Modulation

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Lund University, Sweden

Why switching?

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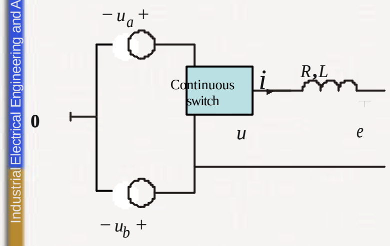
- **Continuous amplifiers have low efficiency**



$$p_{ut}(t) = u \cdot i$$
$$p_{in}(t) = (u_a - u_b) * i$$
$$Antag:$$
$$(u_a - u_b) = U_{dc}$$
$$P_{in} = U_{dc} \cdot i$$
$$h = \frac{P_{ut}}{P_{in}} = \frac{u \cdot i}{U_{dc} \cdot i} = \frac{u}{U_{dc}}$$

Switching amp. Losses

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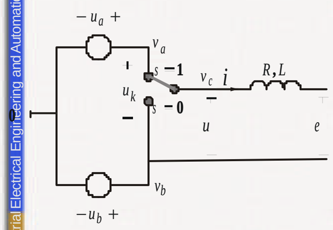

$$u = \begin{cases} 0 \text{ when } s = 0 \\ U_{dc} \text{ when } s = 1 \end{cases}$$
$$P_{in} = \begin{cases} 0 \text{ when } s = 0; \\ u \cdot i \text{ when } s = 1 \end{cases}$$
$$P_{ut} = \begin{cases} 0 \text{ when } s = 0 \\ u \cdot i \text{ when } s = 1 \end{cases}$$
$$h = \frac{P_{ut}}{P_{in}} = \begin{cases} undfined \text{ when } s = 0; \\ 100\% \text{ when } s = 1 \end{cases}$$

Converter topology

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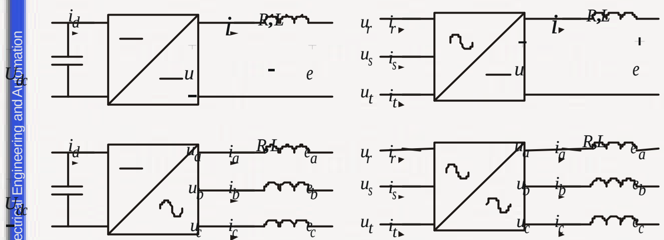
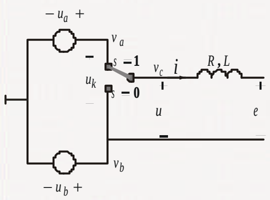


- **1 side capacitive**
- **1 side inductive**
- **ALWAYS!**

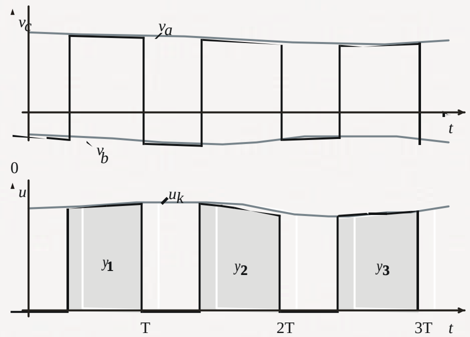
Modulation - Control of voltage time area



$$v_c = \begin{cases} v_a & \text{when } s = 1 \\ v_b & \text{when } s = 0 \end{cases}$$

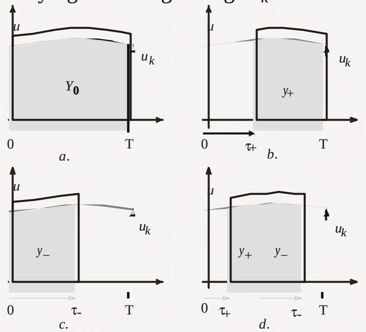
$$u = s \cdot (v_a - v_b) = s \cdot u_k = \begin{cases} u_k & \text{when } s = 1 \\ 0 & \text{when } s = 0 \end{cases}$$

Output voltage



Voltage control options

Assume a limited pulse interval T and a slowly varying switching voltage u_k

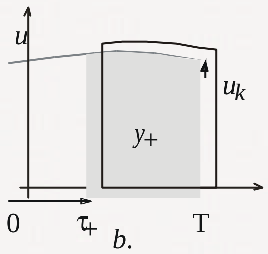


$$Y_0 = \int_0^T u_k(t) \cdot dt$$

$$u_k(t_+) = -\frac{dy(t_+)}{dt_+}$$

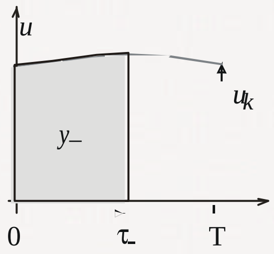
$$u_k(t_-) = \frac{dy(t_-)}{dt_-}$$

Control with positive flank



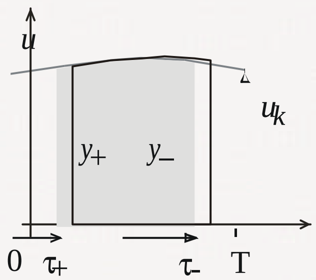
$$y(t_+) = \int_{t_+}^{T} u_k \cdot dt = Y_0 - \int_0^{t_+} u_k \cdot dt$$

Control with negative flank



$$y(t_-) = \int_0^{t_-} u_k \cdot dt$$

Control with both flanks



$$Y_0 = \int_0^{T/2} u_k \cdot dt$$

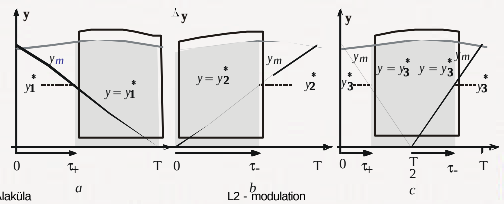
$$y(t_+, t_-) = y_+ + y_-$$

$$y_+ = \int_{t_+}^{T/2} u_k \cdot dt = Y_0 - \int_0^{t_+} u_k \cdot dt$$

$$y_- = \int_{T/2}^{T/2+t_-} u_k \cdot dt$$

Carrier wave modulation

- A reference value y^* for the desired average voltage over one switching period is calculated by an external control system
- A modulation signal y_m is generated, such that $y(t)=y_m(t)$
- The reference is compared to the modulation signal to determine the switching instants.



Voltage time area vs. average voltage

- This far the modulation has been described with voltage time areas, both regarding the estimate of the output voltage time area as a function of the switching time instant, i.e. the modulating wave y_m, and the references for the output voltage time areas y^*.
- In the following sections and chapters, voltage time area is replaced with average voltages.

$$u_m = \frac{y_m}{T_s}$$

$$u^* = \frac{y^*}{T_s}$$

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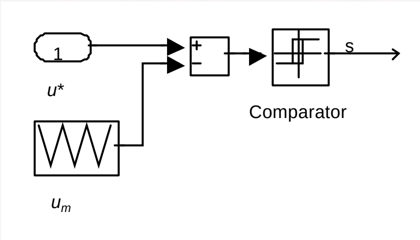
The modulator



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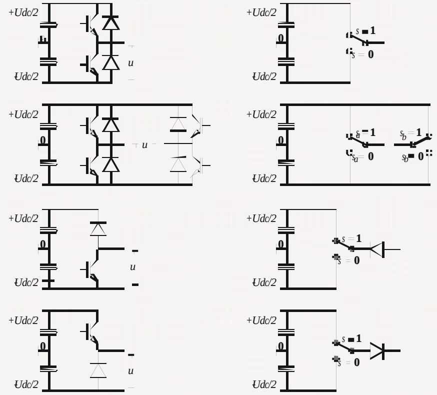
PWM-controlled dc converters



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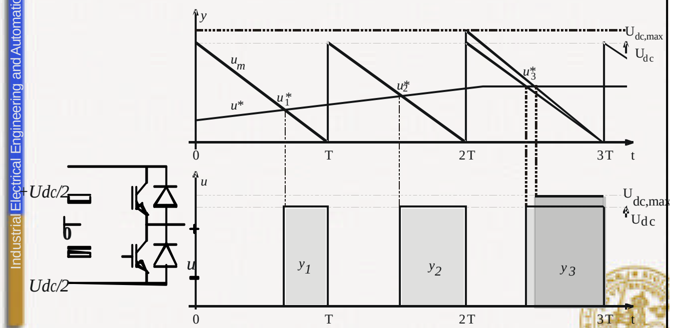
Two quadrant DC converters



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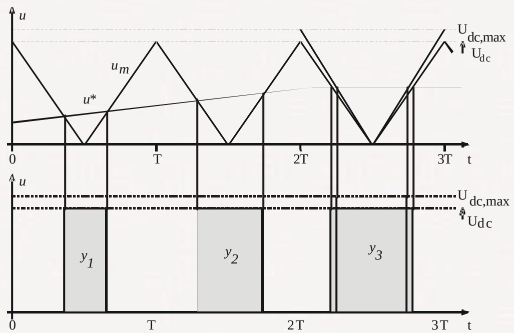
2-quadrant DC converters : II



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2-quadrant DC converters : III

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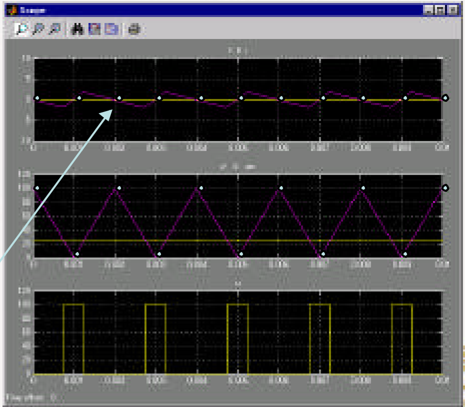
Current sampling – how often?

- When the carrier turns, i.e. With twice the switching frequency!



Example

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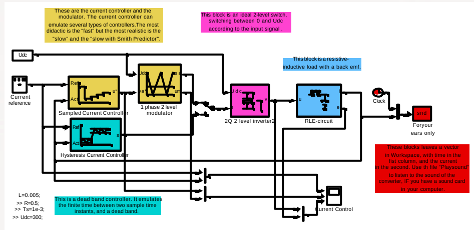
- **Sampling of current**



4 – quadrant DC converters

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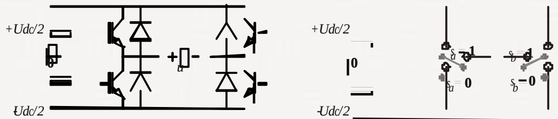

Bridge connected
2 phase potentials, only 1 output voltage = 1 degree of freedom to be used for other purposes.

4-quadrant DC converters

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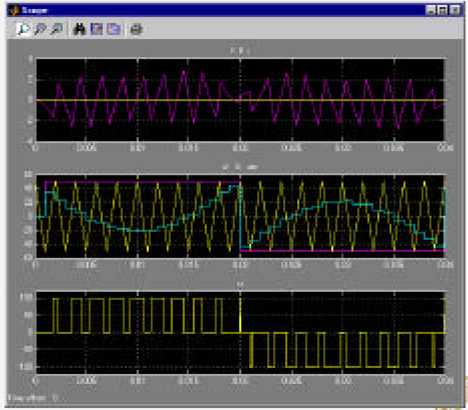
$$u^* = v_a^* - v_b^*$$

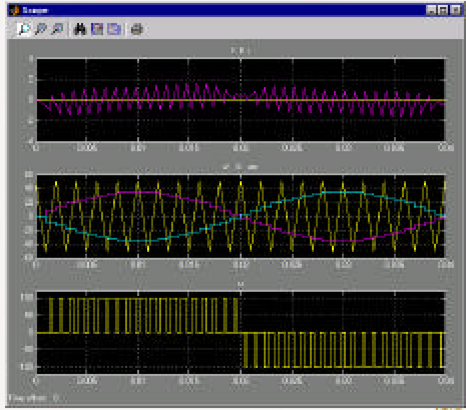
$$alt\,1: v_a^* = sign(u^*)\cdot\frac{U_{dc}}{2} \Rightarrow v_b^* = v_a^* - u^* = sign(u^*)\cdot\frac{U_{dc}}{2} - u^*$$

$$alt\,2: v_a^* = -v_b^* \Rightarrow v_a^* - v_b^* = 2\cdot v_a^* \Rightarrow \begin{cases} v_a^* = \dfrac{u^*}{2} \\ v_b^* = -\dfrac{u^*}{2} \end{cases}$$

4-quadrant DC converters – alt 1



4-quadrant DC converters – alt 2



Example

- **Sampling and symmetry ...**