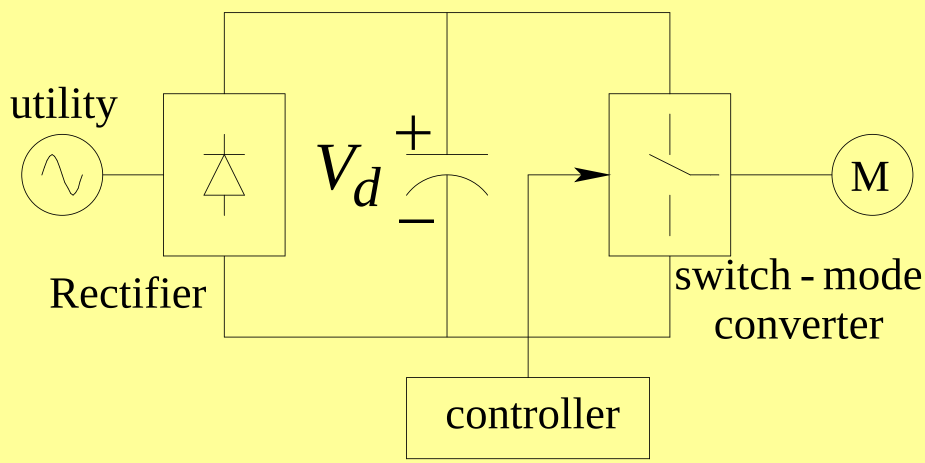
Basic Understanding of Power Processing in Electric Drives

- Role of PPUs
  - Switching Power-Pole as the Building Block
    - PWM Control
    - Average Model

Power Processing Unit (PPU)

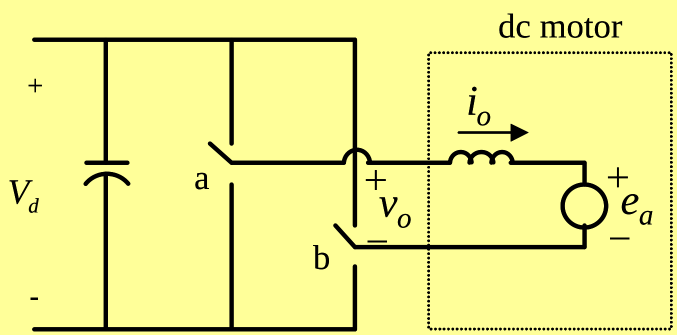
- ☐ Efficient conversion of power from line frequency AC to appropriate form required by the motor

Sub-blocks of PPUs



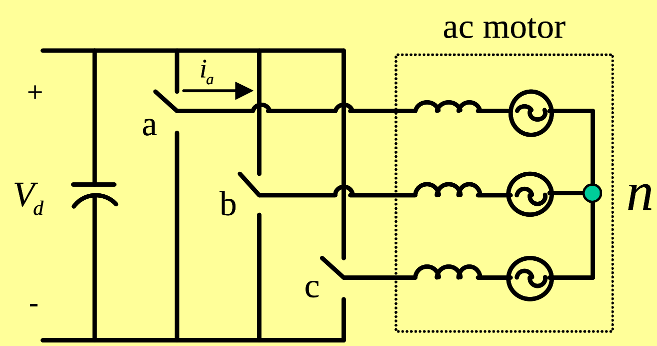
- ☐ Rectifier: Line frequency AC to DC
- ☐ Switch-Mode Converter: DC to the form required by motor

Switch-Mode Converters for dc- and ac-motor drives



(*a*)

For DC Drives

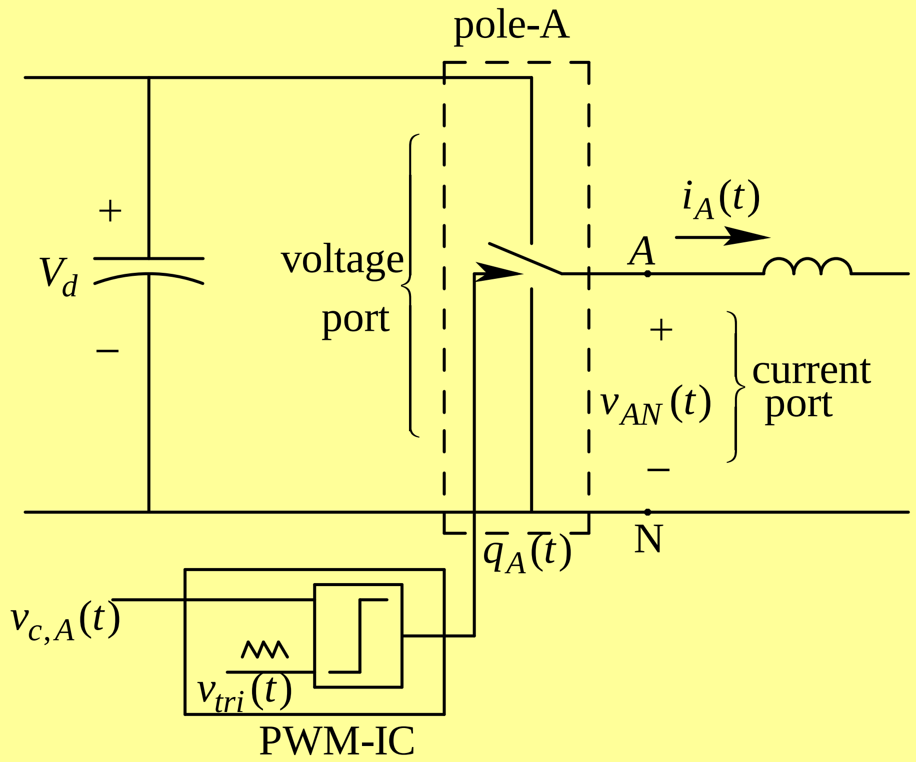


(*b*)

For AC Drives

Analysis of Switch-Mode Converters

- Pole as a Building Block



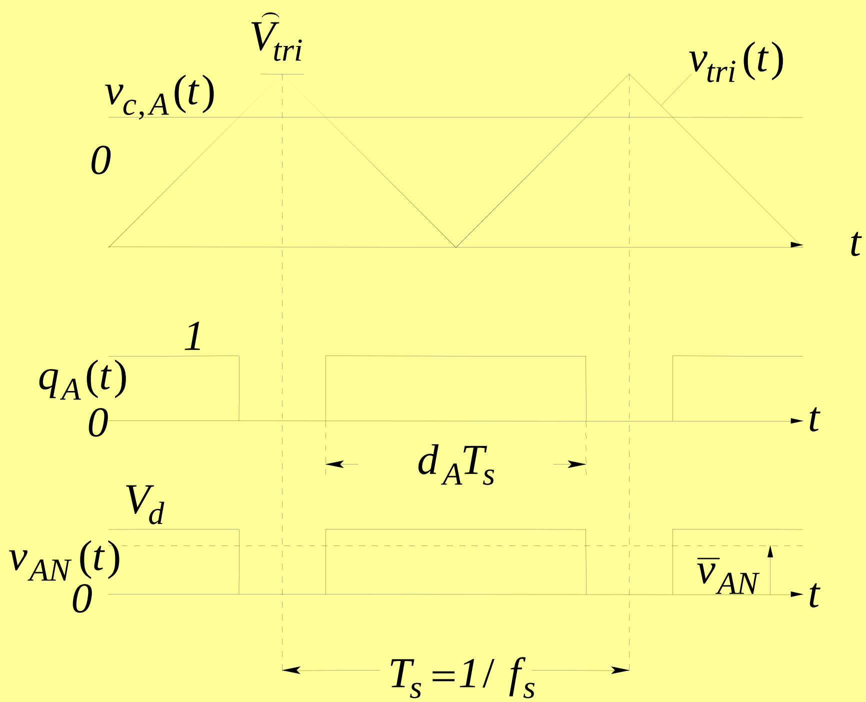
- V_d uncontrolled
- $v_{c,A}$: control voltage depicting desired output voltage
- Switch modulated to produce desired average voltage $\bar{v}_{AN}$

Pulse Width Modulation (PWM)

$$\text{if } v_{c,A}(t) > v_{tri}(t) \Rightarrow q_A(t) = 1 \Rightarrow \text{switch "up"} \Rightarrow v_{AN}(t) = V_d$$

$$\text{if } v_{c,A}(t) < v_{tri}(t) \Rightarrow q_A(t) = 0 \Rightarrow \text{switch "down"} \Rightarrow v_{AN}(t) = 0$$

$$v_{AN}(t) = q_A(t) V_d$$



Average Representation of a Pole

Output Voltage

Average output voltage over one switching cycle

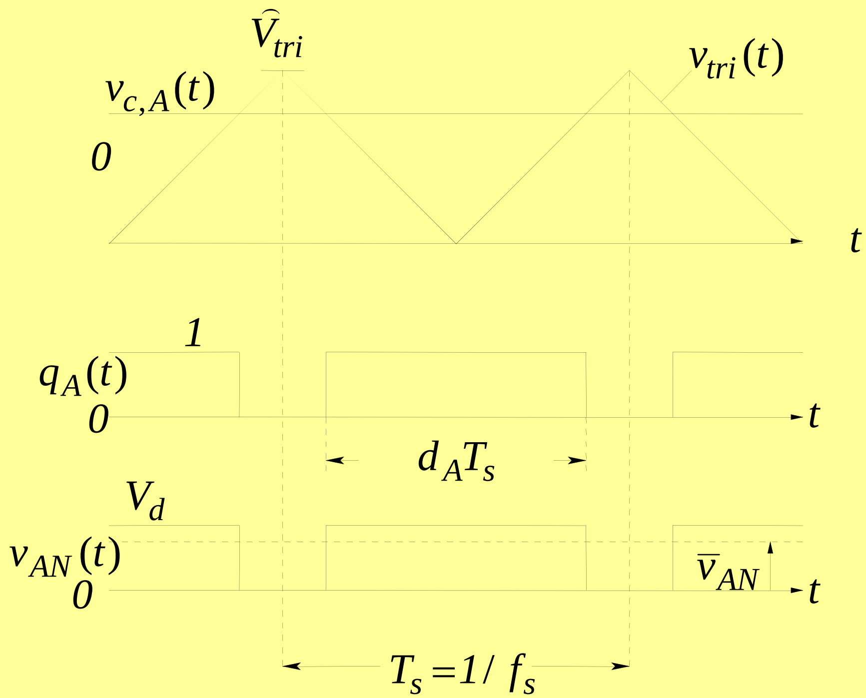
$$\bar{v}_{AN} = \frac{1}{T_s}\int_{T_s} v_{AN}(t)\,dt = d_A V_d$$

Duty ratio $\quad d_A = \dfrac{v_{c,A}}{\hat{V}_{tri}}$

$$\bar{v}_{AN} = \underbrace{\frac{V_d}{\hat{V}_{tri}}}_{k_{pole}} v_{c,A}$$

Pole gain

$$k_{pole} = \frac{V_d}{\hat{V}_{tri}}$$

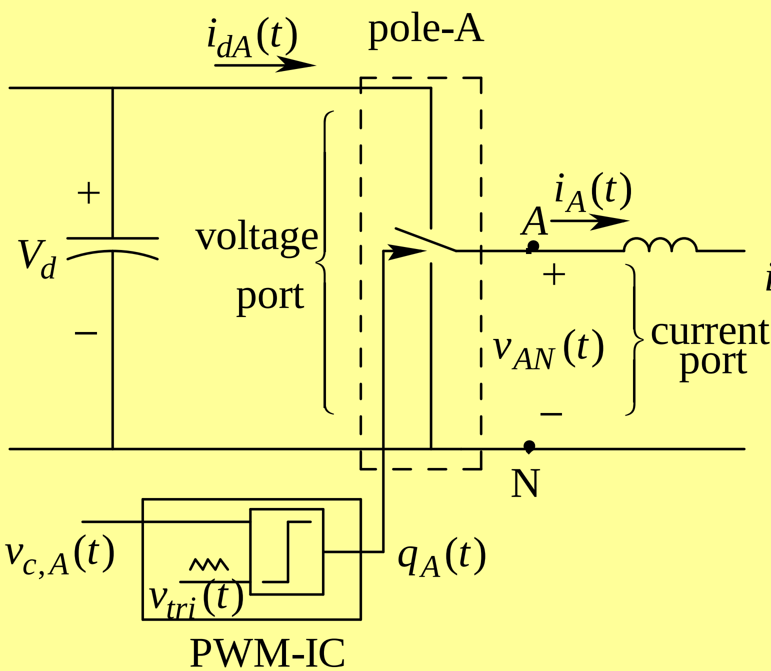


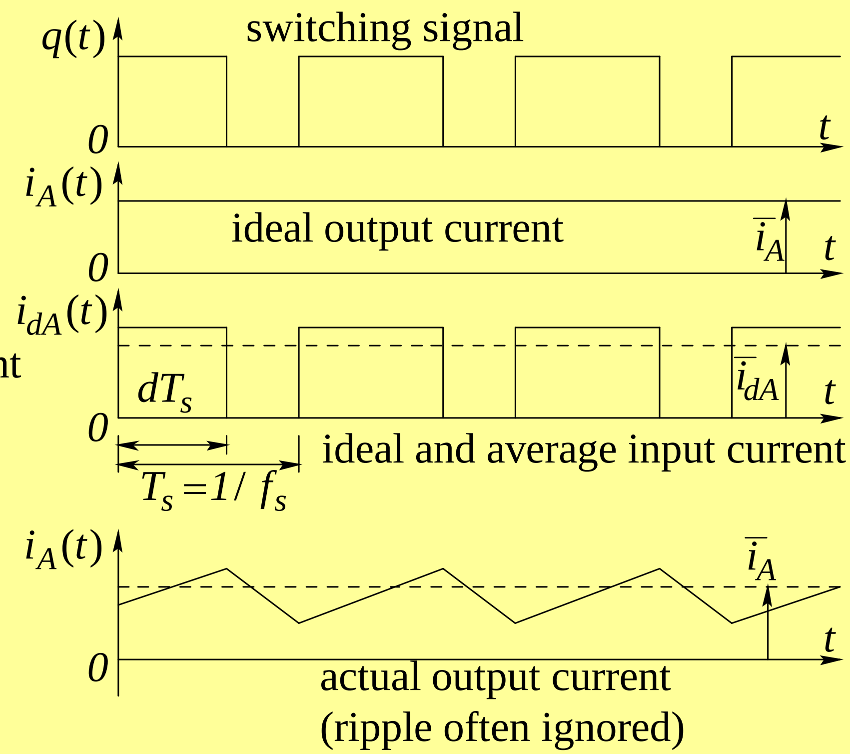
Average Representation of a Pole

Input and Output Currents

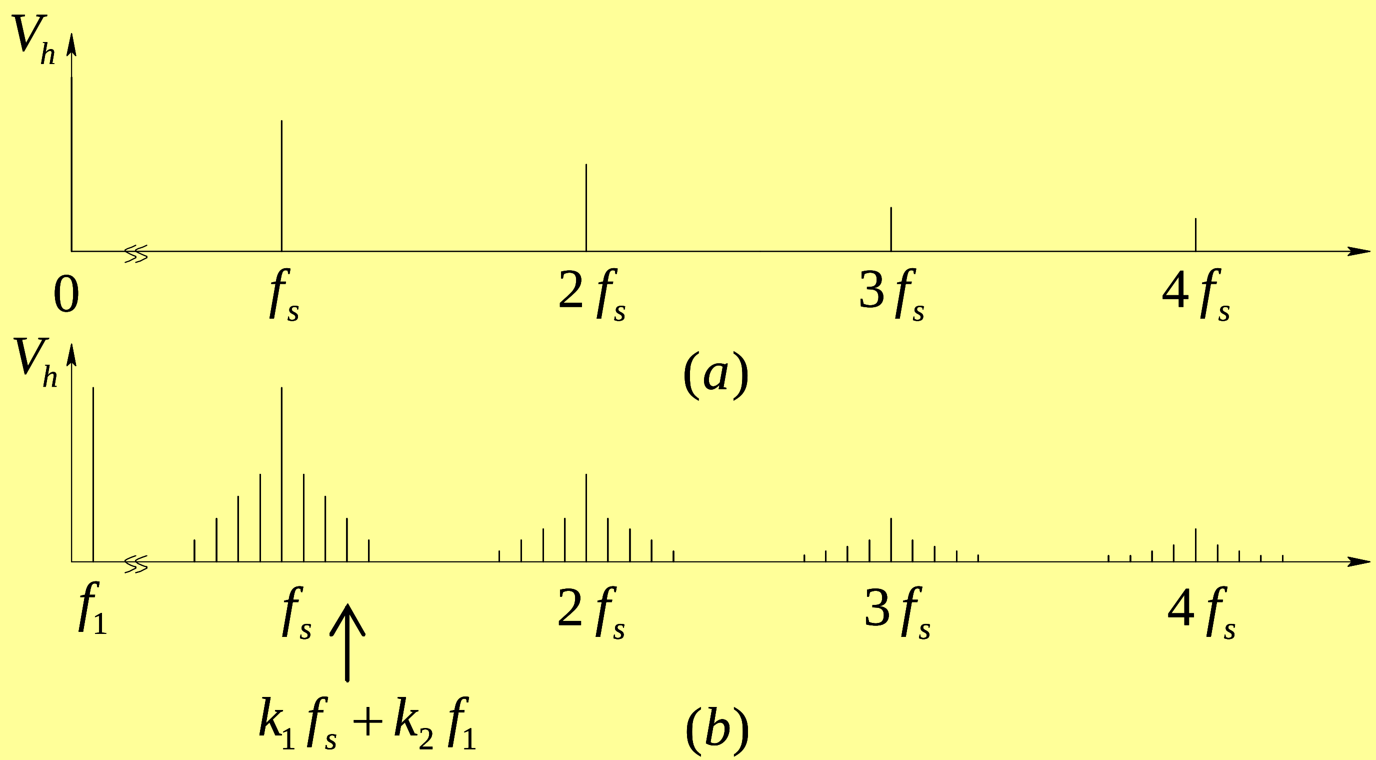
- Assuming ripple in $i_A(t)$ to be negligible, i.e. $i_A(t)=\bar{i}_A(t)$ average values of input and the output currents can be related as,

$$\bar{i}_{dA}(t)=d_A(t)\bar{i}_A(t)$$

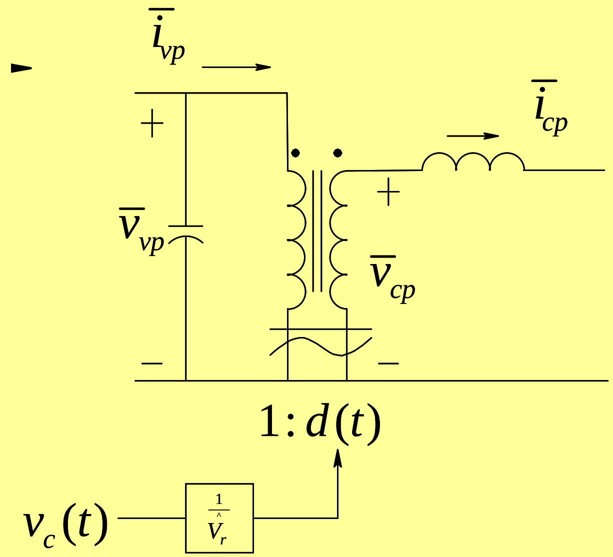




Harmonics in the voltage across the Current-Port



Average Representation of a Pole as An Ideal Transformer



- ☐ Transformer turns-ratio is adjustable via Pulse Width Modulation
- ☐ This Transformer can pass AC and DC currents but only unipolar voltages

Pole as a Two-Quadrant Converter

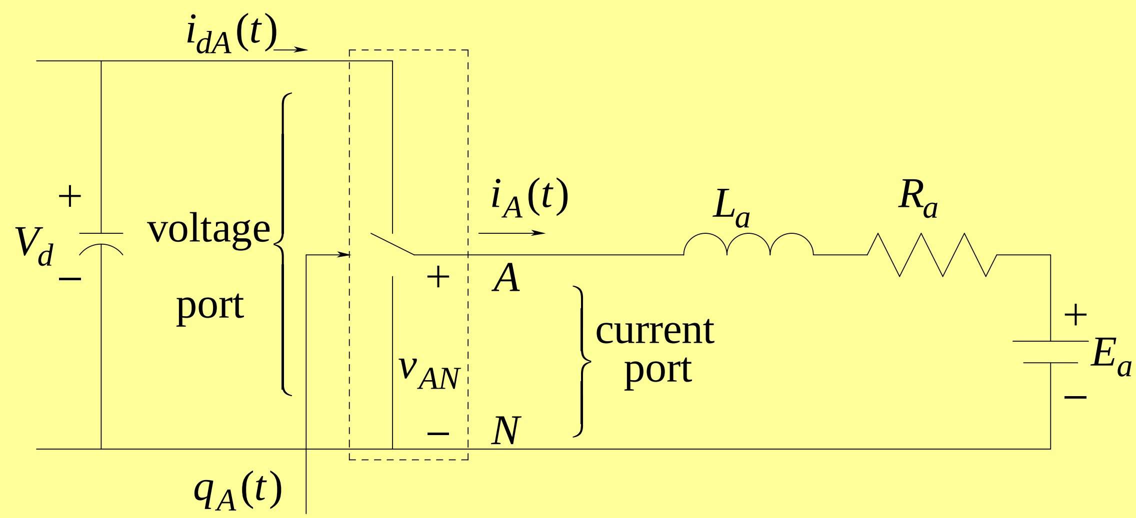
- v_{AN} always positive
- i_A can reverse
  - $i_A > 0$ if $\overline{v}_{AN} > E_a$

    power $V_d \rightarrow E_a$

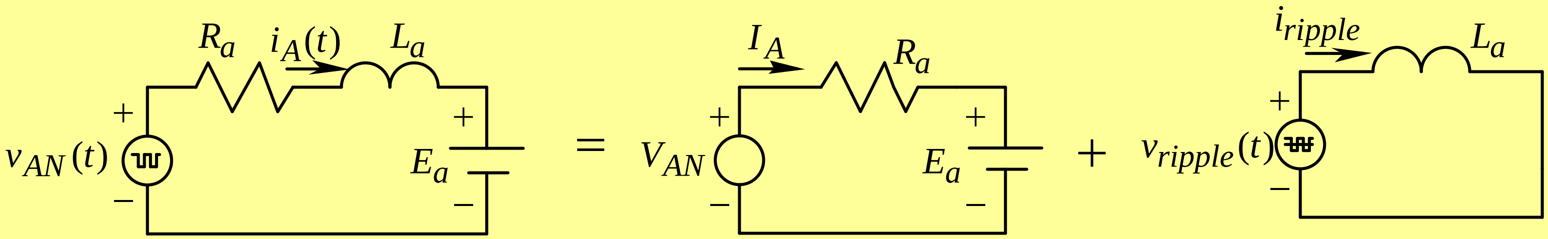
    Buck Mode
  - $i_A < 0$ if $v_{AN} < E_a$

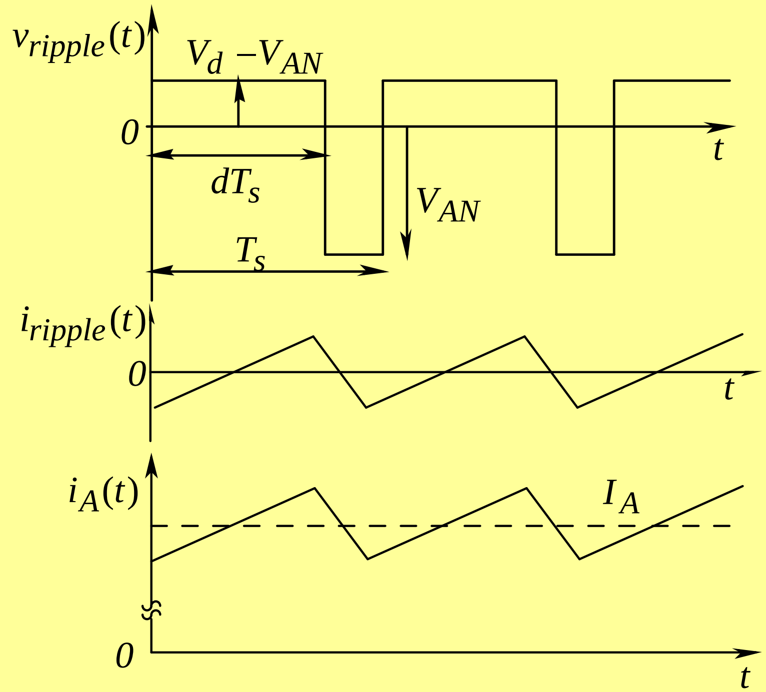
    power $E_a \rightarrow V_d$

    Boost Mode



Calculation of Ripple Current





$$i_A(t) = I_A + i_{ripple}(t)$$

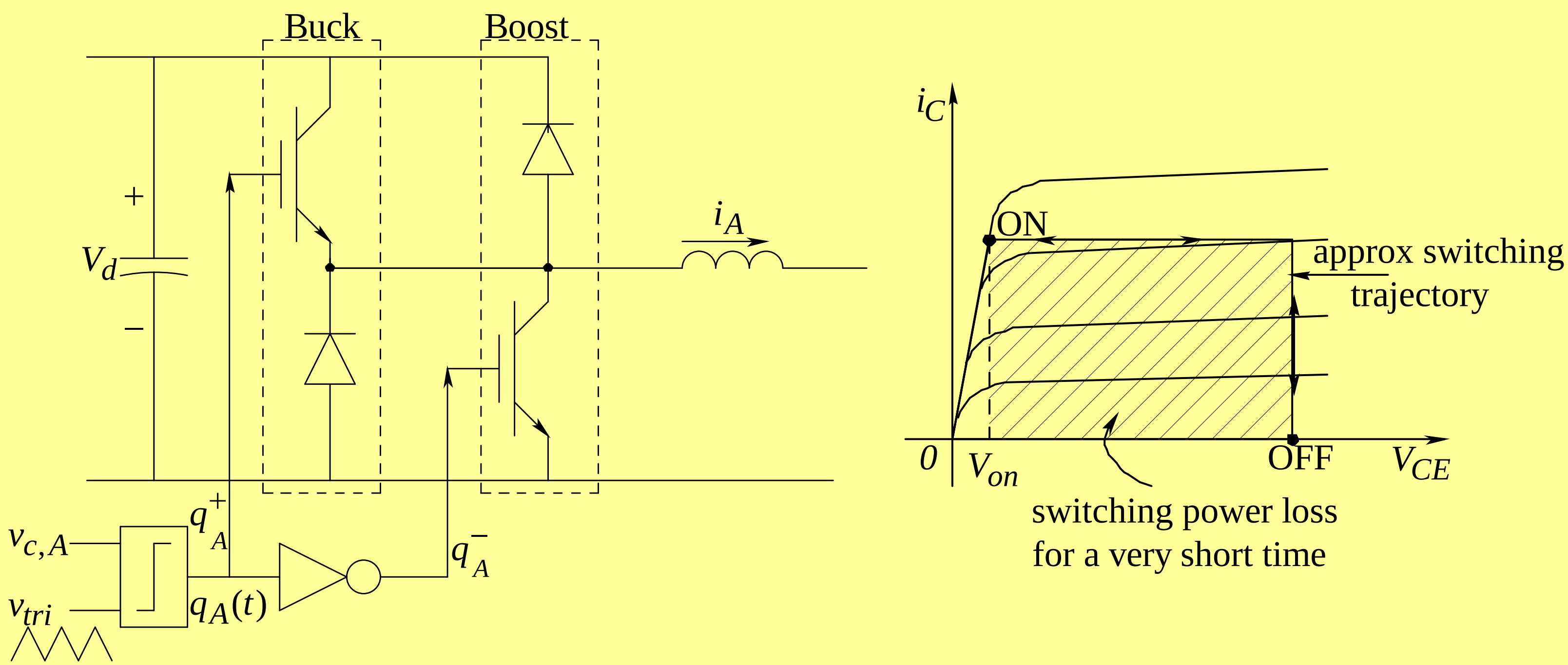
$$v_{AN}(t) = V_{AN} + v_{ripple}(t)$$

$$I_A = \frac{V_{AN} - E_a}{R_a}$$

$i_{ripple}(t) =$ sawtooth with zero DC average

$$\Delta i_A = \frac{\text{volt} - \text{seconds}}{L_a} = \frac{(V_d - V_{AN})dT_s}{L_a}, \text{ or } \frac{V_{AN}(1-d)T_s}{L_a}$$

Implementation of Bi-Positional Switches



- ☐ Switching frequency 6kHz to 50kHz
- ☐ Switching power loss: kept low by fast switching devices
- ☐ Conduction loss: kept low by having switches fully ON or fully OFF

Summary

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  - Switching Power-Pole as the Building Block
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    - Average Model