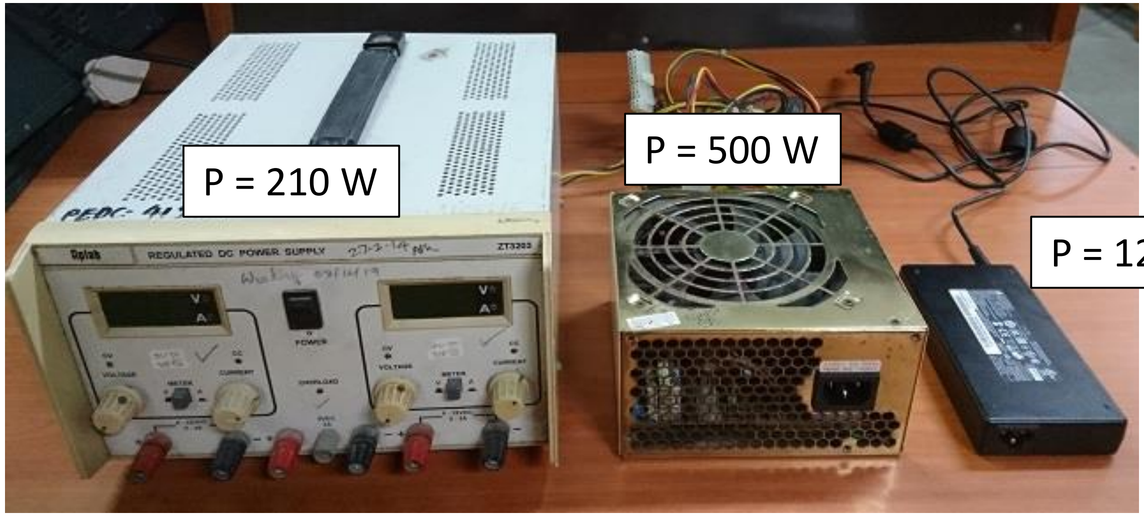
- Close to position ‘1’ for some time and then transfer it to position ‘2’

$$V_O = V_{DC}\frac{T_1}{T_1 + T_2} = V_{DC}D$$

- D is the duty cycle of the switch
- Power loss ≈ 0
  ∵ voltage drop across the device during ON period ≈ 0



DC-DC Conversion: Linear vs. switching power supply



DC-DC Conversion: Buck Converter

$q_c = CV_o \Rightarrow I_c = C\frac{dV_o}{dt}$

Following circuit is a buck converter

L → filter inductor

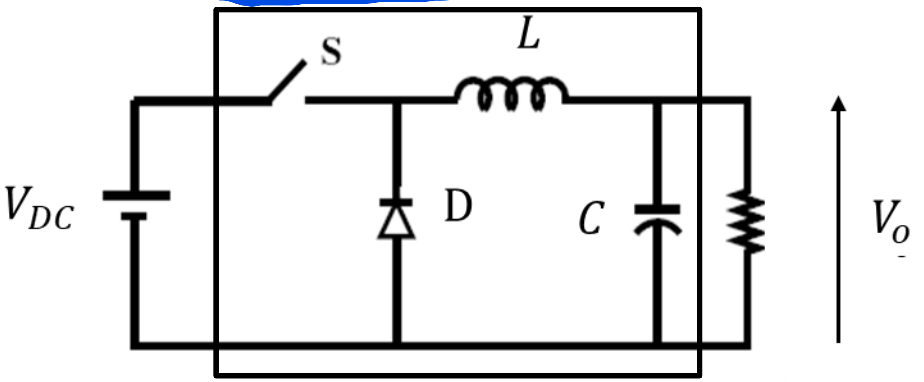
C → filter capacitor

'V_O' is assumed to remain constant

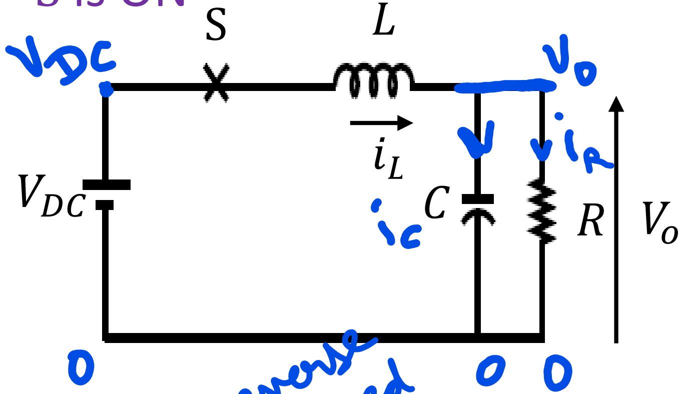
Switch 'S' is switched at a very high frequency

- S is ON for DT second
- S is OFF for $(1 - D)T$ second
- T is switching period, given by

$\boxed{T = \frac{1}{f_{sw}}\ ,\ f_{sw}: \text{switching frequency}}$



S is ON



D= reverse biased

For, $0 < t < DT$

$V_L = V_{DC} - V_o = \text{constant}$

→ i_L increases linearly

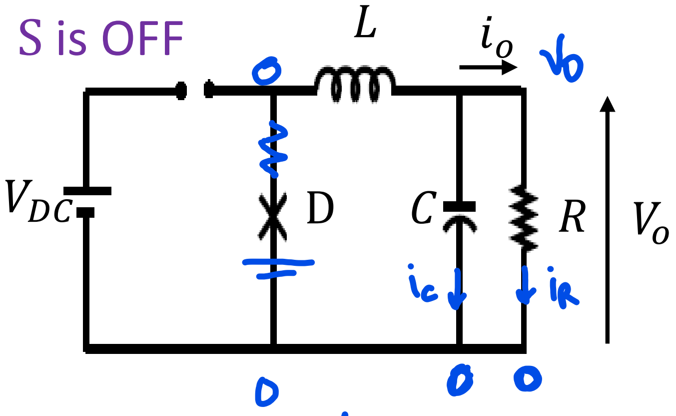
→ $\boxed{i_L = i_C + i_R \text{ (KCL)}}$

→ $\boxed{i_L = C\frac{dv_o}{dt} + \frac{v_o}{R}}$

→ $\boxed{V_D = -V_{DC}}$

$V_s = 0$

S is OFF



For, $DT < t < T$

$\boxed{V_L = -V_o = \text{constant}}$

→ i_L decreases linearly

→ $\boxed{i_L = C\frac{dv_o}{dt} + \frac{v_o}{R}}$

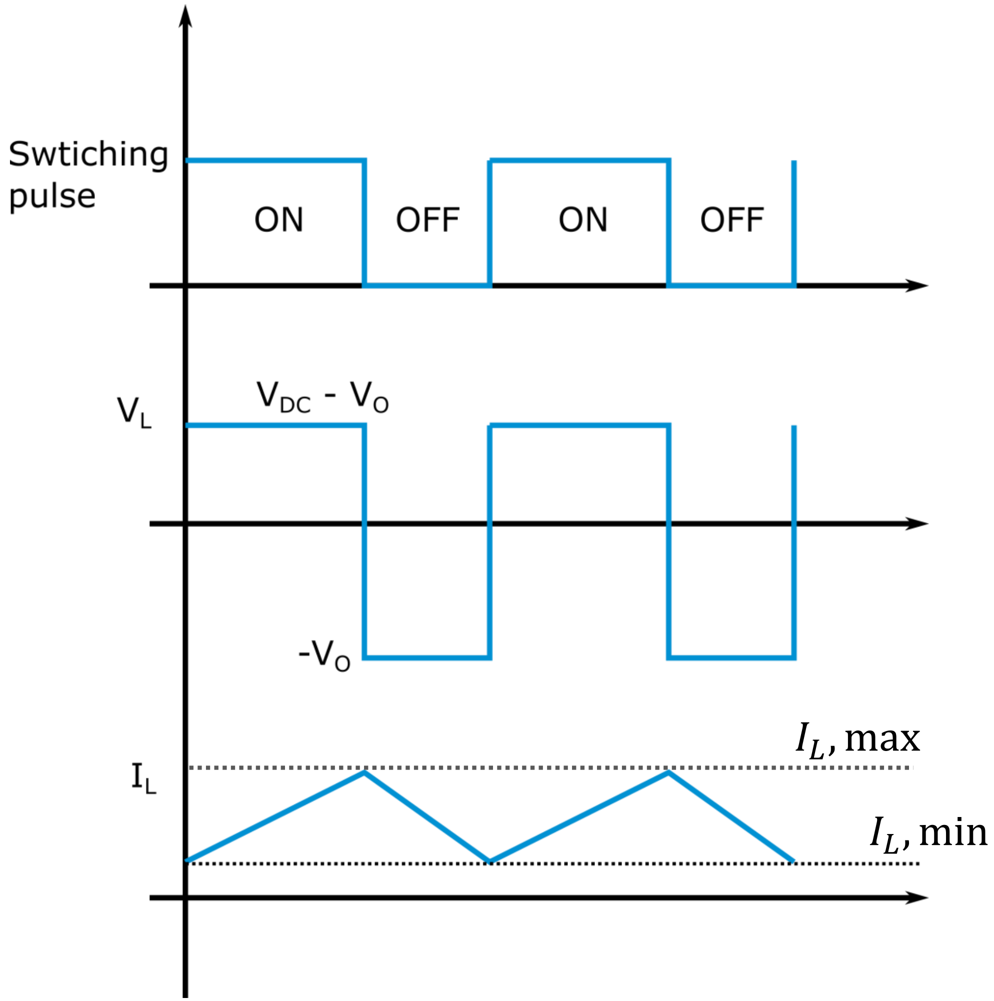
→ $\boxed{V_S = V_{DC}}$

$V_L = -V_o = L\frac{dI_L}{dt} \Rightarrow \frac{dI_L}{dt} = \frac{-V_o}{L} = c$

$V_D = 0$

DC-DC Conversion: Buck Converter

not I_L = constant
but same
cycle



Assume i_L is continuous and steady-state is assumed

Average voltage across L = 0

$$\therefore (V_{DC} - V_o)DT = V_o(1 - D)T$$

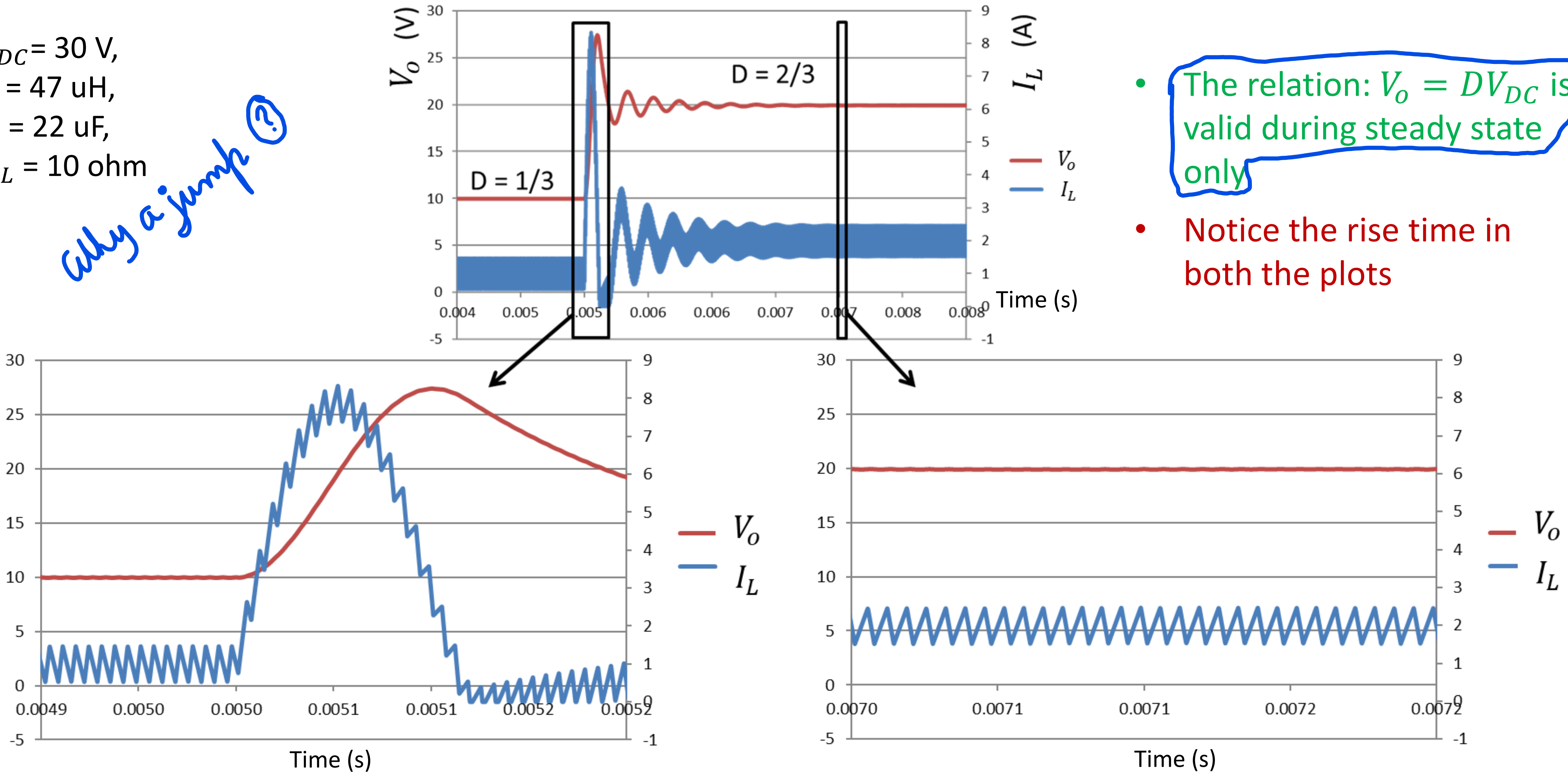
$$V_o = DV_{DC}$$

➔ Buck Converter, Output < Input

DC-DC Conversion: Buck Converter output when 'D' changes

V_{DC}= 30 V,
L = 47 uH,
C = 22 uF,
R_L = 10 ohm

Why a jump ?



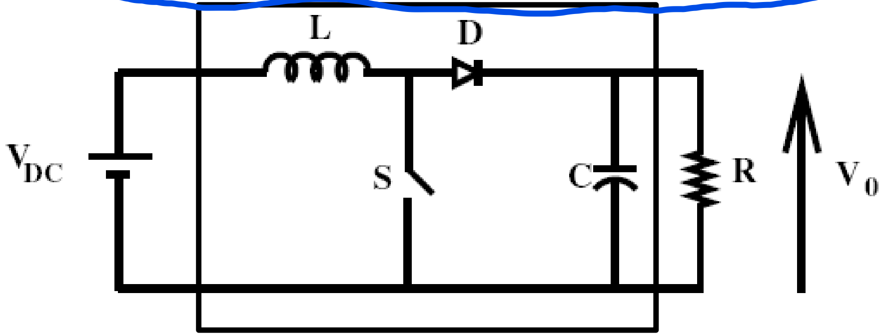
- The relation: $V_o = DV_{DC}$ is valid during steady state only
- Notice the rise time in both the plots

DC-DC Conversion: Boost Converter

Following circuit is a boost converter
L → filter inductor
C → filter capacitor
'V_O' is constant and ripple free

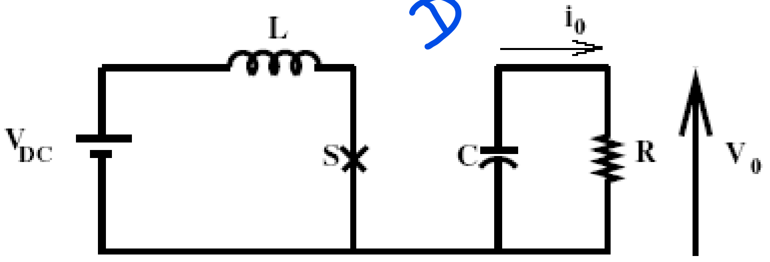
Switch 'S' is switched at a very high frequency

- S is ON for DT time
- S is OFF for $(1-D)T$ time
- T is switching period,
  $T = \frac{1}{f_{sw}}$, f_{sw}: switching frequency



S is ON

D → reverse biased



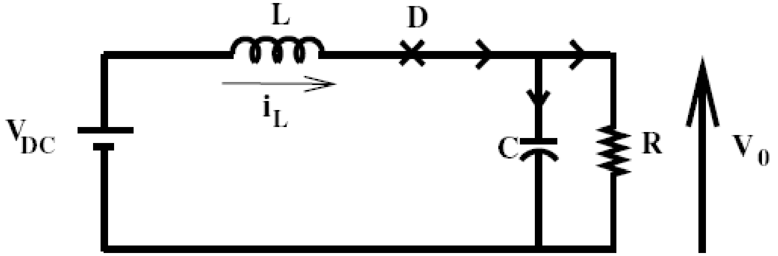
$V_L = V_{DC}$ = Constant

→ I_L increases linearly

→ $I_o = -C\frac{dv_o}{dt} = \frac{v_o}{R}$

S is OFF

→ forward biased



$V_L = V_{DC} - V_o$ = Constant

→ I_L decreases linearly

→ $I_L = C\frac{dv_o}{dt} + \frac{v_o}{R}$