« Energetic Macroscopic Representation (EMR) formalism »

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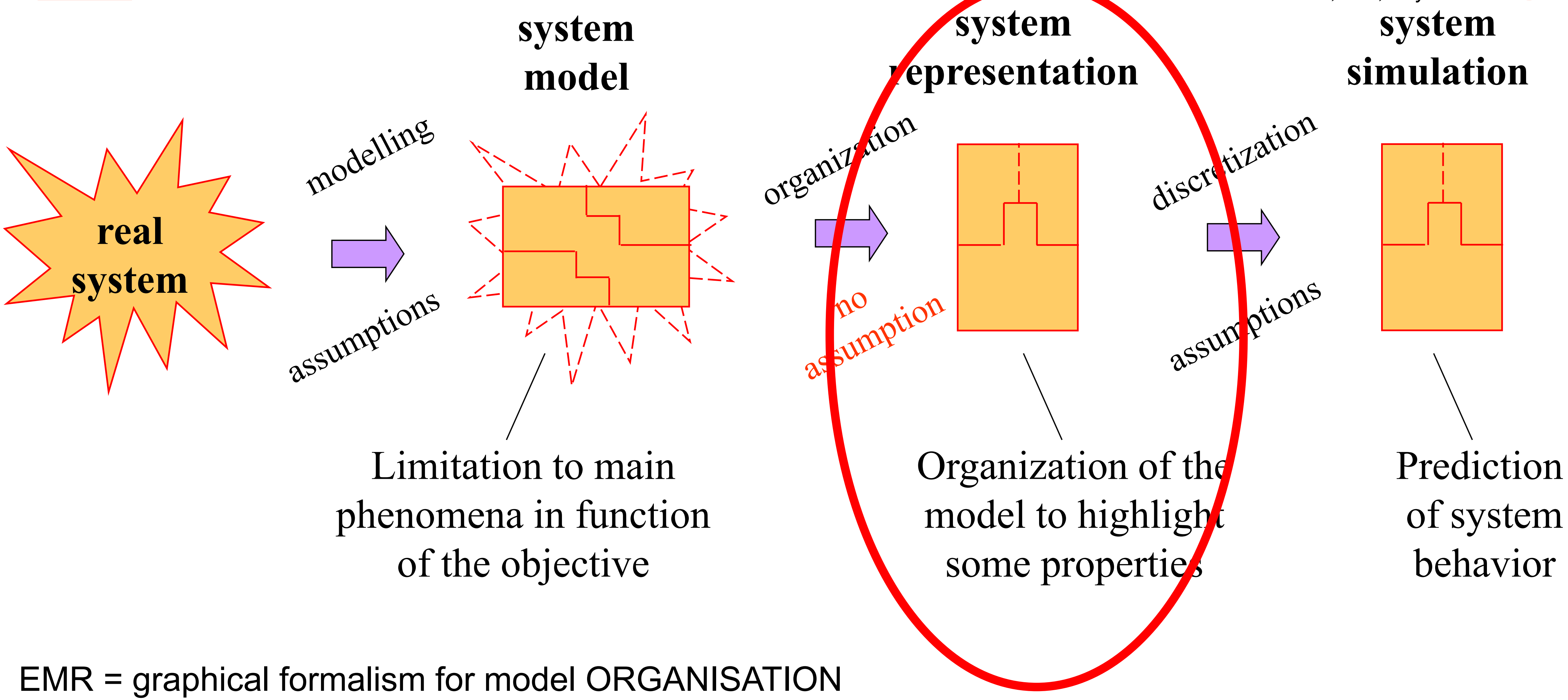


EMR = graphical formalism for model ORGANISATION
(after the modelling step)

Key aspects for energy conversion systems:

- Causality principle (energy)
- Interaction principle (Systemics)

Only 4 energy functions are required to describe energy conversion systems:

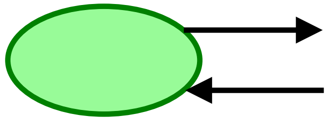
- Energy sources
- Energy storage
- Energy conversion
- Energy distribution

EMR = 4 graphical elements associated with the 4 energy functions

EMR basic elements

- Energy source element -

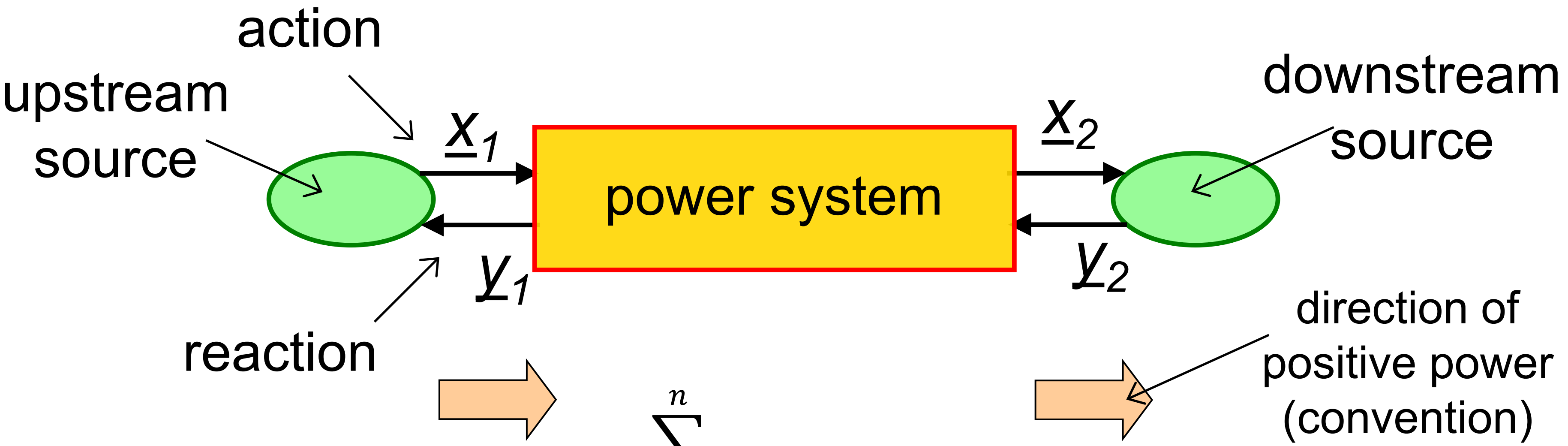
Source



- oval pictogram
- background: light green
- contour: dark green
- 1 input vector (dim n)
- 1 output vector (dim n)

terminal elements which represent the environment of the studied system

generator and/or receptor of energy

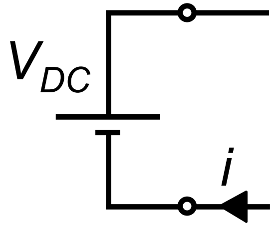


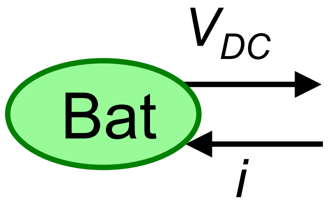
$$p_1 = \underline{x}_1 . \underline{y}_1 = \sum_{i=1}^{n} x_{i1} y_{i1}$$

$$p_2 = \underline{x}_2 . \underline{y}_2$$

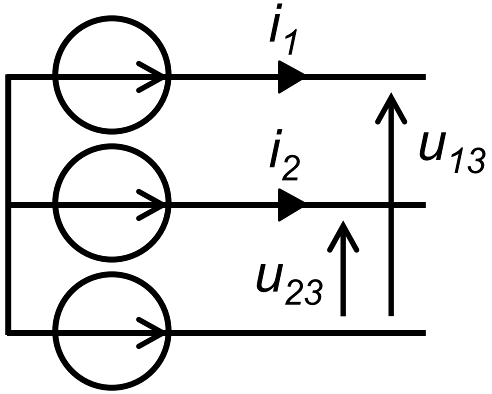
Battery

(voltage source)
generator/receptor of energy



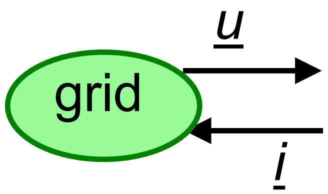


Electrical grid



$$\underline{u} = \begin{bmatrix} u_{13} \\ u_{23} \end{bmatrix}$$

$$\underline{i} = \begin{bmatrix} i_1 \\ i_2 \end{bmatrix}$$



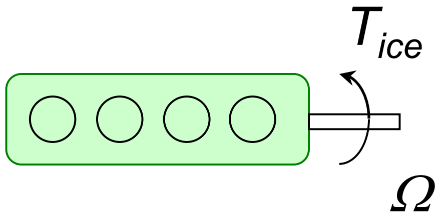
2 independent currents!

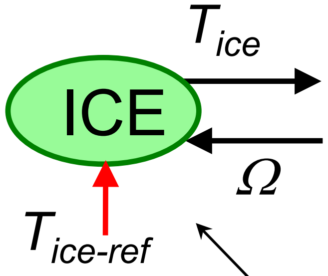
2 independent voltages!

$$p(t)=\underline{u}(t)\,\underline{i}(t)=u_{13}(t)i_1(t)+u_{23}(t)i_2(t)$$

IC engine

(torque source)
generator of energy

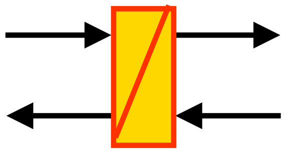




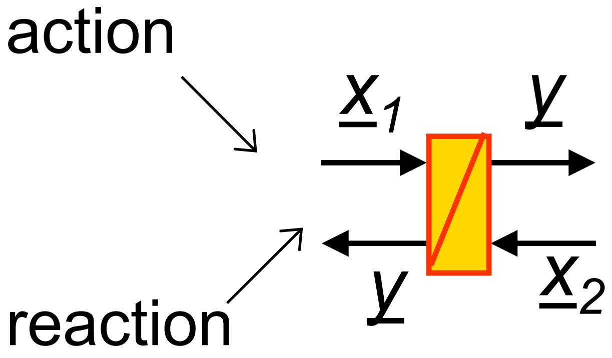
tuning input

- Energy accumulation element -

Accumulator



- rectangle with an oblique bar
- background: orange
- contour: red
- upstream I/O vectors (dim n)
- downstream I/O vectors (dim n)



$p_1 = \underline{x}_1 . \underline{y}$ $p_2 = \underline{x}_2 . \underline{y}$

internal accumulation of energy (with or without losses)

causality principle

Output variable = Energetic variable

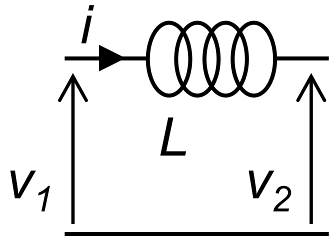
$$\text{output(s)} = \int \text{input(s)}$$

$$\underline{y} \propto \int f(\underline{x}_1, \underline{x}_2)dt$$

$\underline{y}$ = output, delayed with regard to input changes

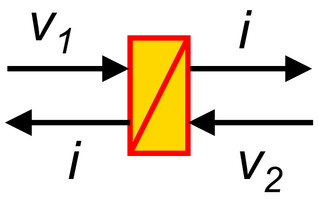
fixed I/O (causal description)

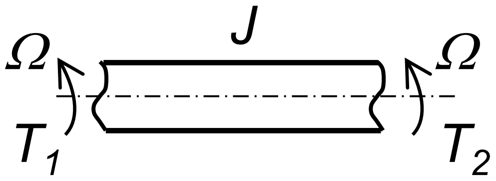
- Energy accumulation element -



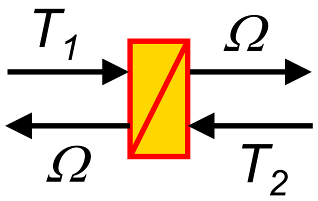
inductor

$$E = \frac{1}{2} L i^2$$

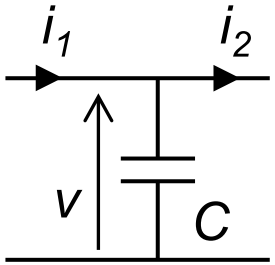




inertia

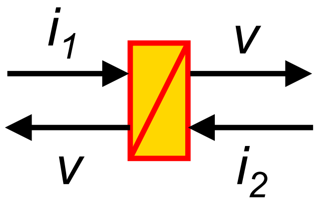


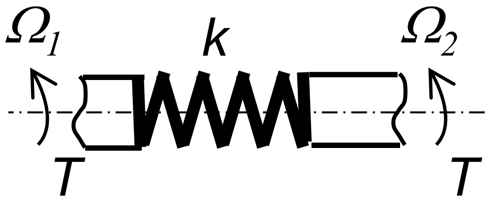
$$E = \frac{1}{2} J \Omega^2$$



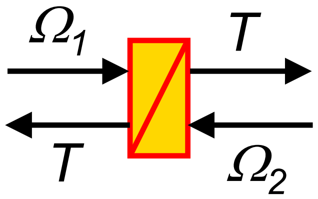
capacitor

$$E = \frac{1}{2} C v^2$$



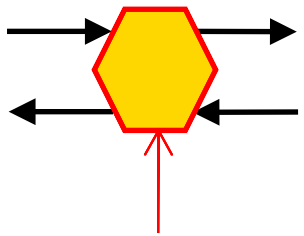


stiffness

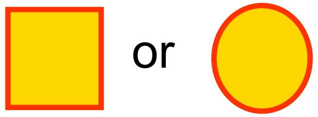


$$E = \frac{1}{2} \frac{1}{k} T^2$$

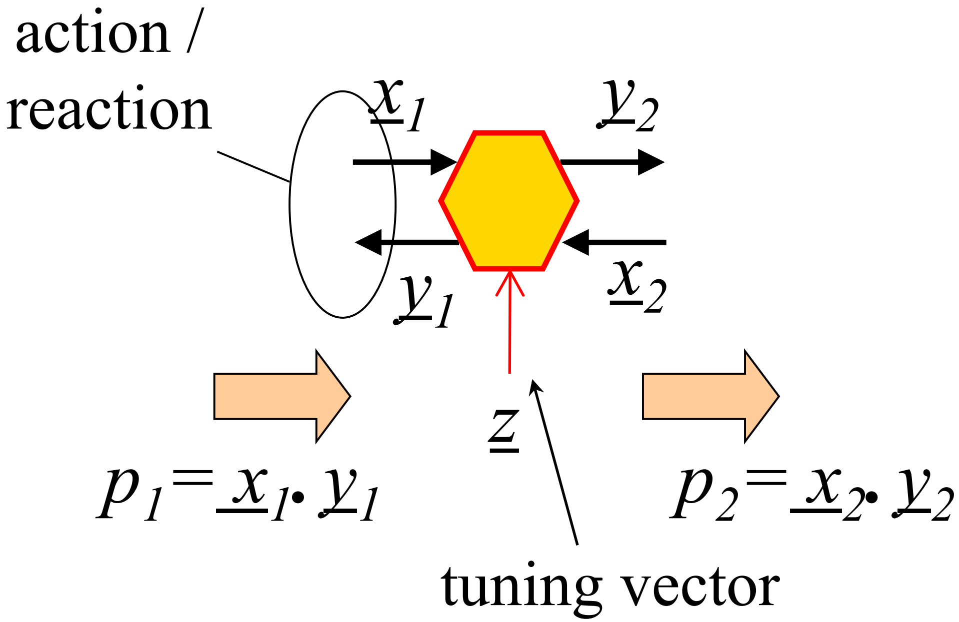
conversion element



various pictograms
background: orange
contour: red
upstream I/O vectors (dim n)
downstream I/O vectors (dim p)
Possible tuning input vector (dim q)



conversion of energy
without energy accumulation
(with or without losses)

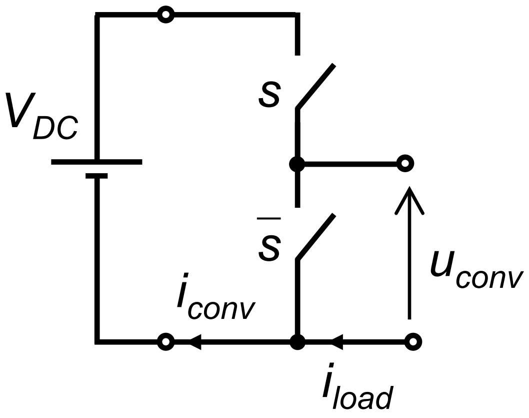


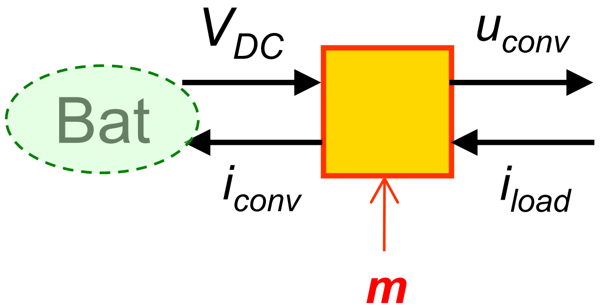
$$\begin{cases} \underline{y}_2 = f(\underline{x}_1, \underline{z}) \\ \underline{y}_1 = f(\underline{x}_2, \underline{z}) \end{cases}$$

no delay!

upstream and downstream
I/O can be permuted
(floating I/O)

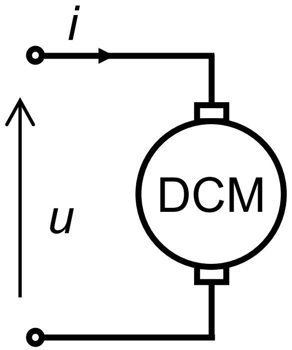
- Energy conversion element -

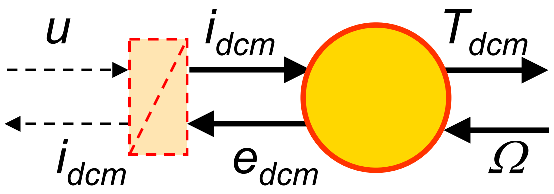




$$\begin{cases} u_{\mathrm{conv}} = m\, V_{\mathrm{DC}} \\ i_{\mathrm{conv}} = m\, i_{\mathrm{load}} \end{cases}$$

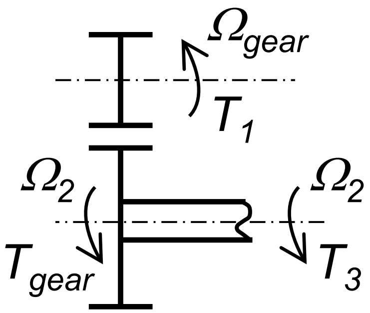
tuning input

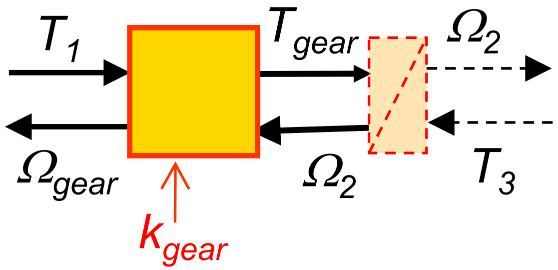




$$L \frac{d}{\mathrm{dt}} i_{\mathrm{dcm}} + r\, i_{\mathrm{dcm}} = u - e_{\mathrm{dcm}}$$

$$\begin{cases} T_{\mathrm{dcm}} = k_{\Phi}\, i_{\mathrm{dcm}} \\ e_{\mathrm{dcm}} = k_{\Phi}\, \Omega \end{cases}$$

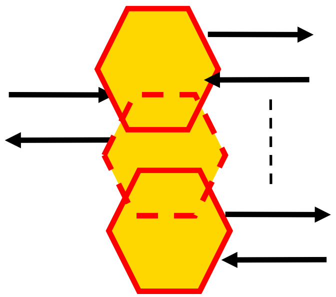




$$\begin{cases} T_{\mathrm{gear}} = k_{\mathrm{gear}}\, T_1 \\ \Omega_{\mathrm{gear}} = k_{\mathrm{gear}}\, \Omega_2 \end{cases}$$

$$J \frac{d}{\mathrm{dt}} \Omega_2 = T_{\mathrm{gear}} - T_3$$

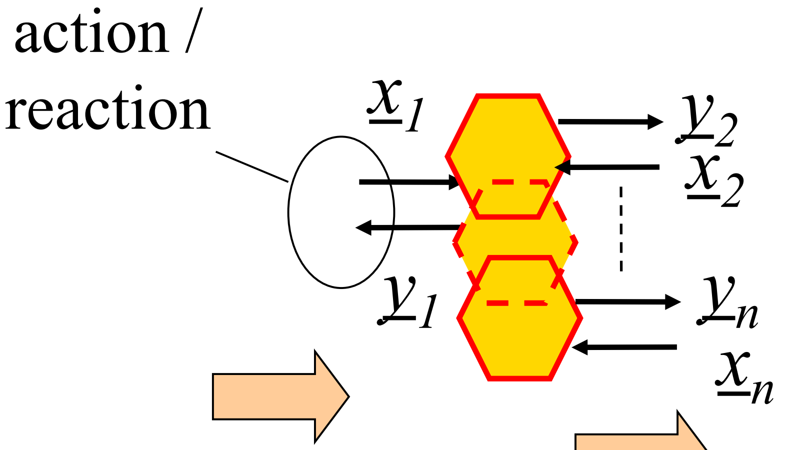
coupling element



- various overlapped pictograms
- background: orange
- contour: red
- pairs of I/O vectors
- N pairs, N-1 pictograms

distribution of energy
without energy accumulation
without tuning
(with or without losses)

no delay!

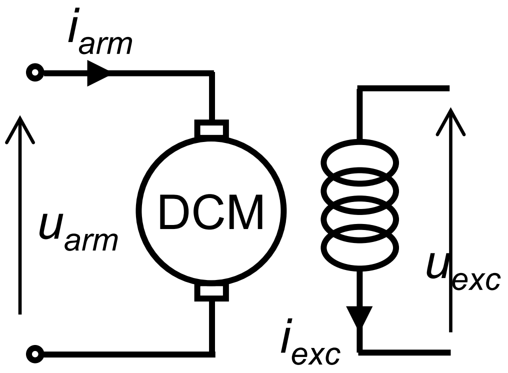


$$p_1 = \underline{x}_1 \cdot \underline{y}_1$$

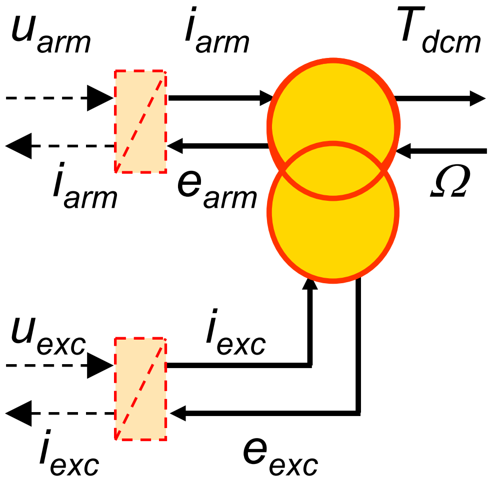
$$p_s = \sum_{i=2}^{n} \underline{x}_n \cdot \underline{y}_n$$

$$\begin{cases} \underline{y}_1 = f_1(\underline{x}_1, \ldots \underline{x}_n) \\ \ldots \\ \underline{y}_n = f_n(\underline{x}_1, \ldots \underline{x}_n) \end{cases}$$

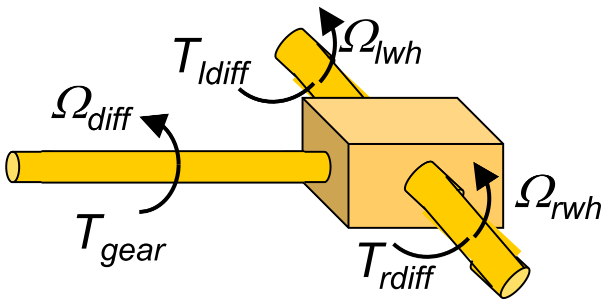
Field winding DC machine



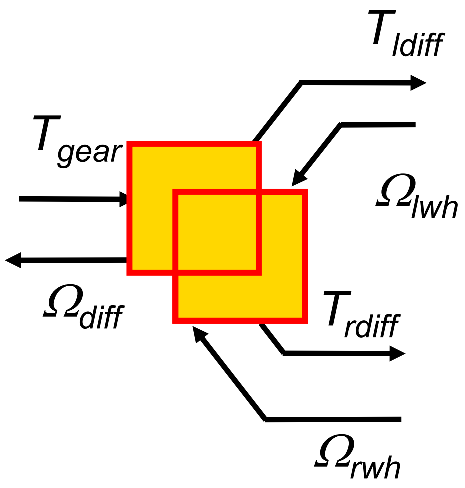
$$\begin{cases} T_{dcm} = k\, i_{exc}\, i_{arm} \\ e_{arm} = k\, i_{exc}\, \Omega \end{cases}$$



Mechanical differential

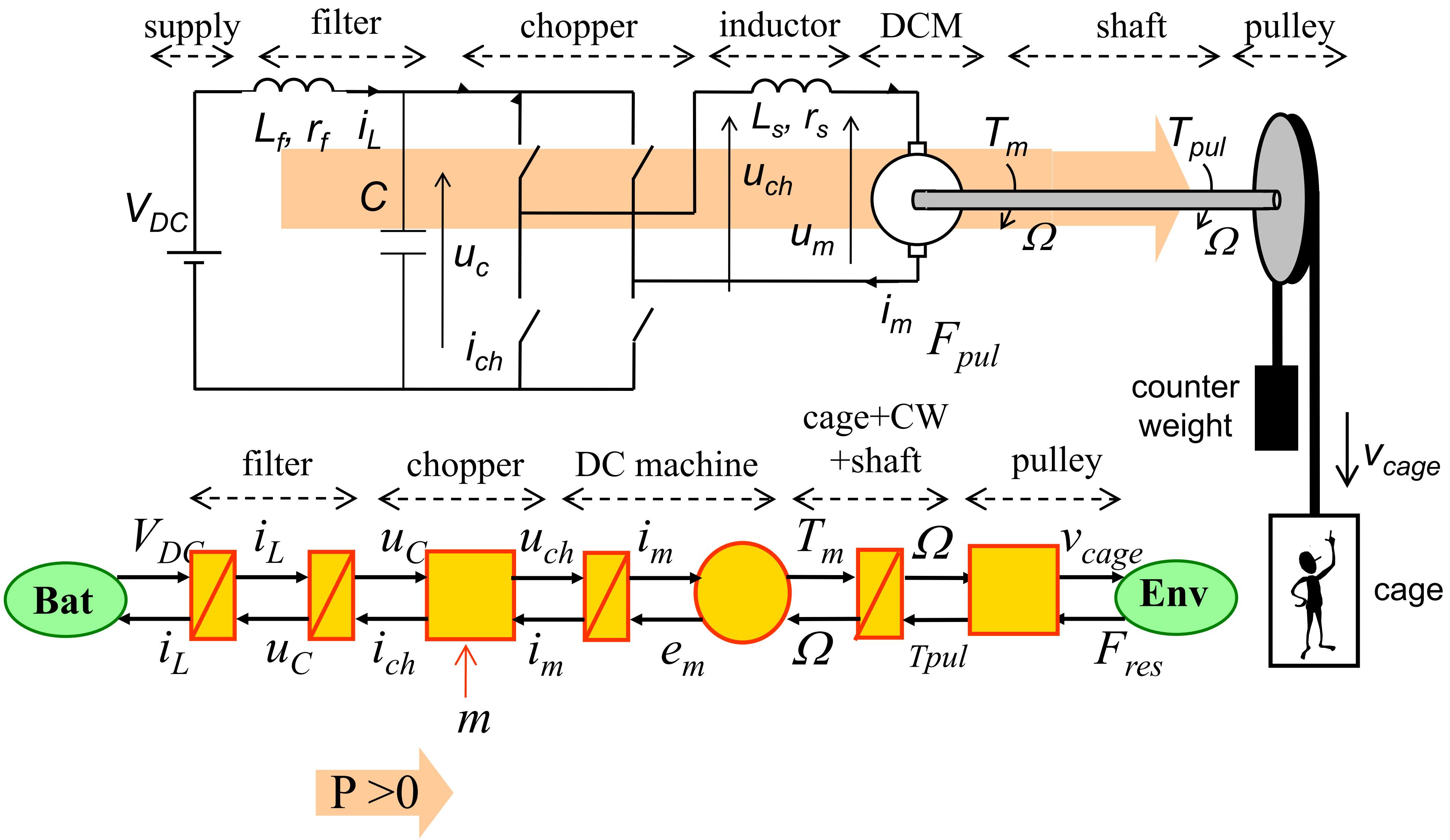


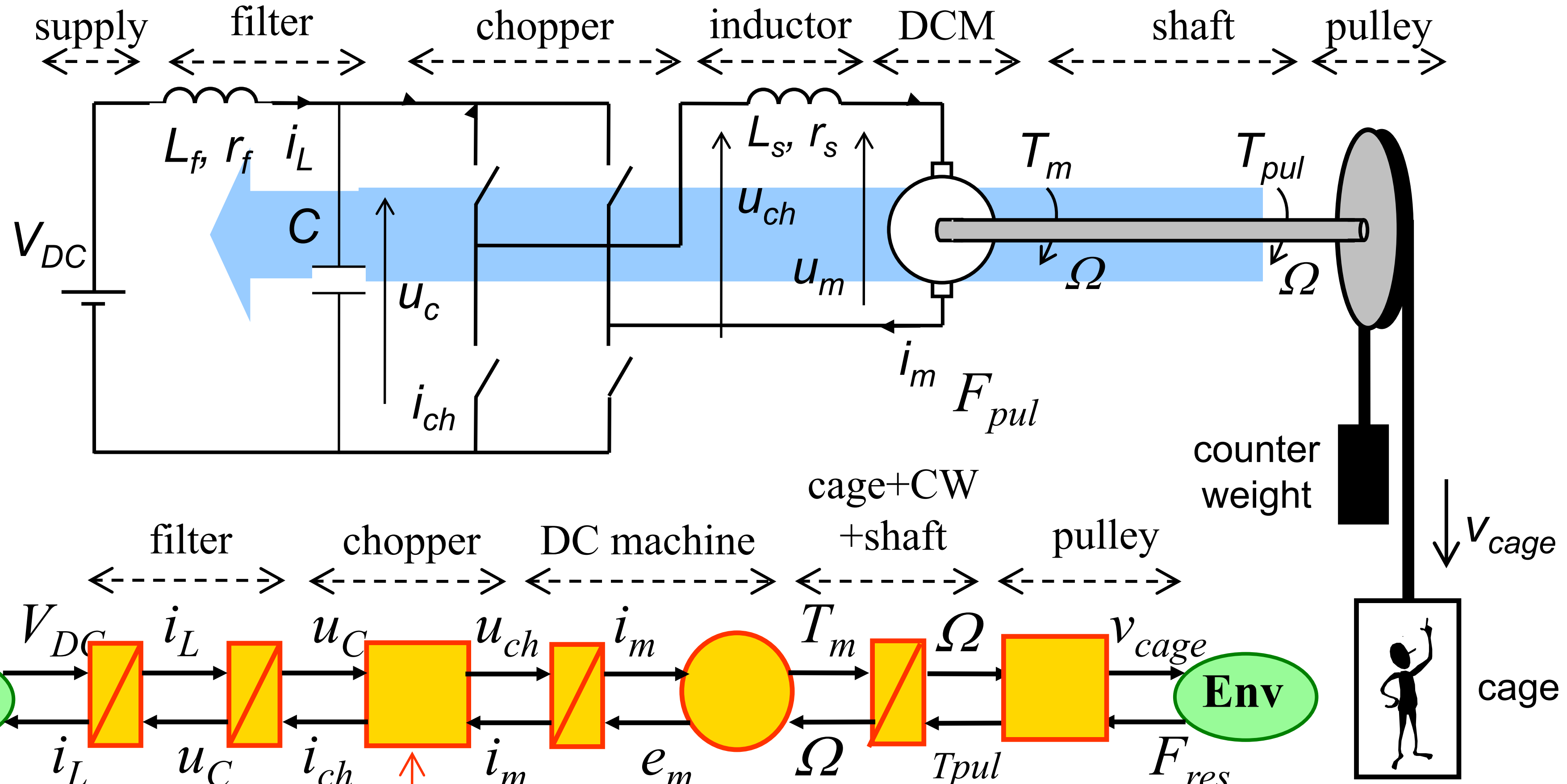
$$\begin{cases} T_{ldif} = T_{rdif} = \dfrac{T_{gear}}{2} \\ \Omega_{dif} = \dfrac{\Omega_{lwh} + \Omega_{rwh}}{2} \end{cases}$$

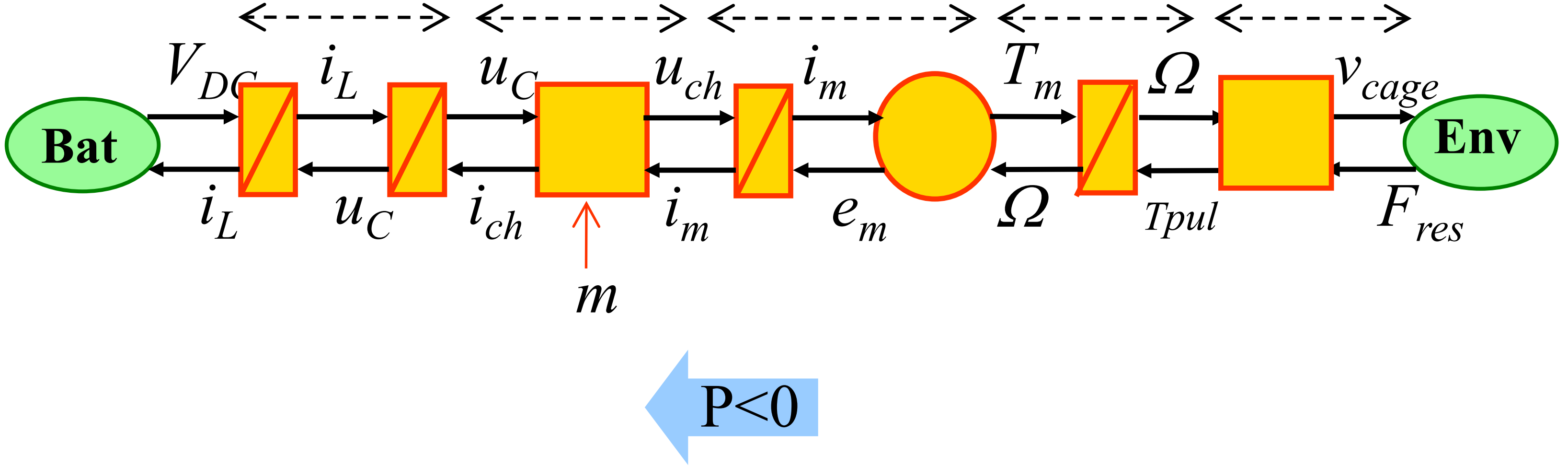


Example of complete EMR

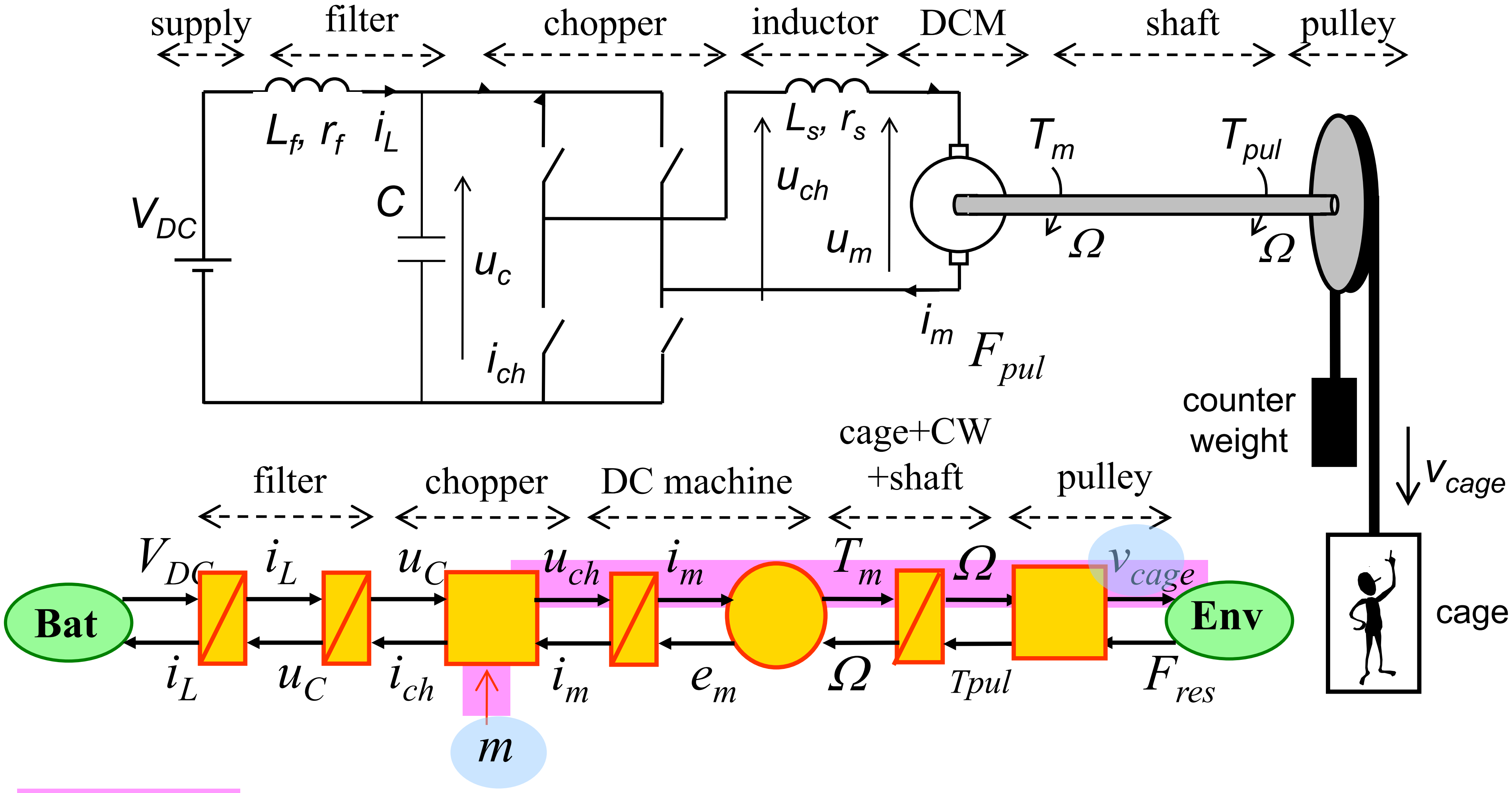
- Lift example -




supply
filter
chopper
inductor
DCM
shaft
pulley
L_f, r_f
i_L
V_{DC}
C
u_c
i_{ch}
L_s, r_s
u_{ch}
u_m
i_m
T_m
T_{pul}
Ω
Ω
F_{pul}
counter weight
v_{cage}
cage


filter
chopper
DC machine
cage+CW
+shaft
pulley
Bat
V_{DC}
i_L
i_L
u_C
u_C
i_{ch}
u_{ch}
i_m
i_m
e_m
T_m
Ω
Ω
Tpul
v_{cage}
F_{res}
Env
m
P<0

- Lift example -



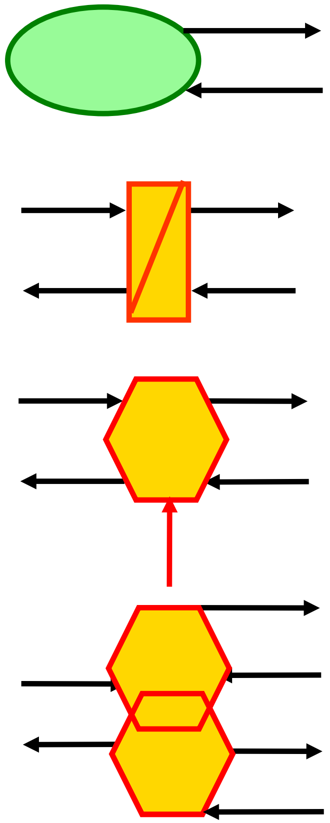
tuning path

EMR = multi-physical graphical description

Systemics: elements connected by action/reaction

Basic elements = energetic functions

Causality: I/O defined by accumulation elements and sources



Energy source (potential tuning)

Energy accumulation

Energy conversion (potential tuning)

Energy distribution

Association rules

enable keeping physical causality in conflict of association

Tuning paths

can be deduced from EMR

valuable for control design

« Biographies and references »

- Authors -

Dr. Clement MAYET, University of Lille, L2EP,
PhD in Electrical Engineering at University of Lille in 2016
Associate Prof. at CNAM Paris from 2018 to 2023
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Associate Editor of IEEE VTS Magazine since 2020
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Coordinator of the GDR TACT (CNRS French research cluster on Touch)
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Research topics: piezo-electric actuators and tactile devices using EMR

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[Bouscayrol 2000] A. Bouscayrol, & al. "Multimachine Multiconverter System: application for electromechanical drives", *European Physics Journal - Applied Physics,* vol. 10, no. 2, May 2000, pp. 131-147 (common paper GREEN Nancy, L2EP Lille and LEEI Toulouse, according to the SMM project of the GDR-SDSE).

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[Bouscayrol 2023] A. Bouscayrol, B. Lemaire-Semail, "Energetic Macroscopic Representation and Inversion-Based Control", Encyclopedia of electrical and electronic power engineering, Vol. 3, pp 365-375, Elsevier, DOI : 10.1016/B978-0-12-821204-2.00117-3, ISBN : 978-0-12-823211-8, 2023.

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Thanks for your attention !