TSTE19 Power Electronics

Lecture 11

Tomas Jonsson

ISY/EKS

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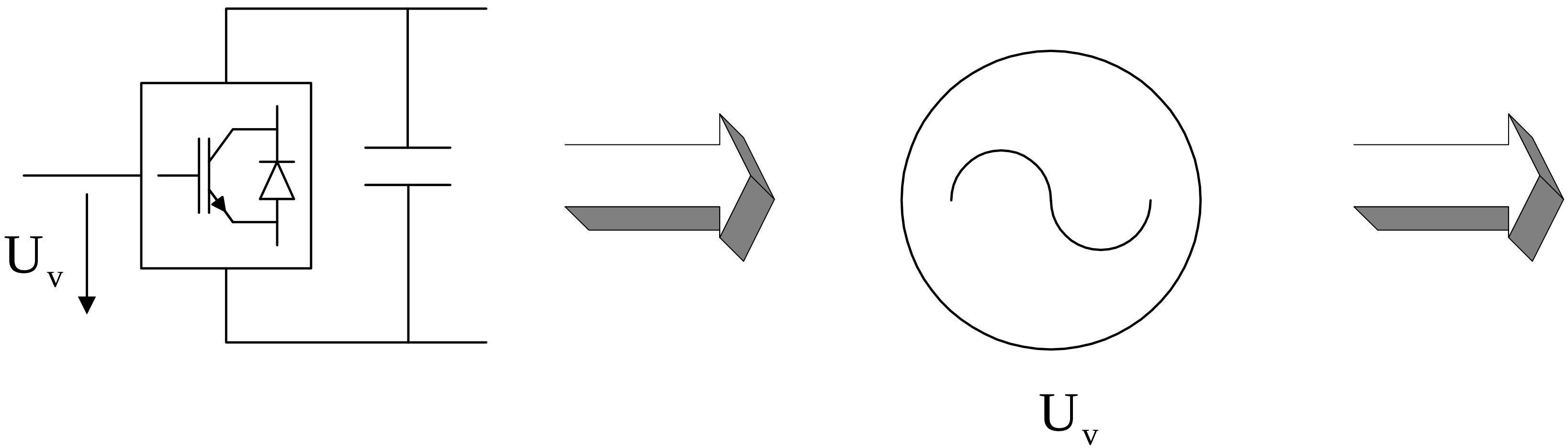
Outline

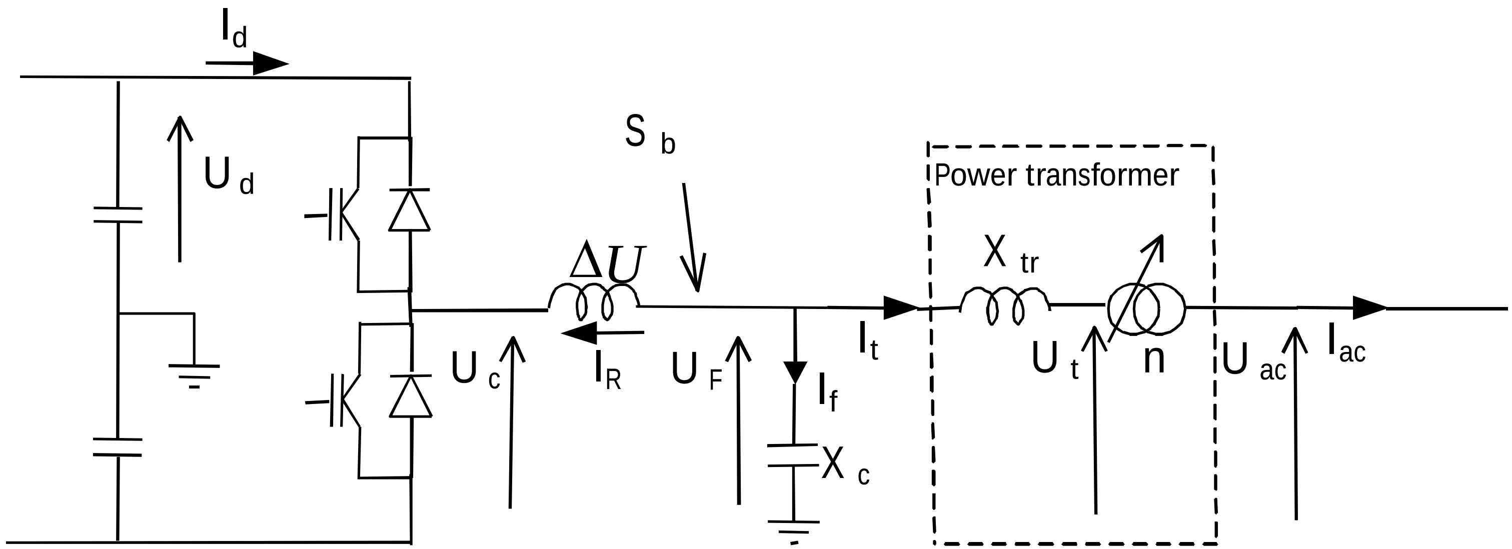
- Converter control
- Snubber circuits
- Lab 3 introduction

Basic control principle.
Voltage Source Converter (VSC)



adjustable { amplitude
phase angle
frequency

Control of Active and Reactive Power

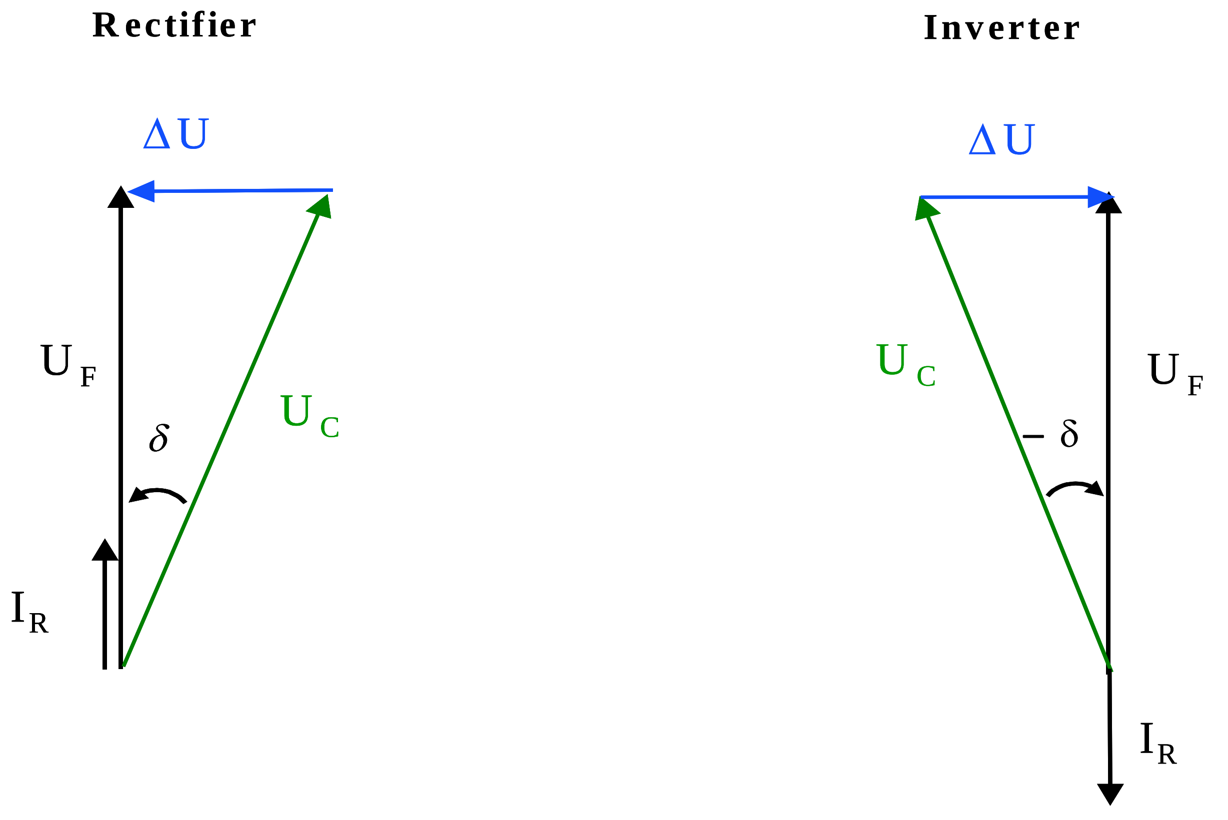


$$\vec{S}_b = P + jQ = \sqrt{3} \times \vec{U}_F \times \vec{I}_R^{\,*}$$

$$P = \frac{U_F \times U_C \times \sin\delta}{\omega L}$$

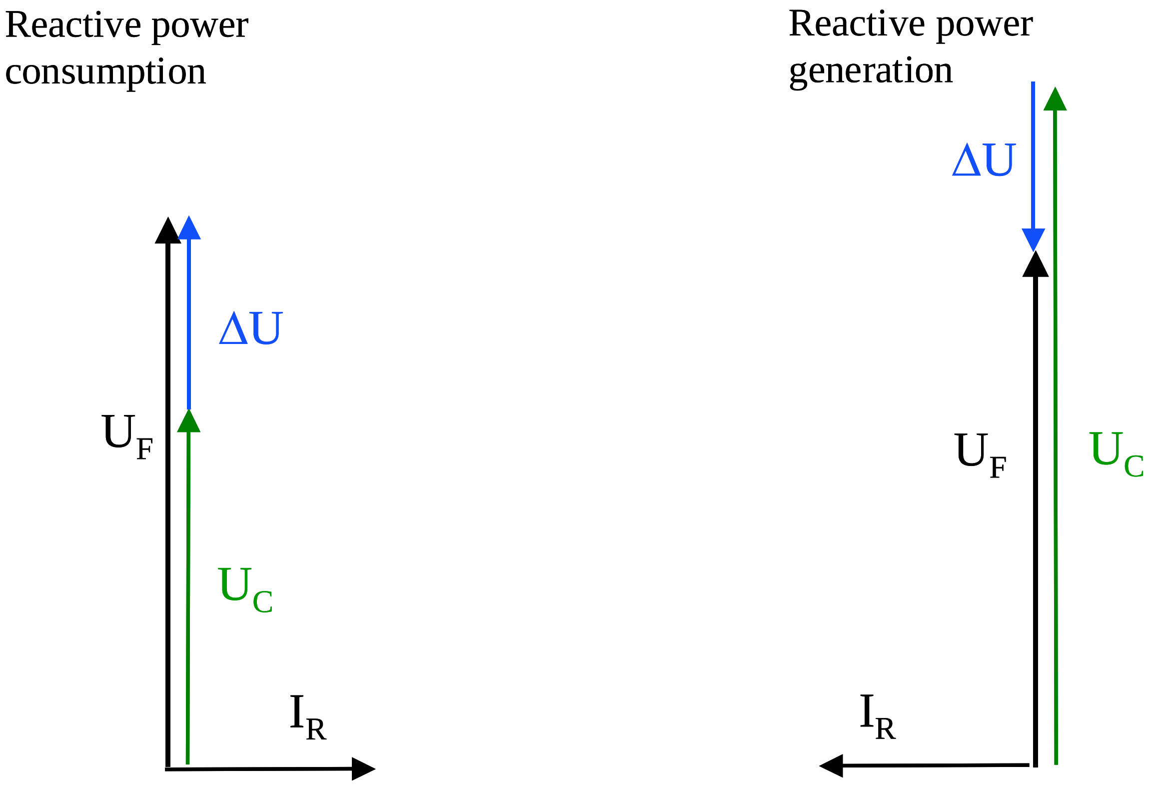
$$Q = -\frac{U_F \times (U_F - U_C \times \cos\delta)}{\omega L}$$

Control of Active Power



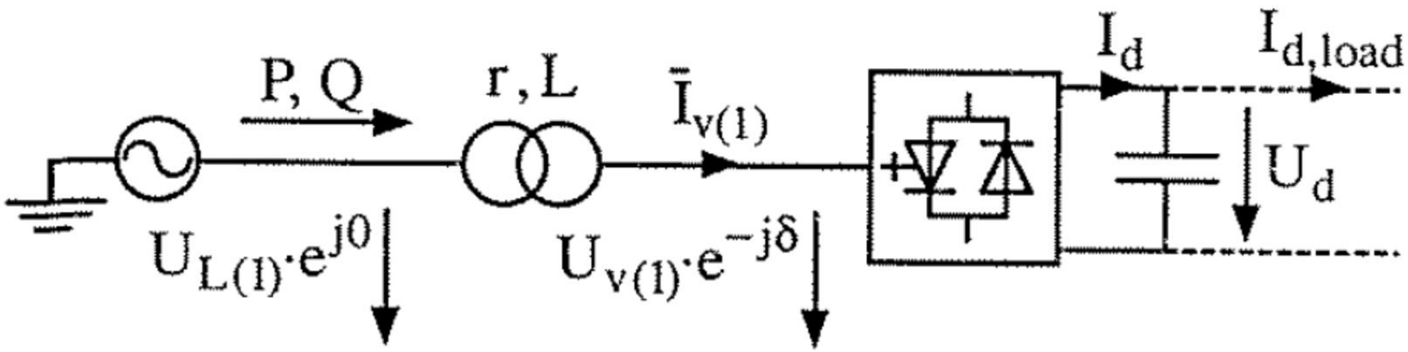
If the Uc is in phase-lag, the active power flows from AC to DC side (rectifier)
If the Uc is in phase-lead, the active power flows from DC to AC side (inverter)

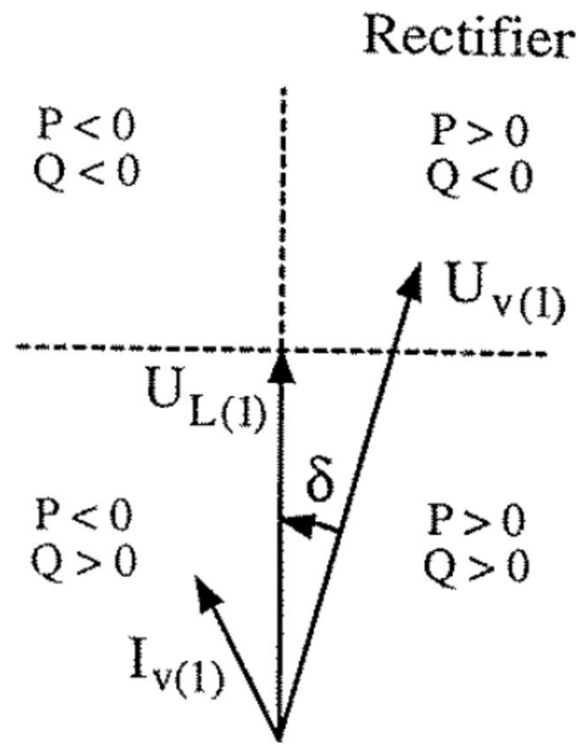
Control of Reactive Power



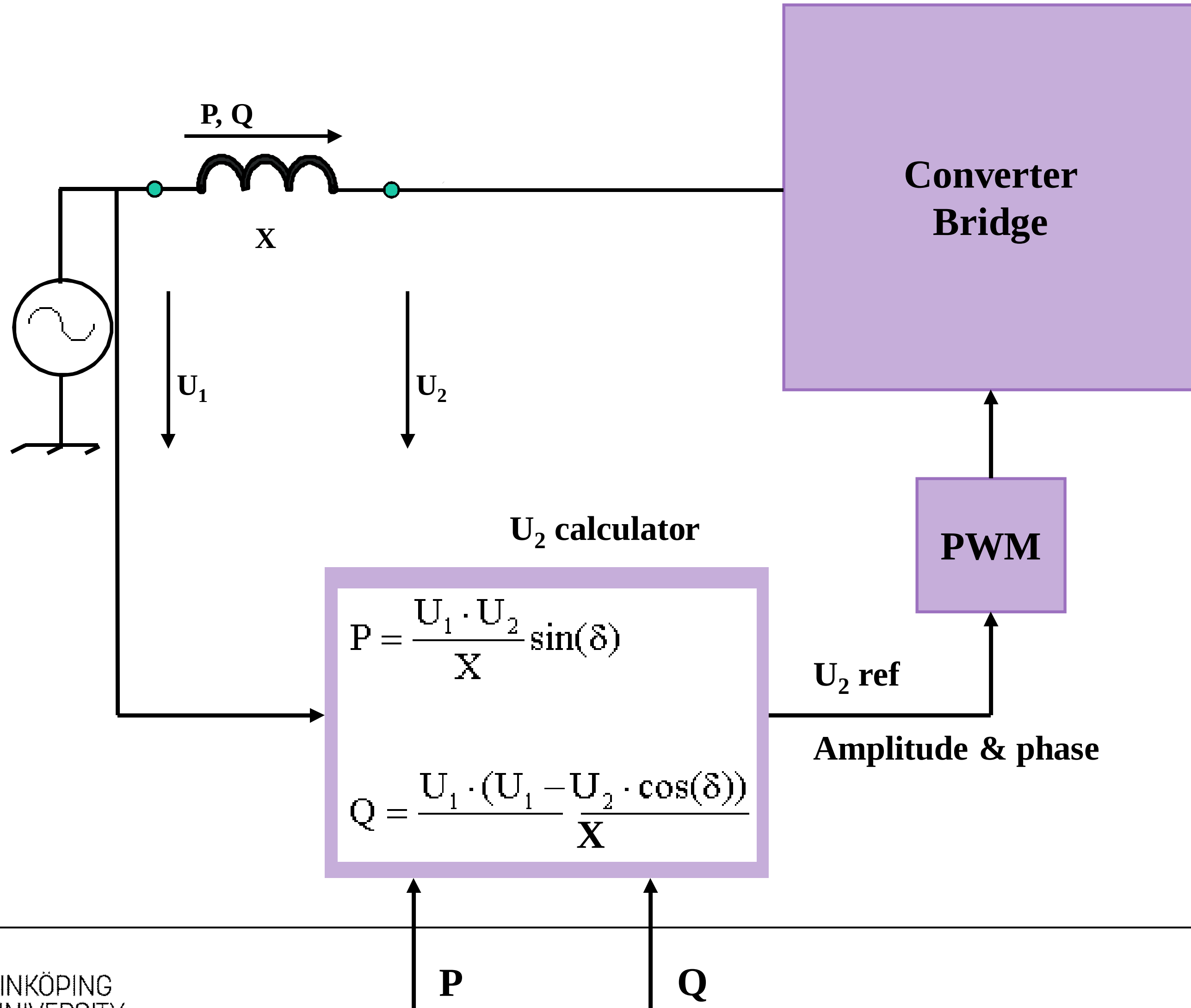
If U_F > Uc, there is reactive power consumption.
If $U_C > U_F$, there is reactive power generation.

Control of P and Q in 4 quadrants

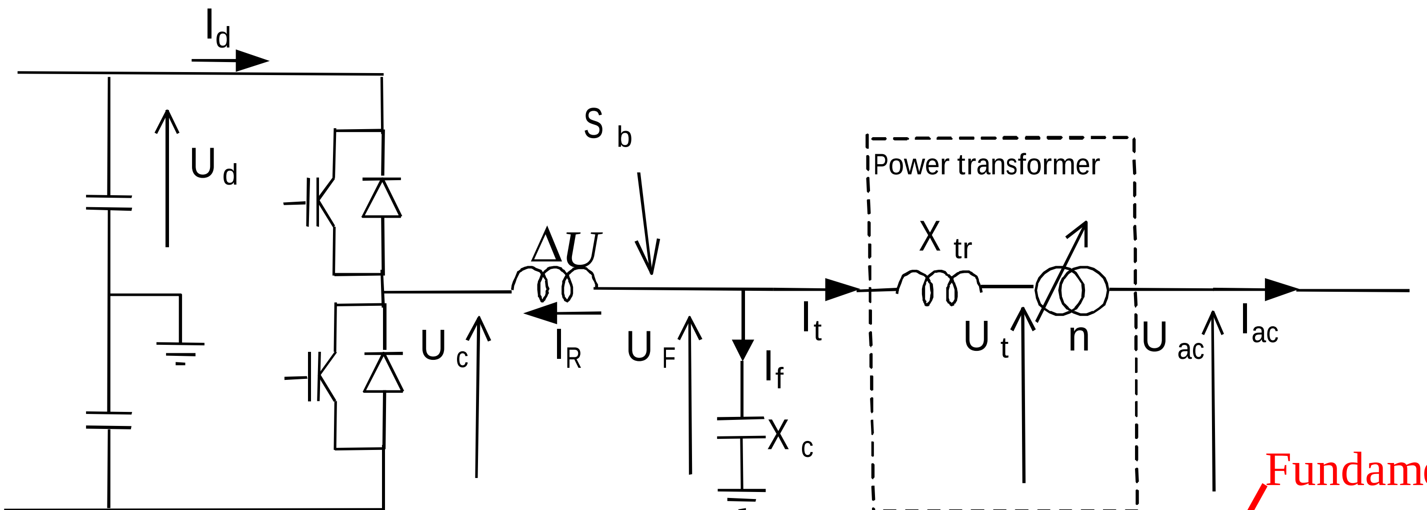


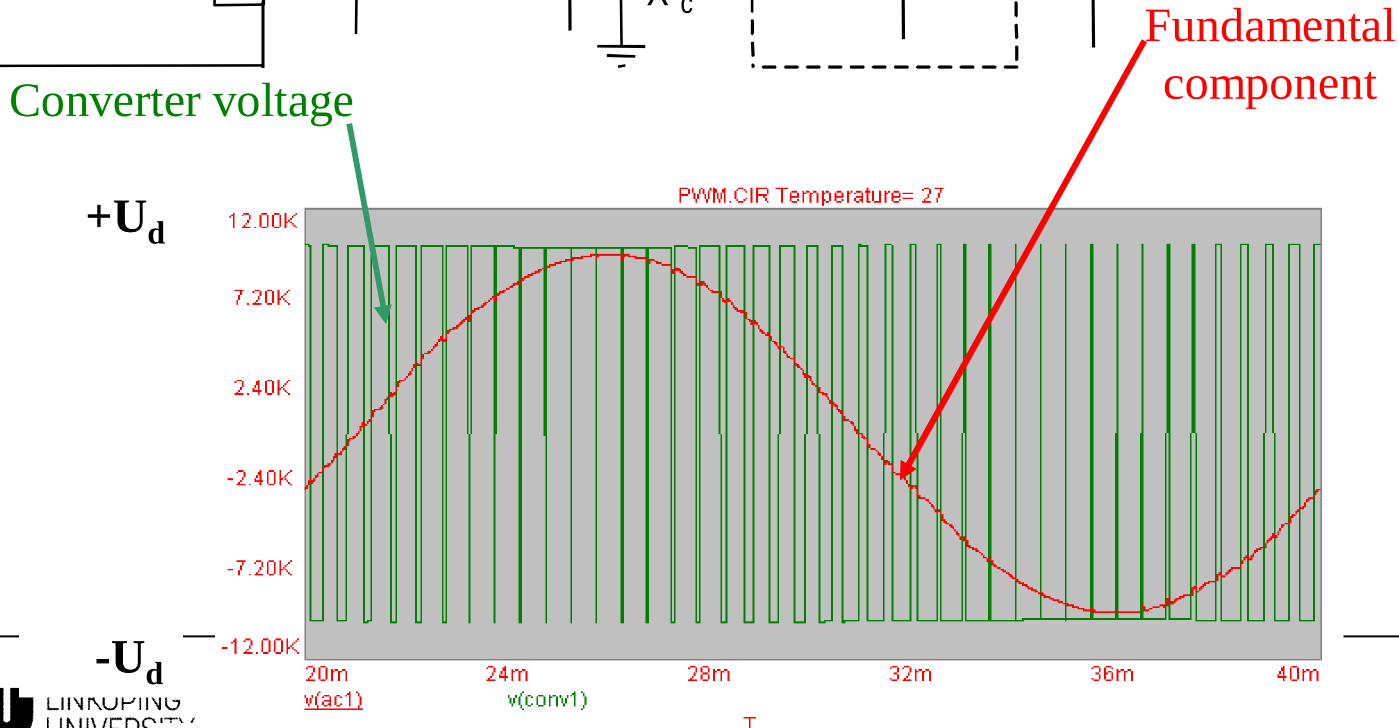


Calculation of Control Signal

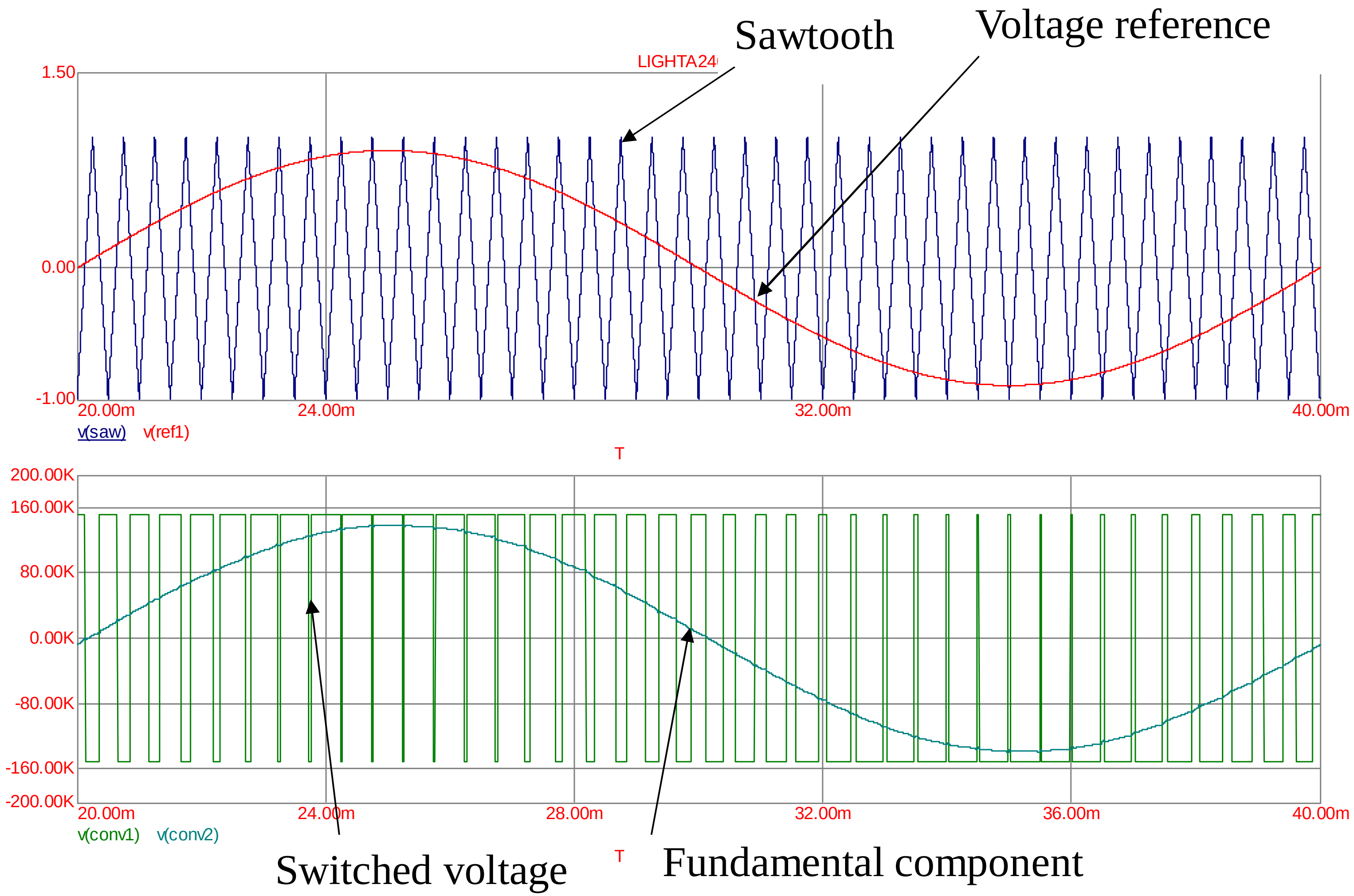


Voltage Source Converter with Pulse Width Modulation



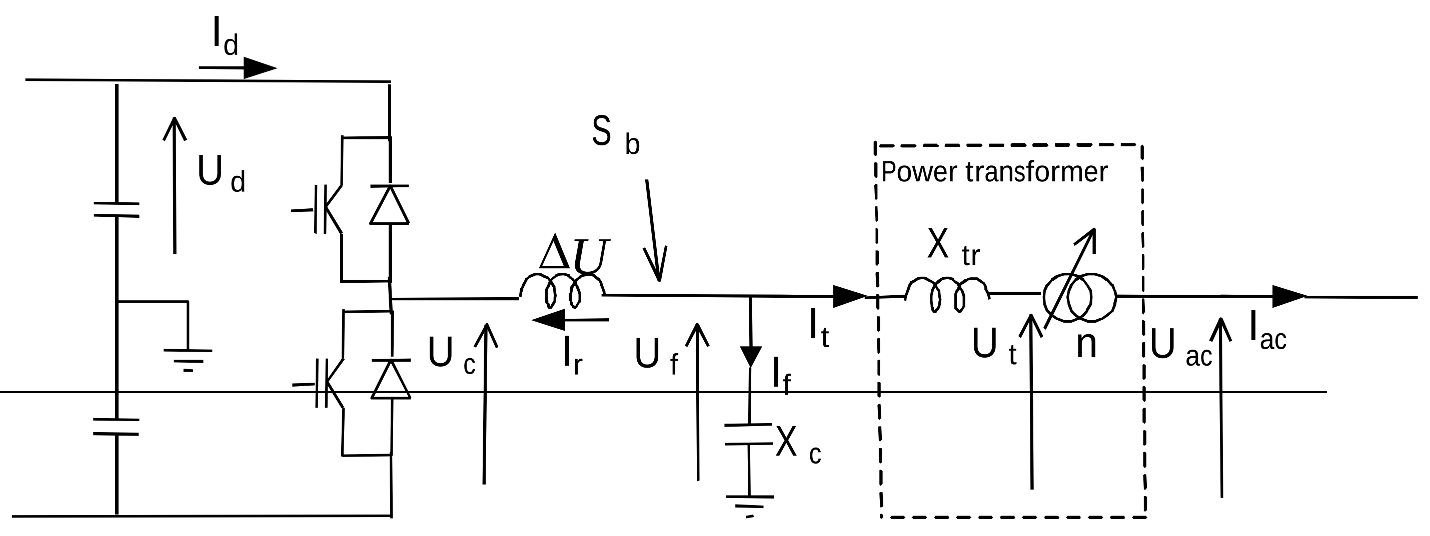


PWM- generation of pulses



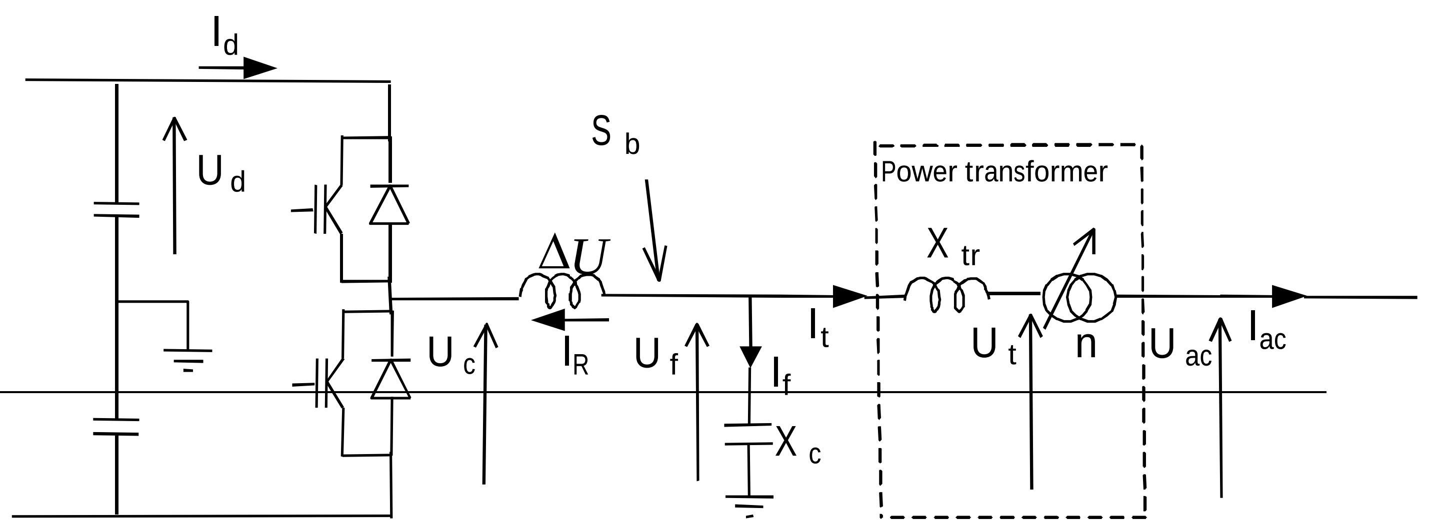
Feed-forward control

- $U_c = U_f + L\frac{di_r}{dt}$
- $U_{cRef} = (Feedforward) + (Feedback)$
- $U_{cRef} = U_f + L\frac{di_r}{dt} + k\left(i_r - i_{rRef}\right)$
  - $i_{rRef} = \hat{I}_{rRef}\cos(\omega t + \varphi)$

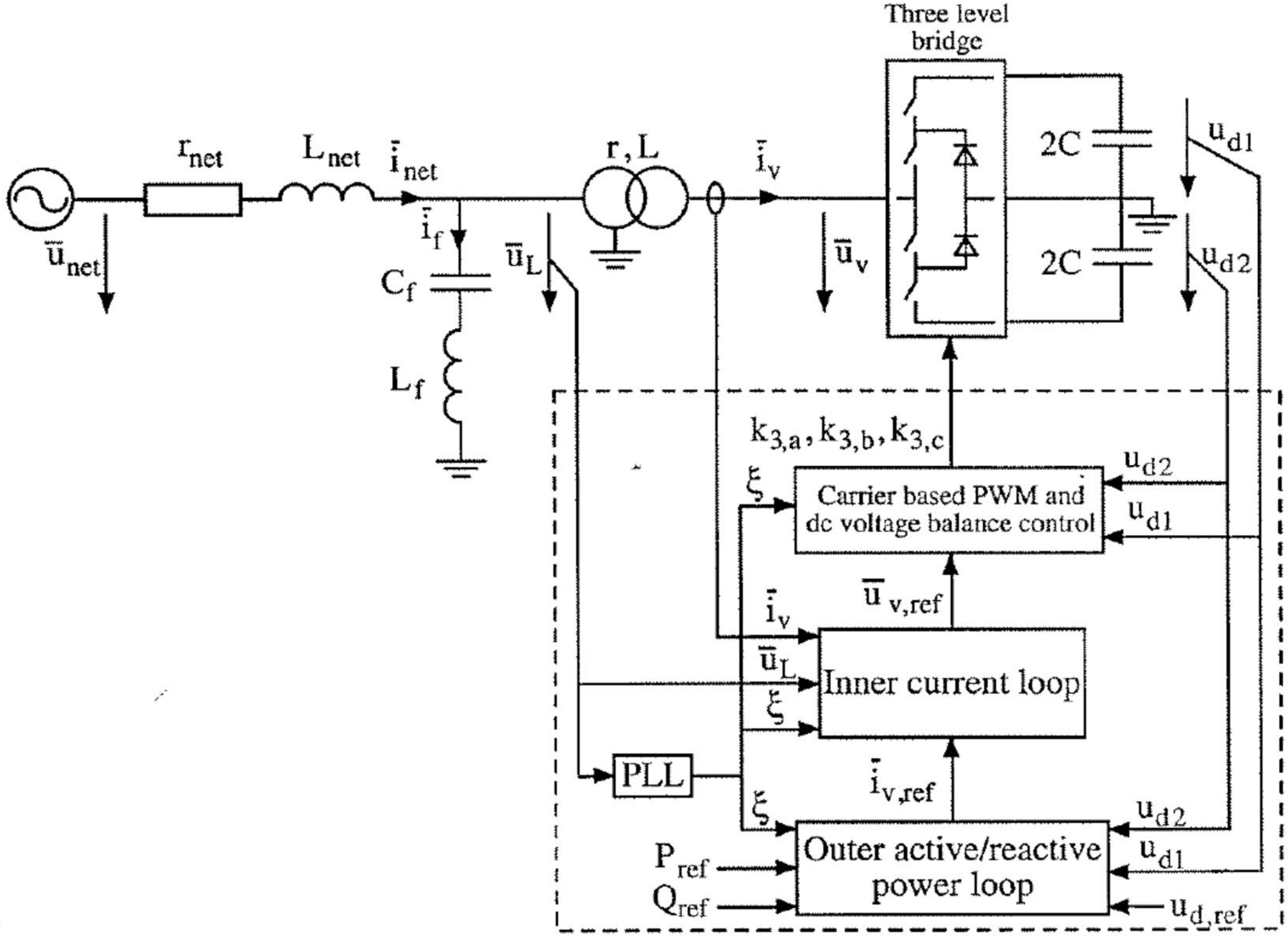


Vector control

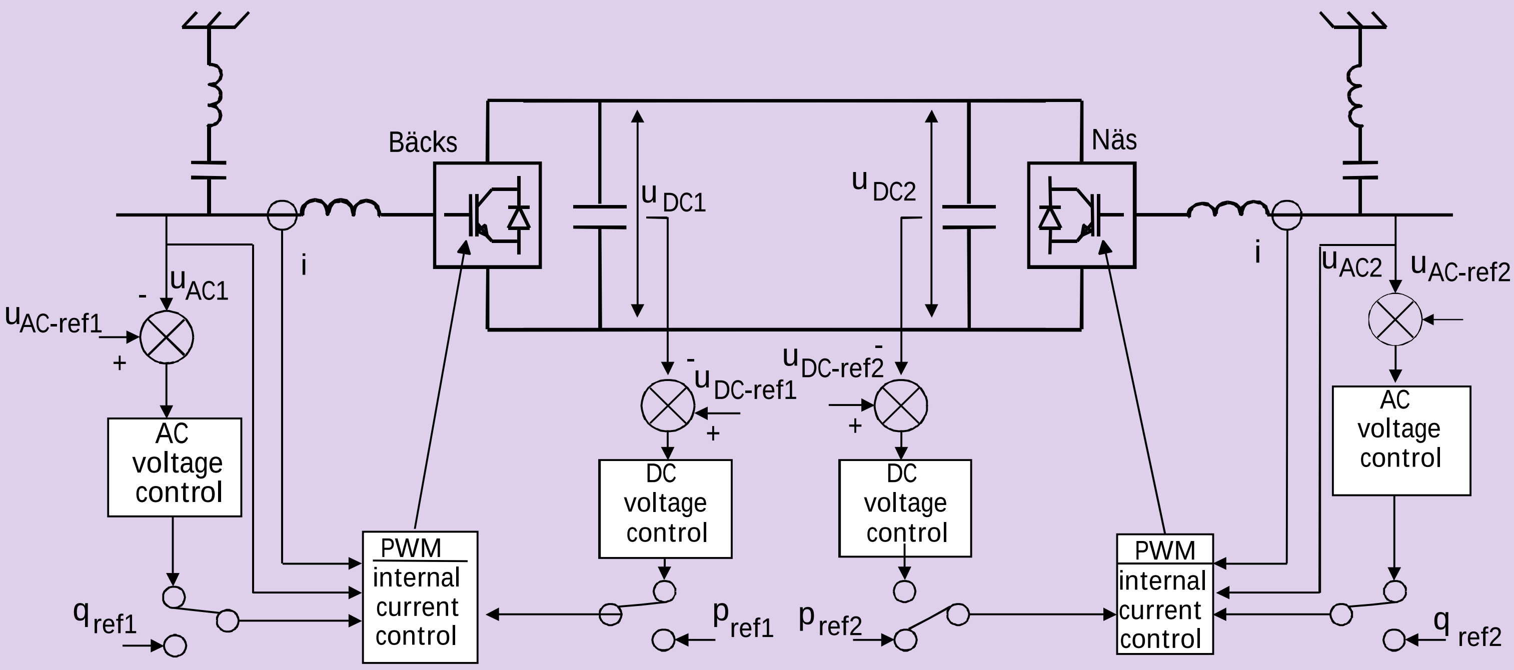
- $\overline{U}_c = \overline{U}_f + j\omega L\overline{I}_R$
- $\overline{I}_{rDQ} = i_r e^{-j\omega t} = \begin{cases} I_{rD} = i_r \cos\omega t \\ I_{rQ} = i_r \sin\omega t \end{cases}$
- $\overline{U}_{cDQref} = \overline{U}_{fDQ} + j\omega L\overline{I}_{rDQ} + k\left(\overline{I}_{rDQ} - \overline{I}_{rDQref}\right)$
- PLL required to define ωt



System with feed-forward and vector control

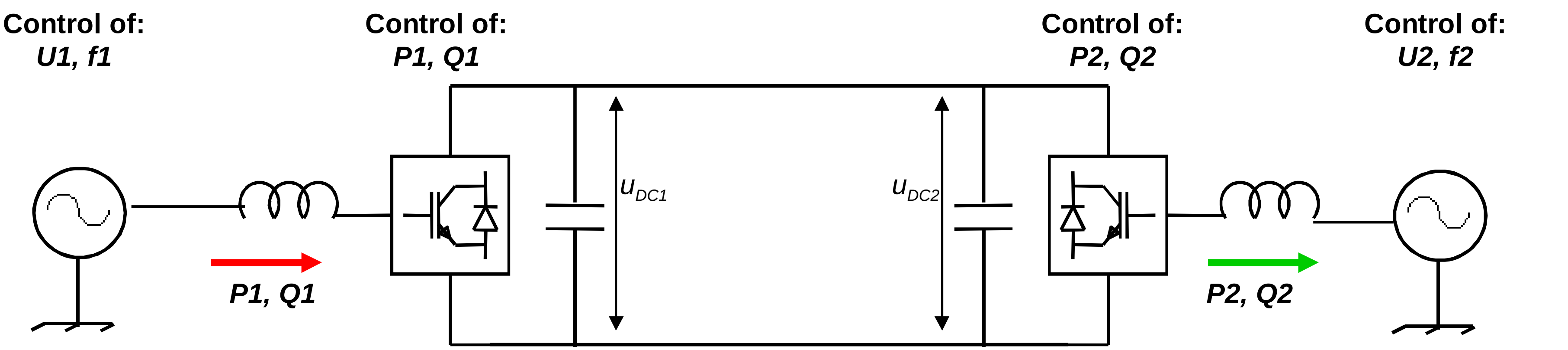


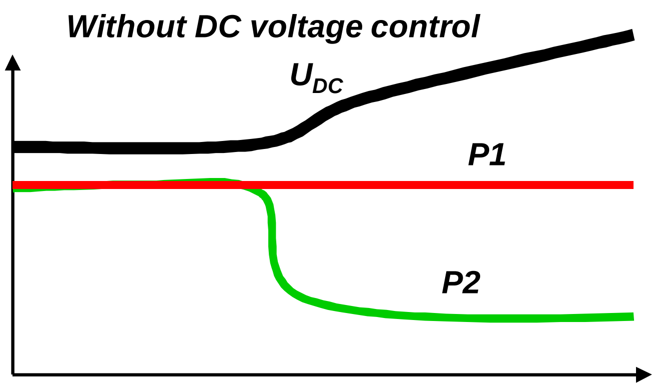
Control of AC - DC – AC converter



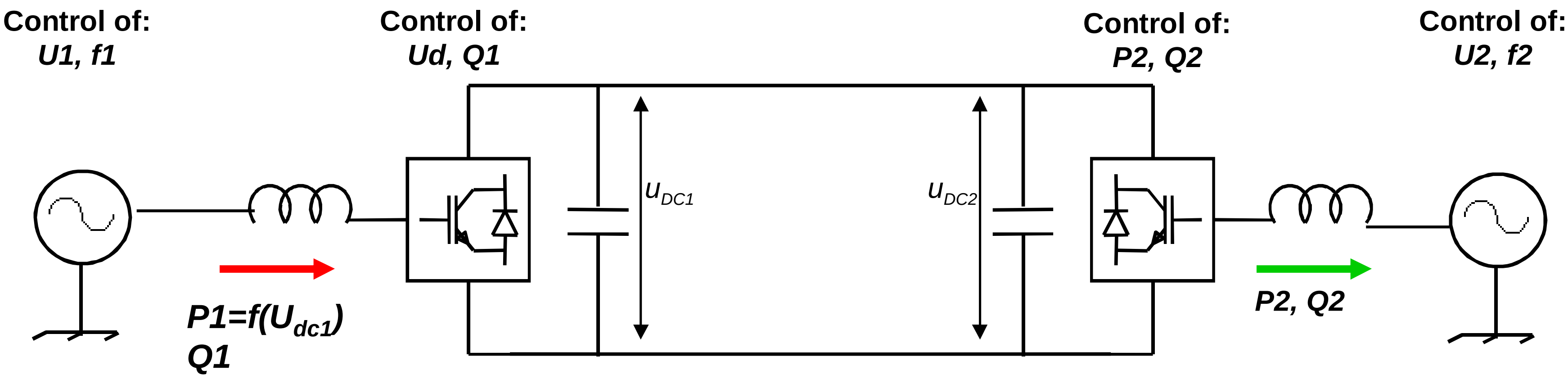
Principle control of HVDC-Light

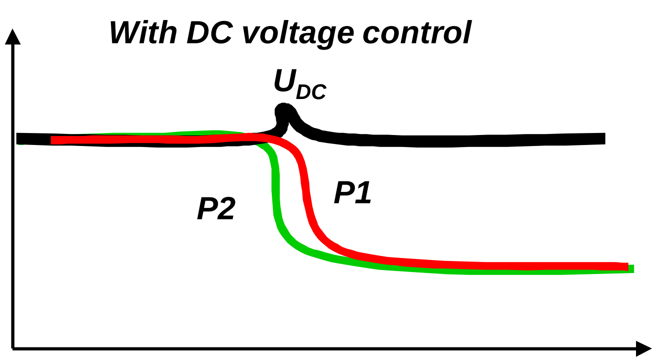
DC Power versus DC voltage





DC voltage control





Lecture 11

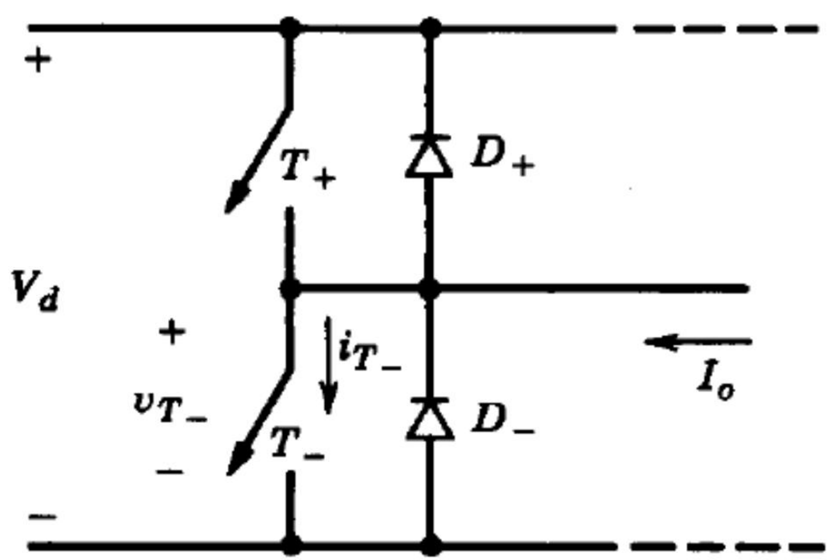
Snubber circuits

Problem with switching converters

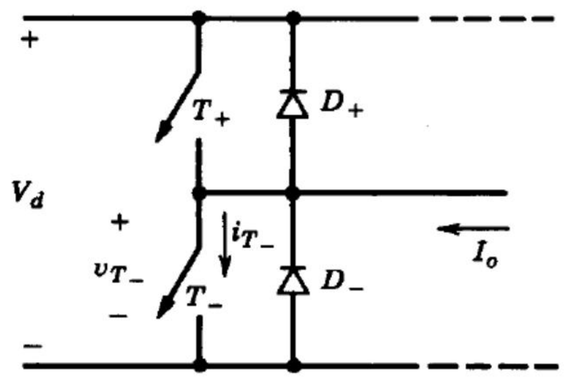
- Switches turns on/off while conducting large currents
  - Recovery time create large power dissipation
- di/dt generates EMI (Electromagnetic interference)
- Small size requires higher switching frequencies

Example, full bridge leg

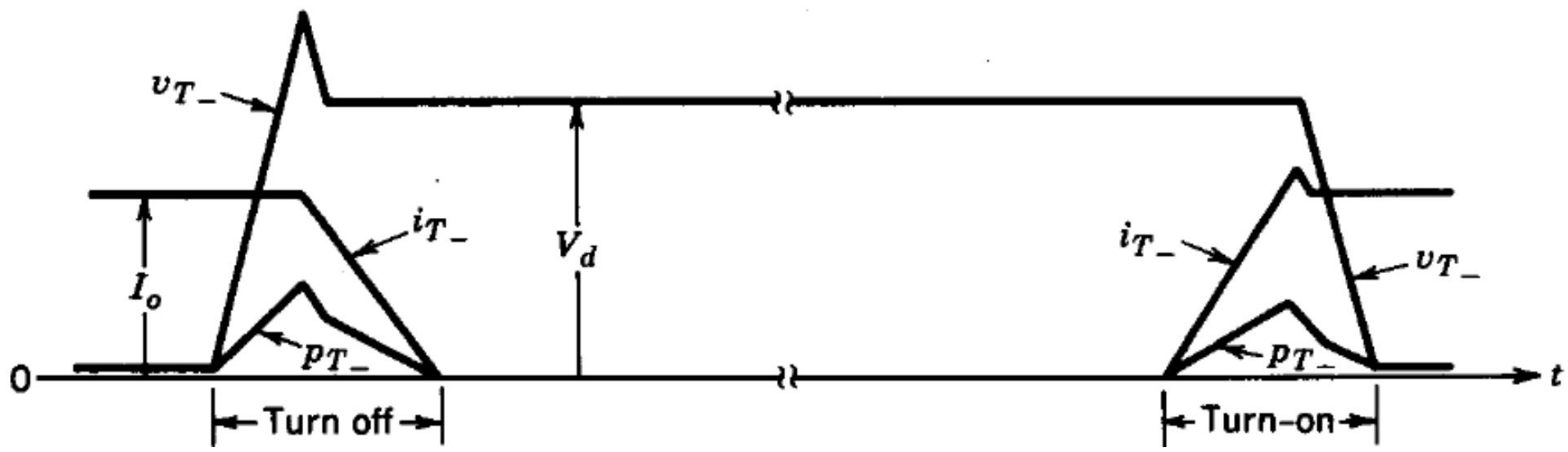
- Finite di/dt and dv/dt
- Parasitics: L, C, R
- I_O can be both positive and negative



Hard switching waveform

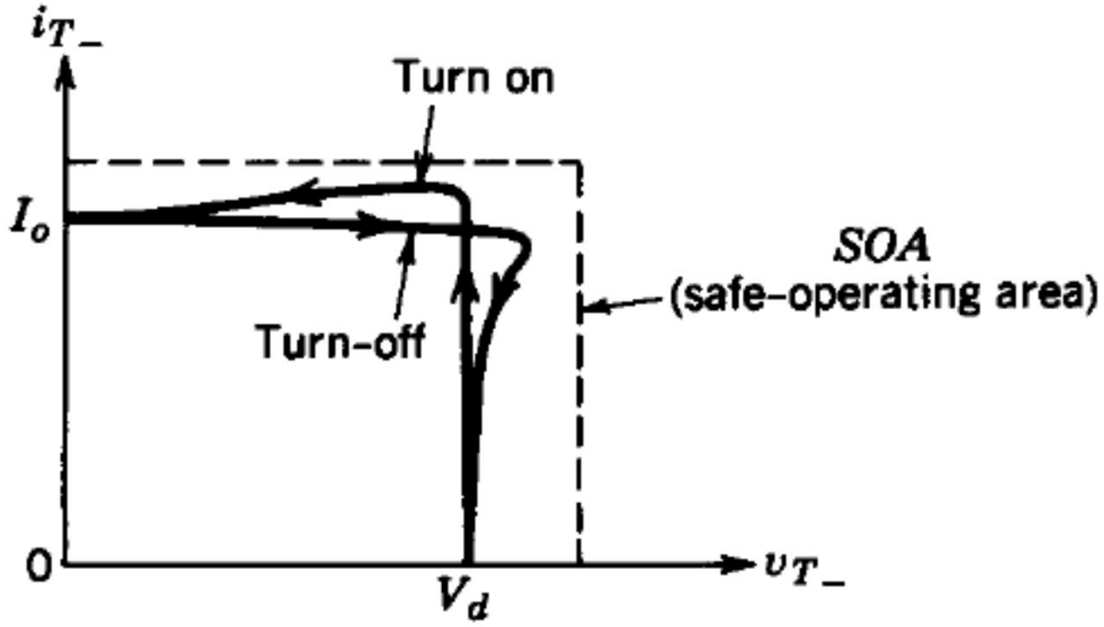


- Stray inductance gives voltage overshoot
- Stray capacitance gives current overshoot
- Parasitics limits di/dt and dv/dt
- $P_{T-} = v_{T-}\ i_{T-}$



Switch voltage and current

- Short moments of high power dissipation
  - Device must cope with the power dissipation
  - Overshoot increases required SOA

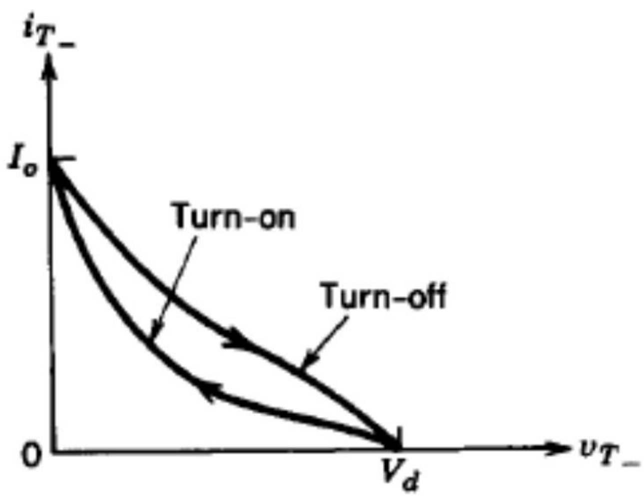


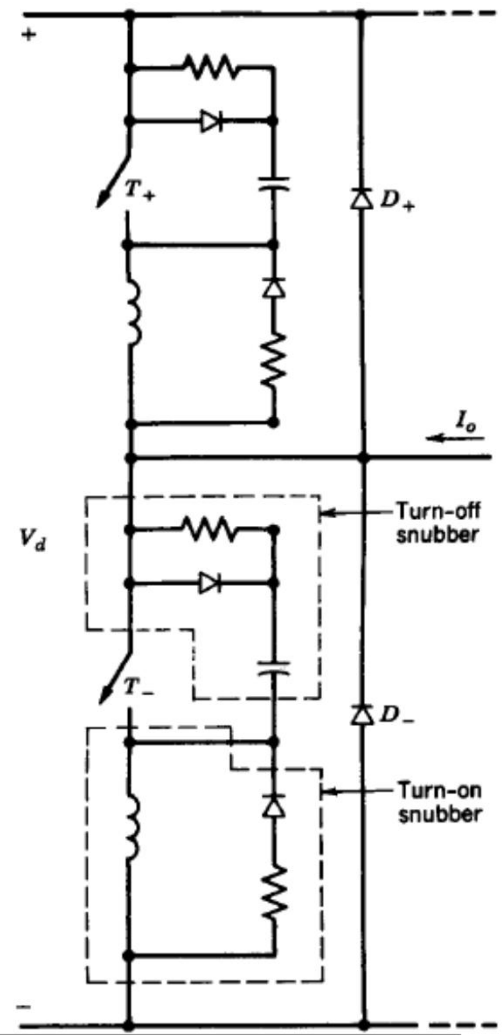
Component characteristic goal

- High di/dt and dv/dt to reduce power loss
- Short recovery time diodes
- Components must cope with short time full power dissipation
- Large stress on components due to power dissipation changes (material stress etc)

Snubber circuits

- Connected in parallel/serial with the switches
- Turn-on snubber
  - Inductor limits di/dt
  - Capacitance limits dv/dt
- Power now lost in snubber instead of switch

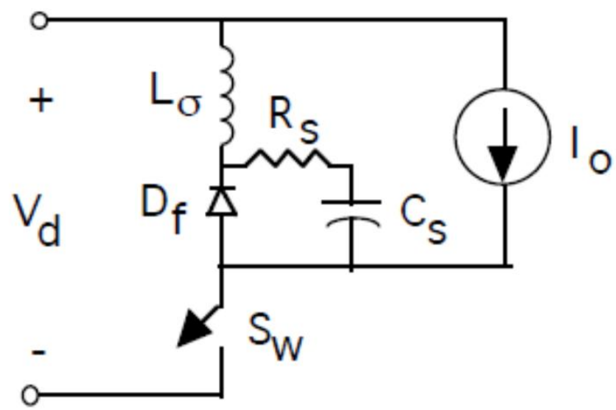




Snubber circuits

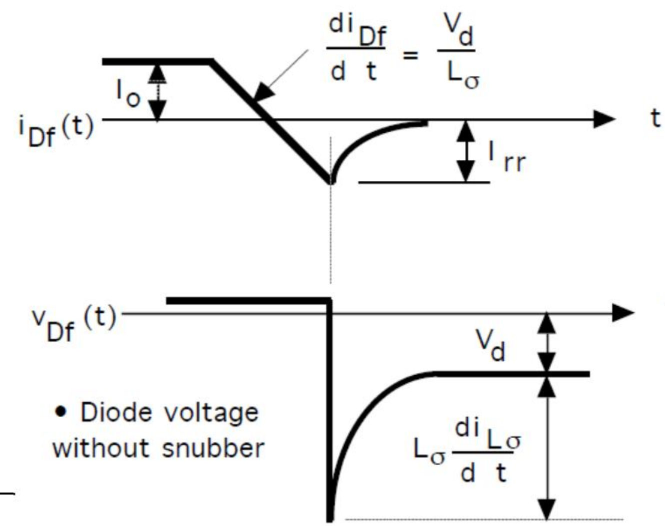
- Protect semiconductors
  - Limit voltages applied during turn-off transients
  - Limit device currents during turn-on transients
  - Limit the rate of rise (di/dt) of currents
  - Limit the rate of rise (dv/dt) of voltages
  - Shape the switching trajectory at turn on and turn off
- Three major classes
  - Unpolarized series RC snubbers
  - Polarized RC snubbers
  - Polarized LR snubbers

Diode snubbers



- L_σ stray inductance
- R C snubber circuit
- Problem when switch turns on
  - Current starts to flow in wrong direction
  - When diode turns off then Lσ tries to force continued current
- Diode breakdown if

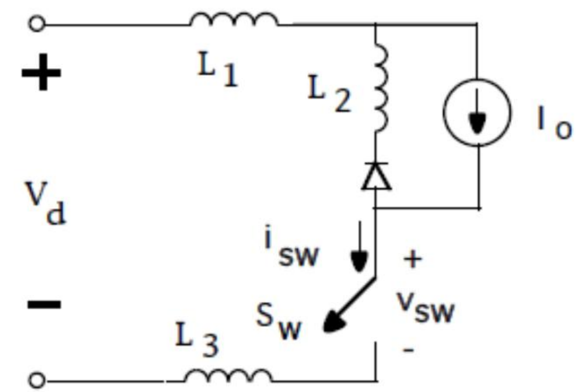
$$V_d + L_\sigma \frac{di_{L\sigma}}{dt} > BV_{VB}$$



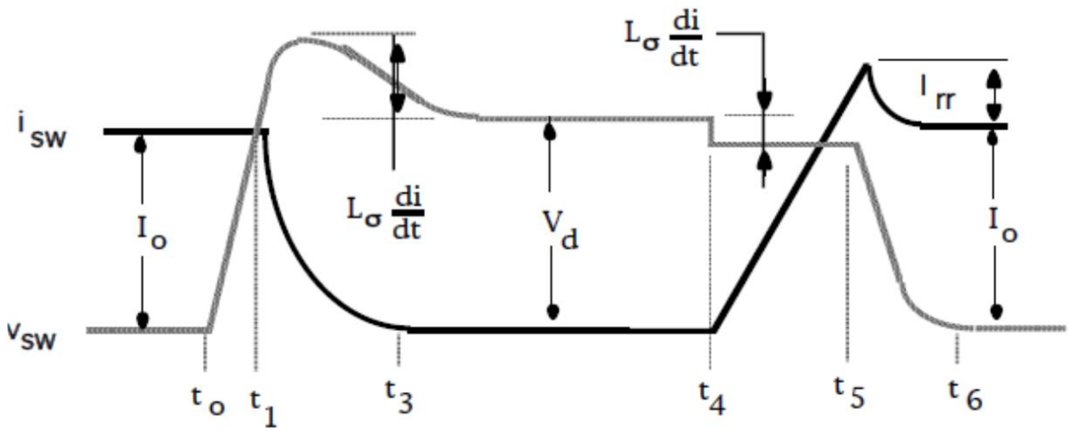
Snubber circuits for controlled switches

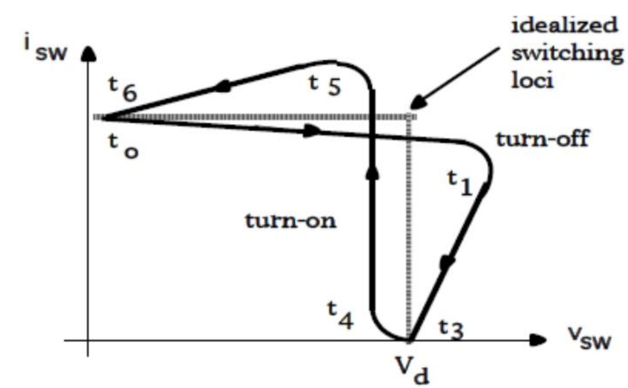
- Step-down example
  - Lσ = L1 + L2 + L3 stray inductances
- Voltage and current overshoot due to inductances
- Three snubber types
  - Turn-off, turn-on, over-voltage

Step-down converter



Switch current and voltage waveforms



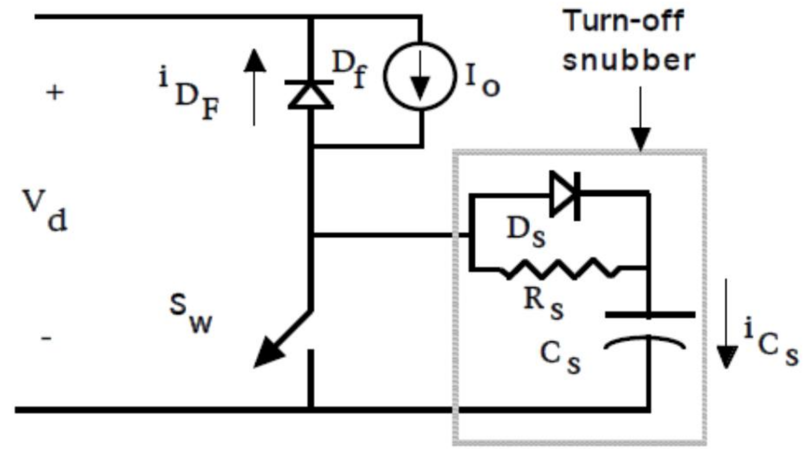


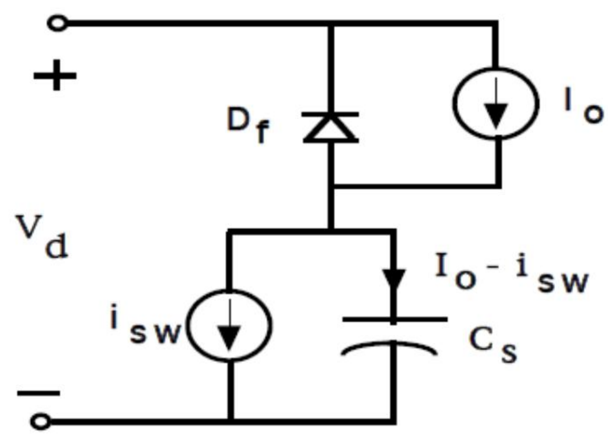
Turn-off snubber circuit for controlled switches

- Diode to only include R_s at switch turn-on
- Simplified circuit for switch turn-off

$$i_{sw}(t) = I_0\left(1 - \frac{t}{t_{fi}}\right)$$

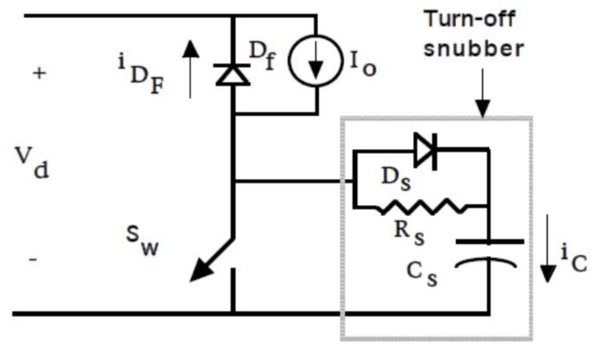
- Switch current at switch turn-off not affected by snubber circuit

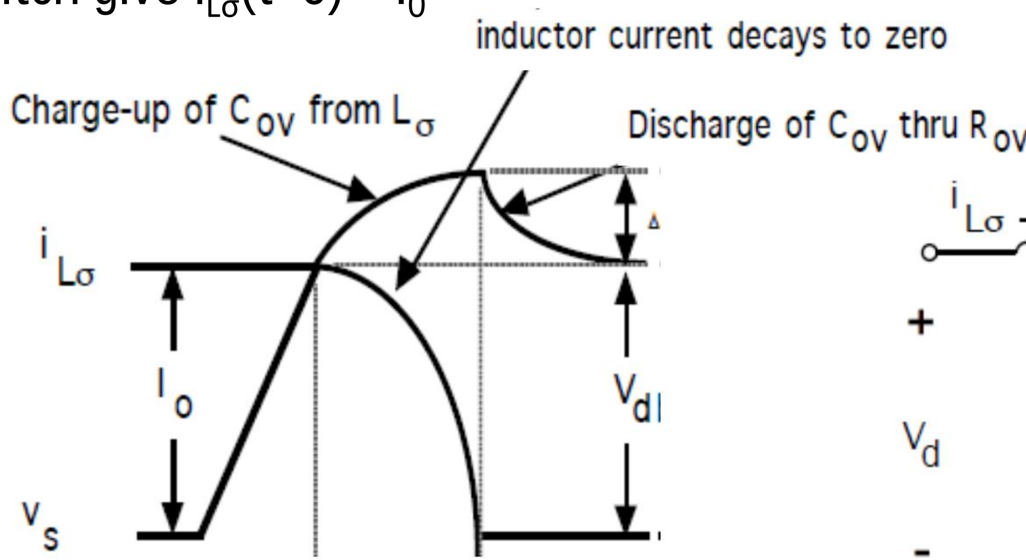


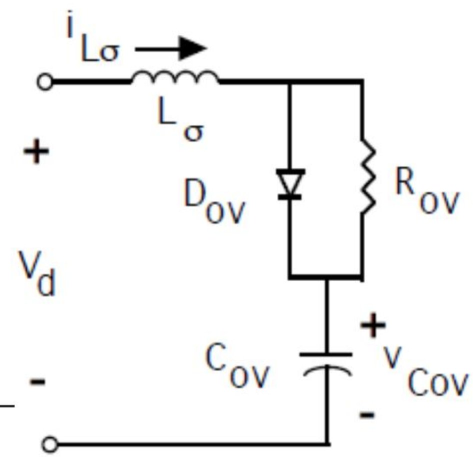


Overvoltage snubber function

- At transistor switch-off completed t = 0
  - $V_{COV} = V_D$
  - I_0 goes through D_f
  - Fast switch give $i_{L\sigma}(t=0) = I_0$

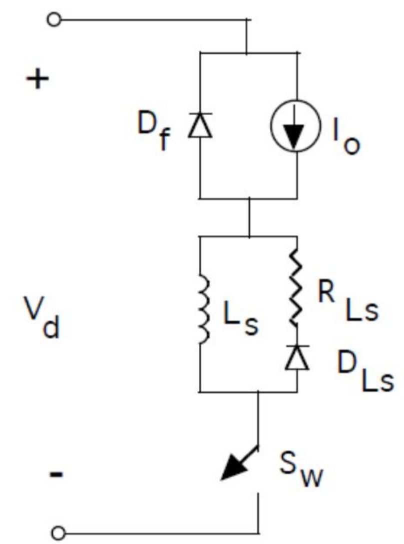


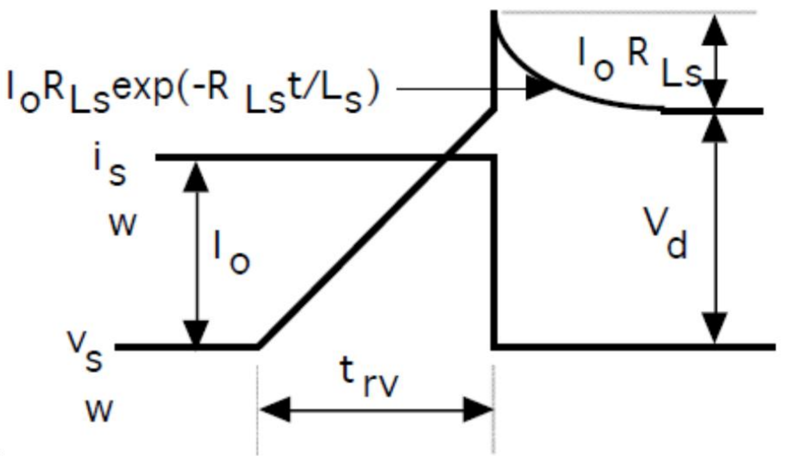




Turn-on snubber

- To limit dI/dt through switch at turn-on
- Turn-off Thyristors (GTO, IGCT) has limited dI/dt capability
- At switch turn-off, stored energy in L_s must be dissipated.
- D_{LS} and R_{Ls} forms discharge circuit for the inductor L_s





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