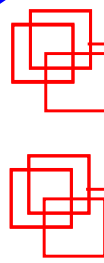


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"Energetic Macroscopic Representation"



« EMR AND INVERSION-BASED CONTROL OF RENEWABLE ENERGY SYSTEMS »

Dr. Walter LHOMME, Prof. Alain BOUSCAYROL

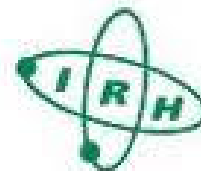
L2EP, University Lille1, MEGEVH network,

Alain.Bouscayrol@univ-lille1.fr

Dr. Loïc BOULON

HRI, Université du Québec à Trois-Rivières,

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1. Wind Energy Conversion System

- Studied System
- EMR of the WECS
- Inversion-based control of the WECS

2. PhotoVoltaic Conversion System

- Studied System
- EMR of the PV system
- Inversion-based control of the PV system

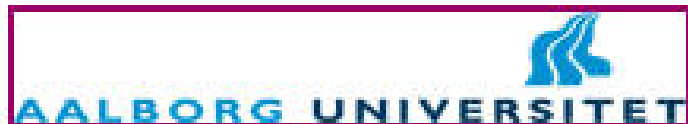
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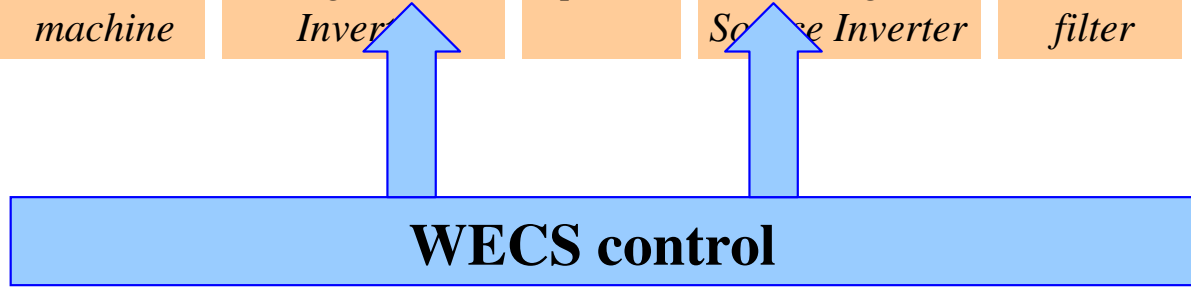
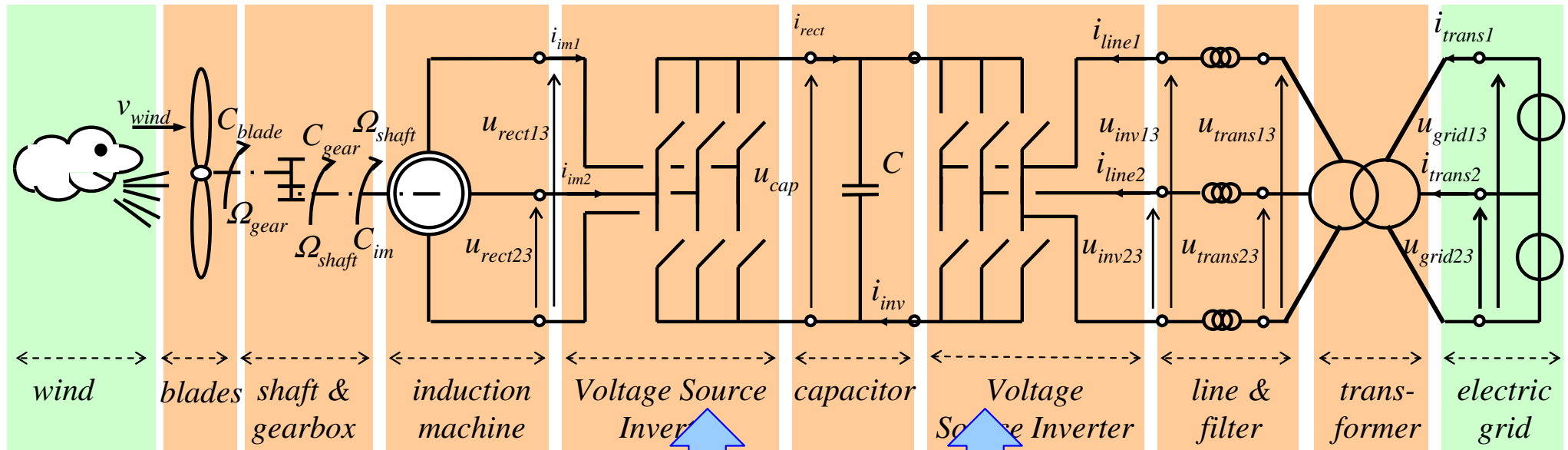
« WIND ENERGY CONVERSION SYSTEM »

A. Bouscayrol, X. Guillaud
(University of Lille 1, France)

R. Teodorescu
(University of Aalborg, Denmark)



Chosen WECS for variable speed and variable frequency:
a squirrel cage IM and two VSI

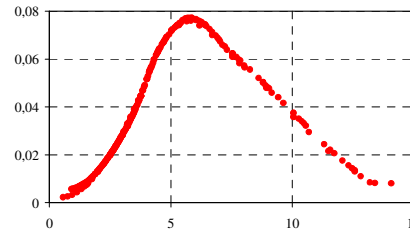
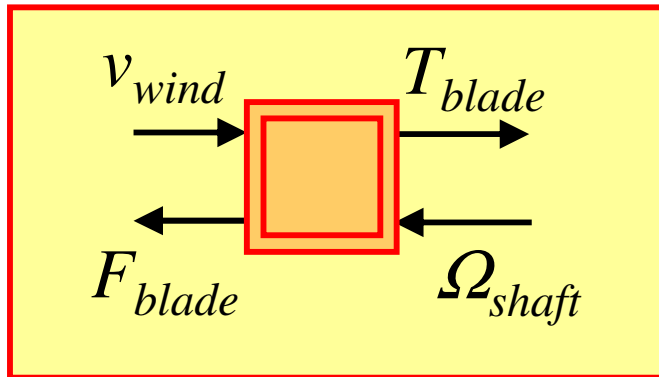
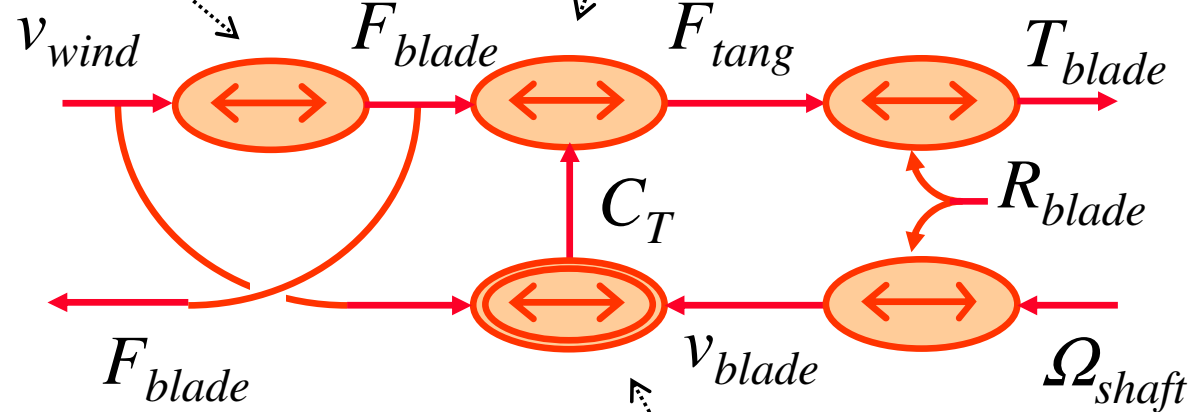


Technical requirements: provide the maximum active power P
and control the reactive power Q

$$F_{blade} = \frac{1}{2} \rho S v_{wind}^2$$

$$F_{tang} = C_T(\lambda) F_{blade}$$

$$\begin{cases} T_{blade} = R_{blade} F_{tang} \\ v_{blade} = R_{blade} \Omega_{shaft} \end{cases}$$

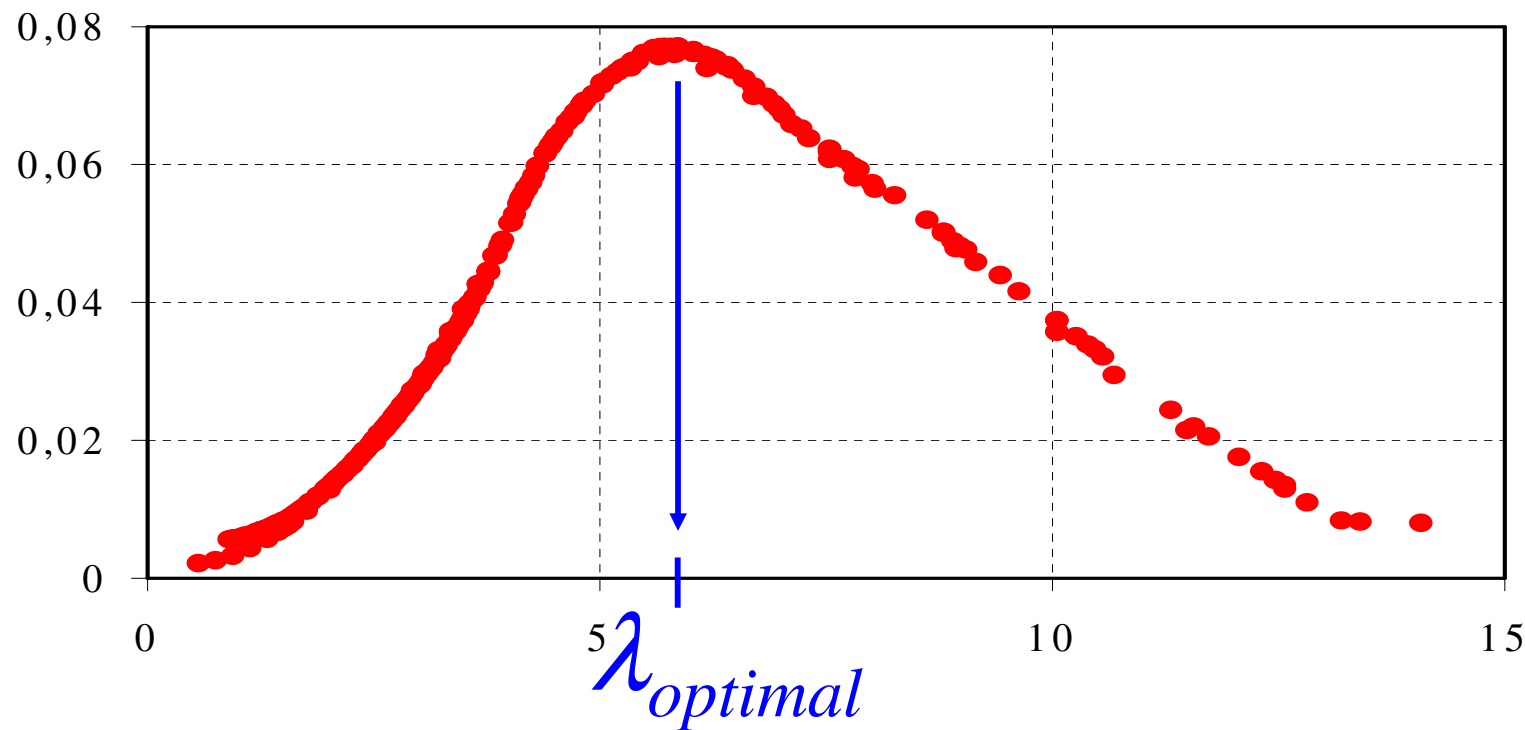


$$\lambda = \frac{v_{blade}}{v_{wind}} = \frac{R_{blade} \Omega_{shaft}}{v_{wind}}$$

$$P_{wind} = F_{blade} v_{wind} = \frac{1}{2} \rho S v_{wind}^3$$

$$P_{target} = C_p(\lambda) P_{wind}$$

$C_P(pu)$

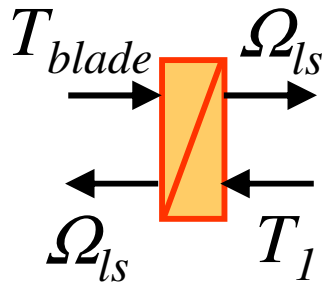


$$\lambda = \frac{v_{blade}}{v_{wind}} = \frac{R_{blade} \Omega_{shaft}}{v_{wind}}$$

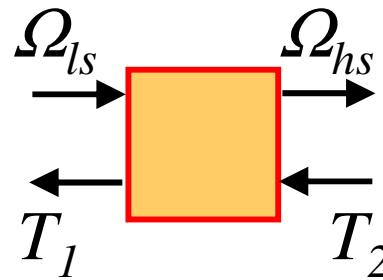
$$J_1 \frac{d}{dt} \Omega_{ls} + f \Omega_{ls} = T_{blade} - T_1$$

$$\begin{cases} T_1 = k_{gear} T_2 \\ \Omega_{hs} = k_{gear} \Omega_{ls} \end{cases}$$

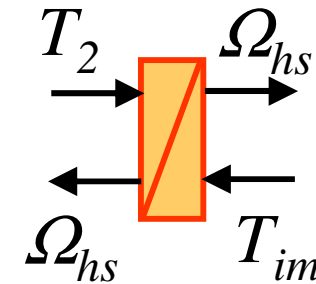
$$J_2 \frac{d}{dt} \Omega_{hs} + f_2 \Omega_{hs} = T_2 - T_{im}$$



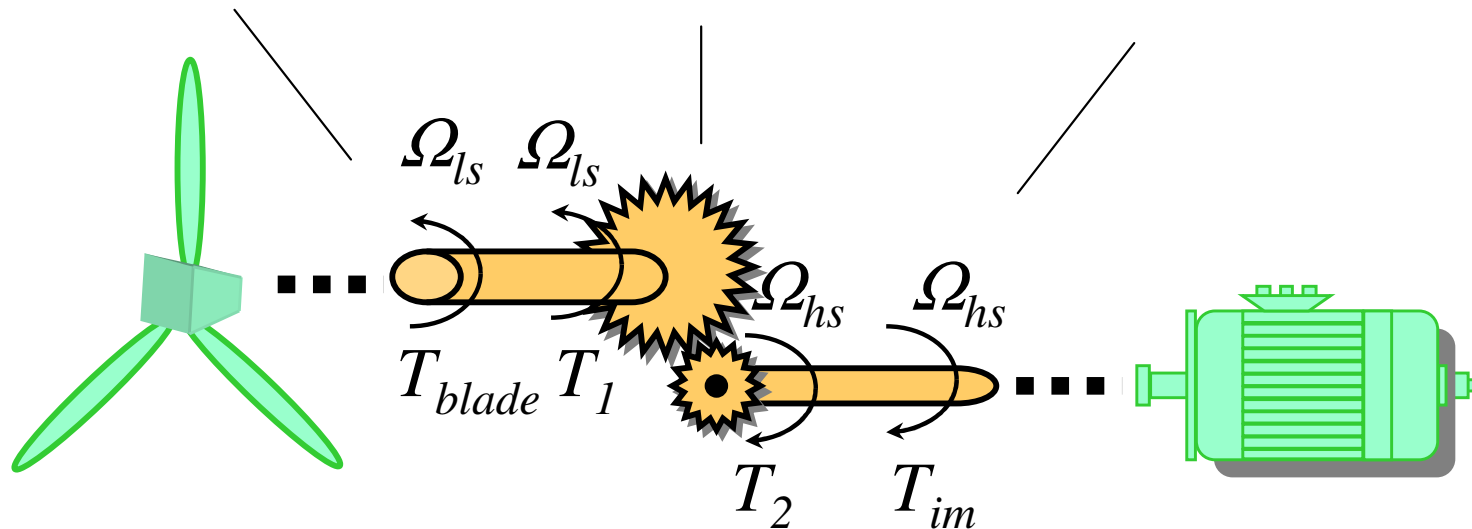
slow speed shaft



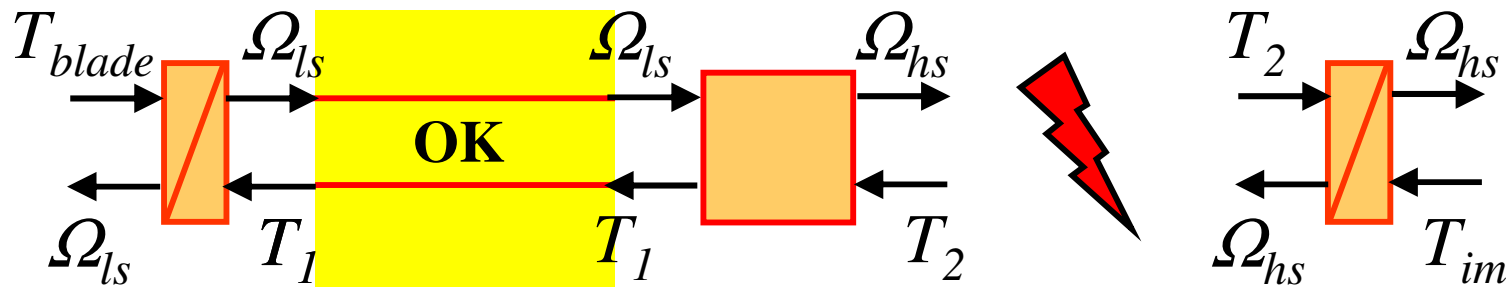
gearbox



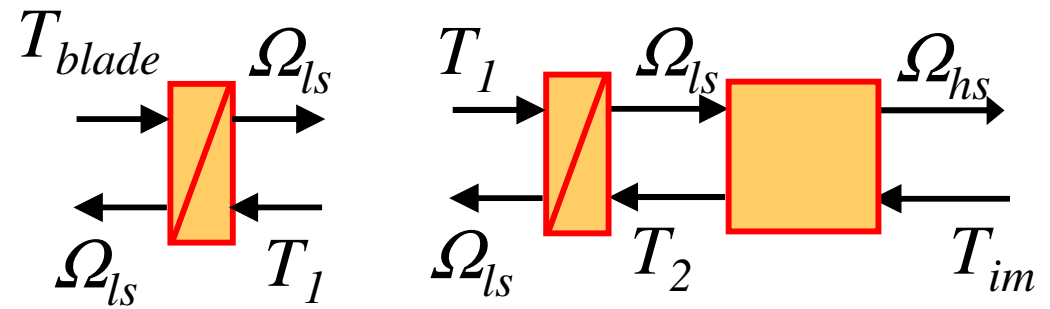
high speed shaft



Element association?

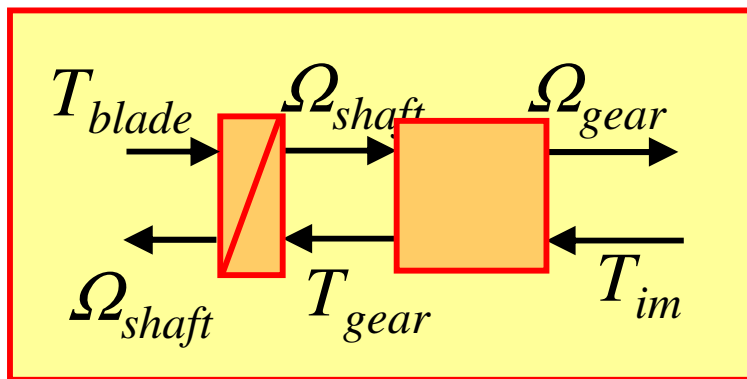


1. permutation



2. merging $J_{eq} = J_1 + \frac{J_2}{k^2}$

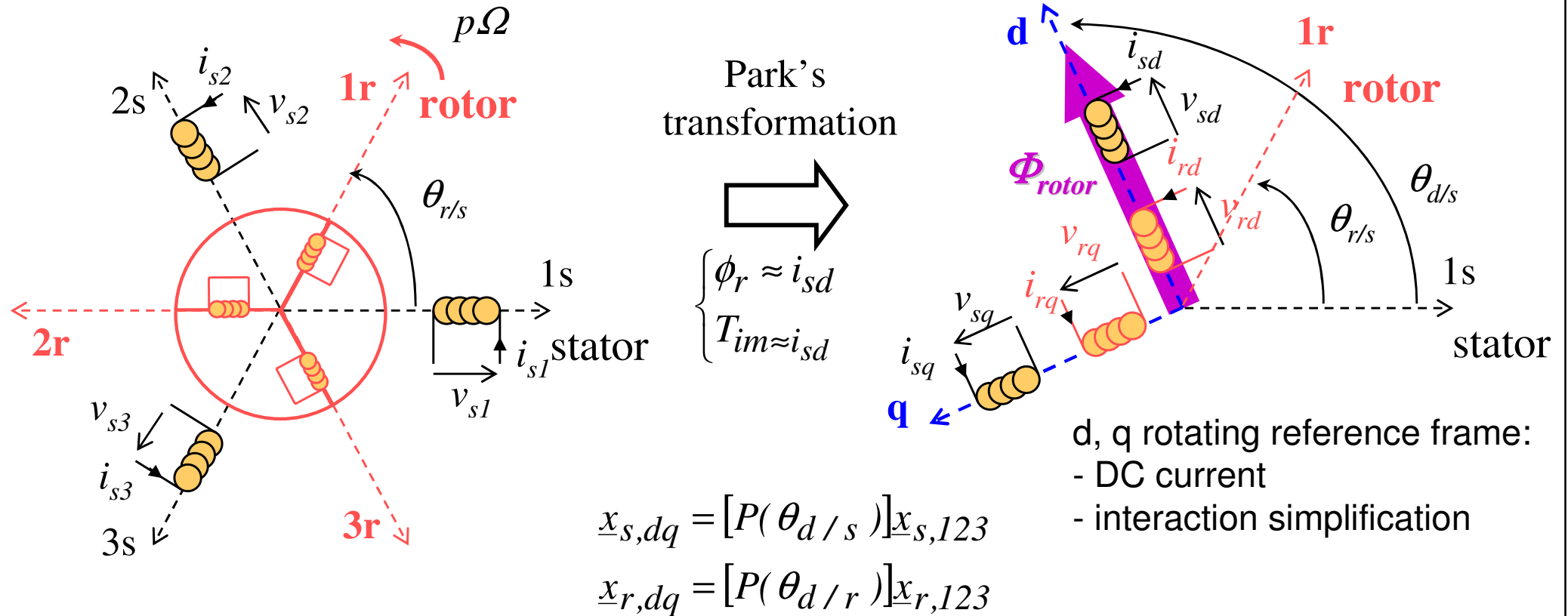
Equivalent power train



- EMR of the squirrel cage IM -

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- 1 – the position θ is function of time: difficult to control AC currents
- 2 – strong interaction between phases

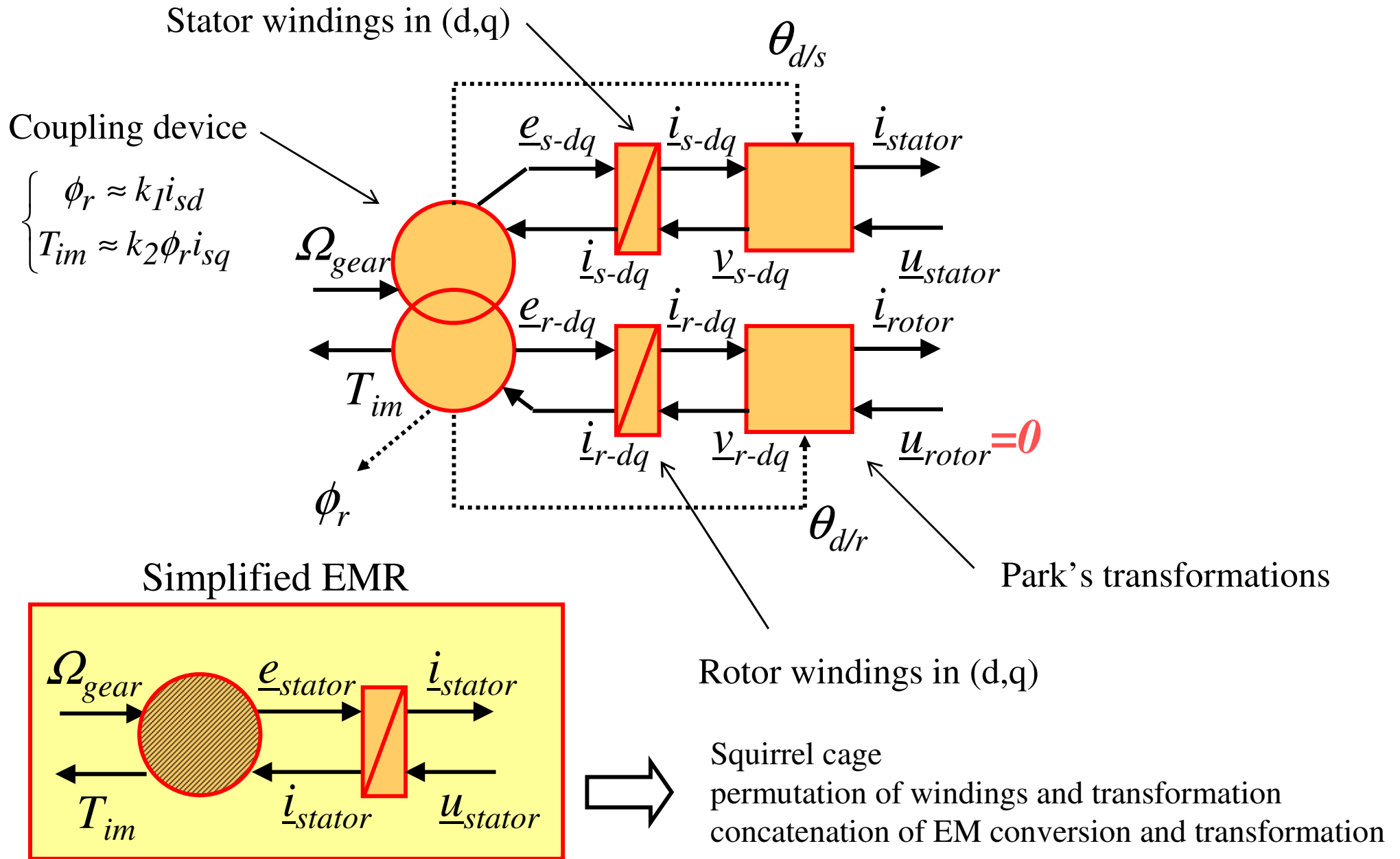


Modelling simplifications:

$$\begin{cases} \phi_r \approx k_1 i_{sd} \\ T_{im} \approx k_2 \phi_r i_{sq} \end{cases}$$

- EMR of the squirrel cage IM -

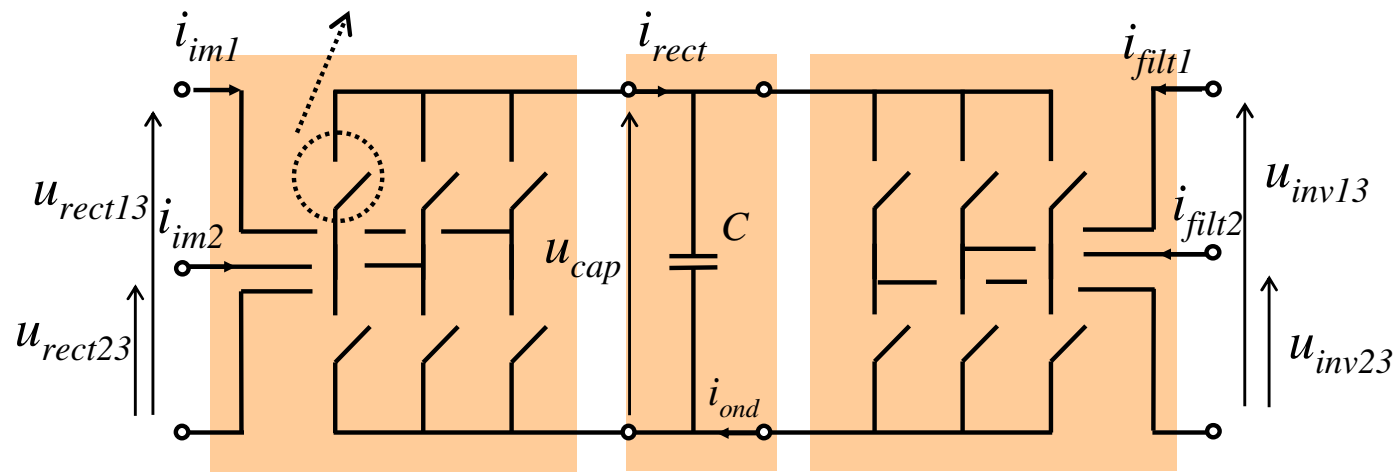
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- EMR of the back-to-back VSI -

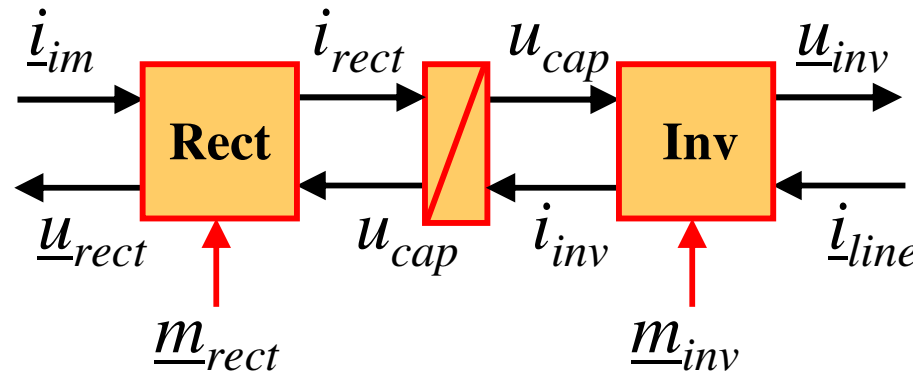
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$$s_{11} = \begin{cases} 1(\text{closed}) \\ 0(\text{open}) \end{cases}$$



$$\underline{m}_{rect} = \begin{bmatrix} s_{11} - s_{13} \\ s_{12} - s_{13} \end{bmatrix}$$

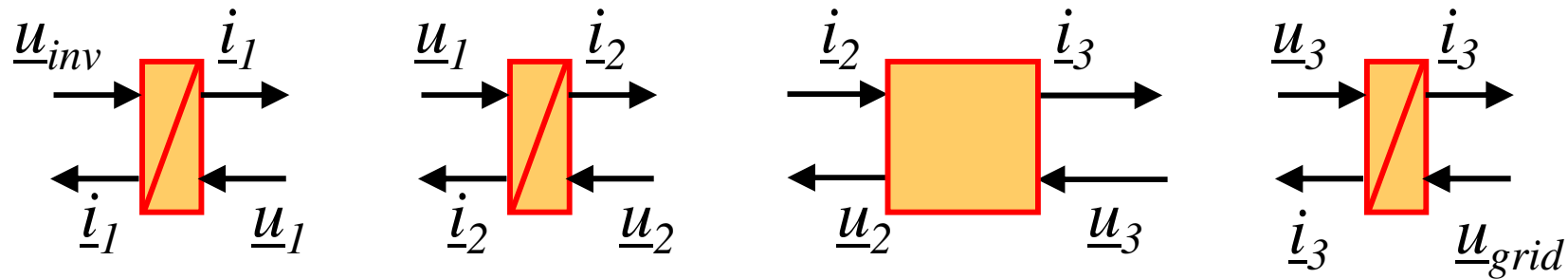
$$\begin{cases} \underline{u}_{rect} = \underline{m}_{rect} u_{cap} \\ \underline{i}_{rect} = \underline{m}_{rect}^t \underline{i}_{im} \end{cases}$$



$$C \frac{d}{dt} u_{cap} = i_{rect} - i_{inv}$$

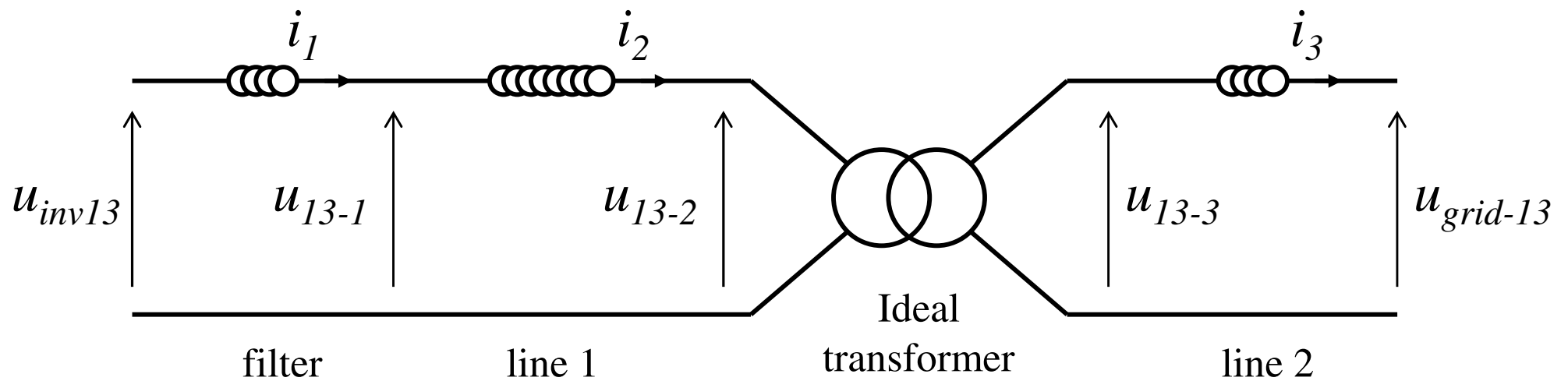
$$L_1 \frac{d}{dt} \underline{i}_1 + R_3 \underline{i}_1 = \underline{u}_{inv} - \underline{u}_1$$

$$\begin{cases} \underline{u}_2 = m_{trans} \underline{u}_3 \\ \underline{i}_3 = m_{trans} \underline{i}_2 \end{cases}$$

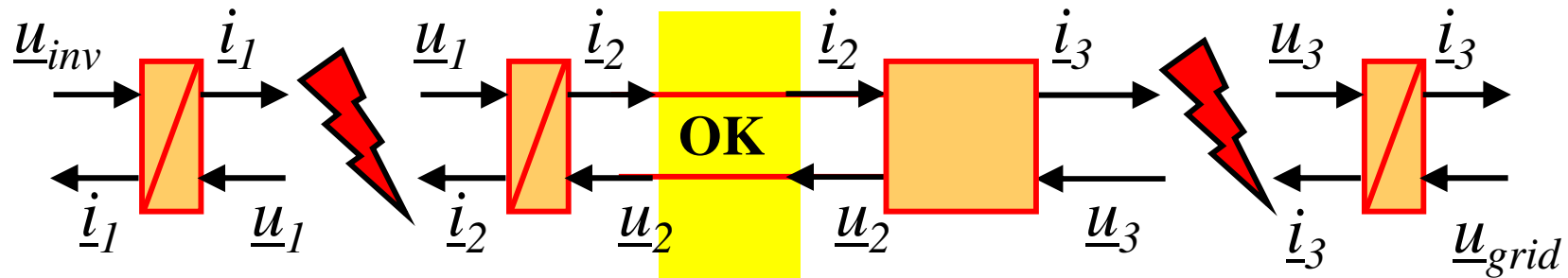


$$L_2 \frac{d}{dt} \underline{i}_2 + R_3 \underline{i}_2 = \underline{u}_1 - \underline{u}_2$$

$$L_3 \frac{d}{dt} \underline{i}_3 + R_3 \underline{i}_3 = \underline{u}_3 - \underline{u}_{grid}$$

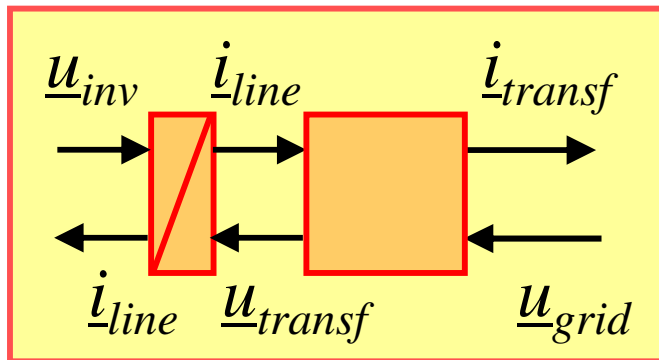


Element association?



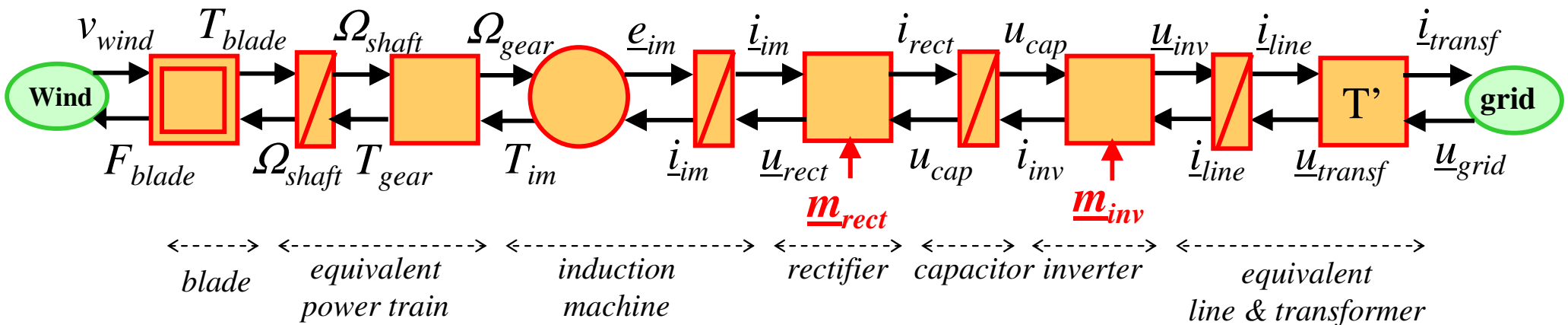
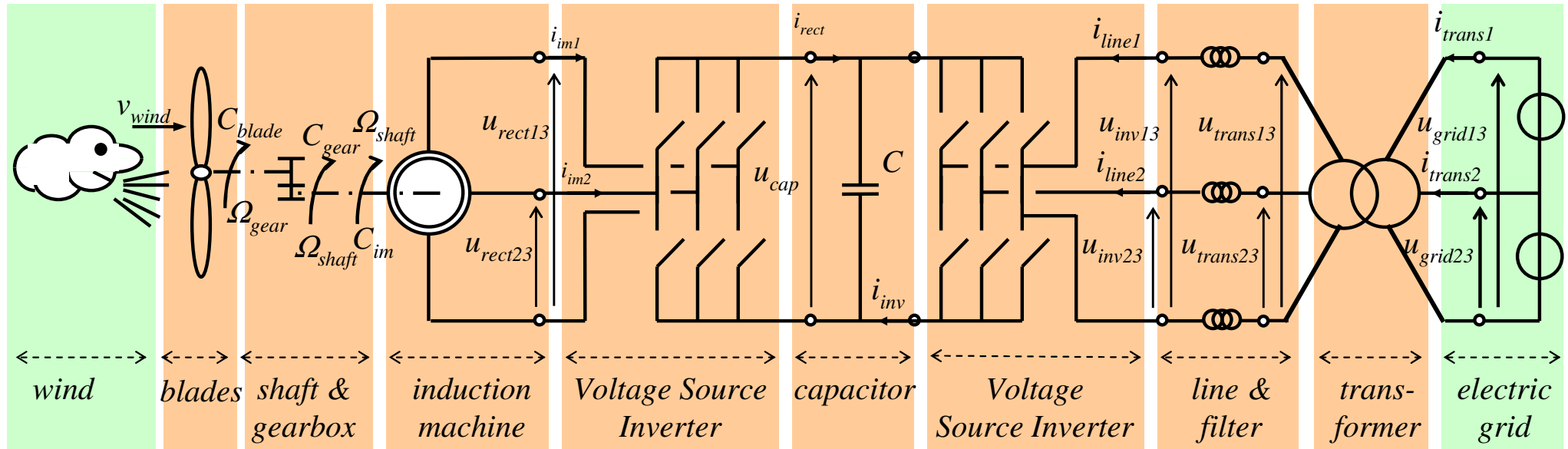
1. merging

2. permutation



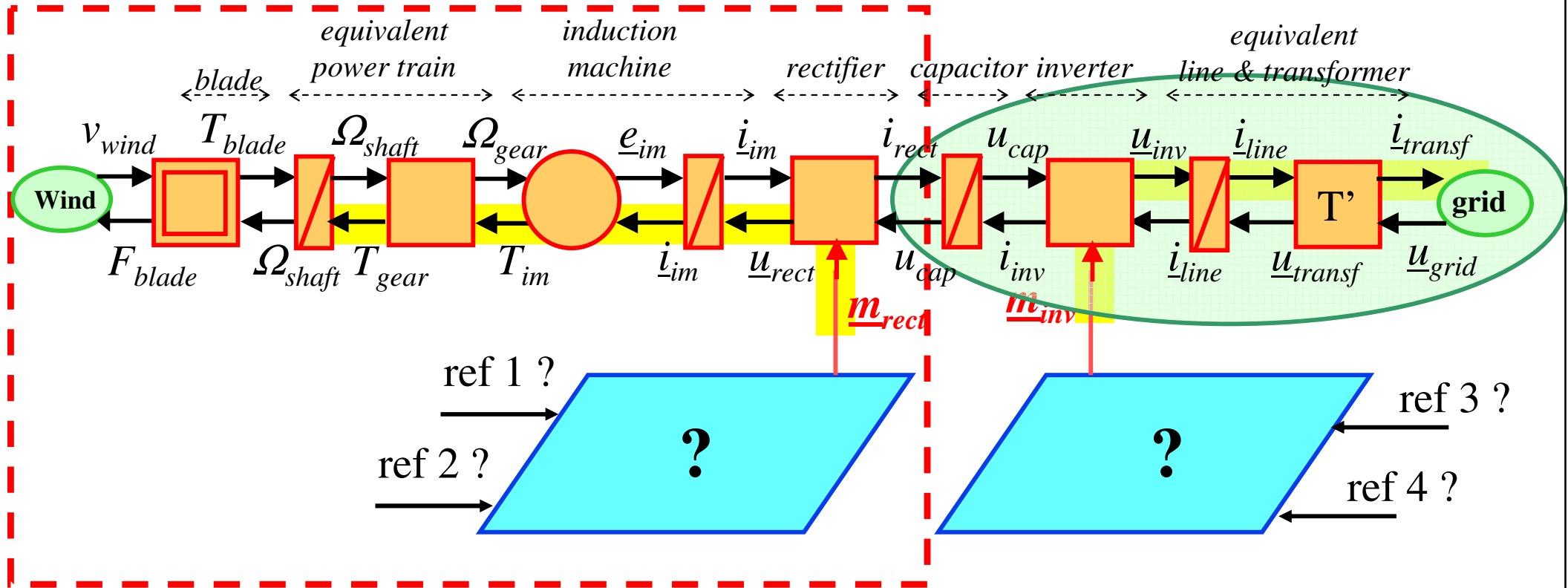
3. merging

$$L_{eq} = L_1 + L_2 + \frac{L_3}{m_{trans}^2}$$



- Tuning chains of the WECS -

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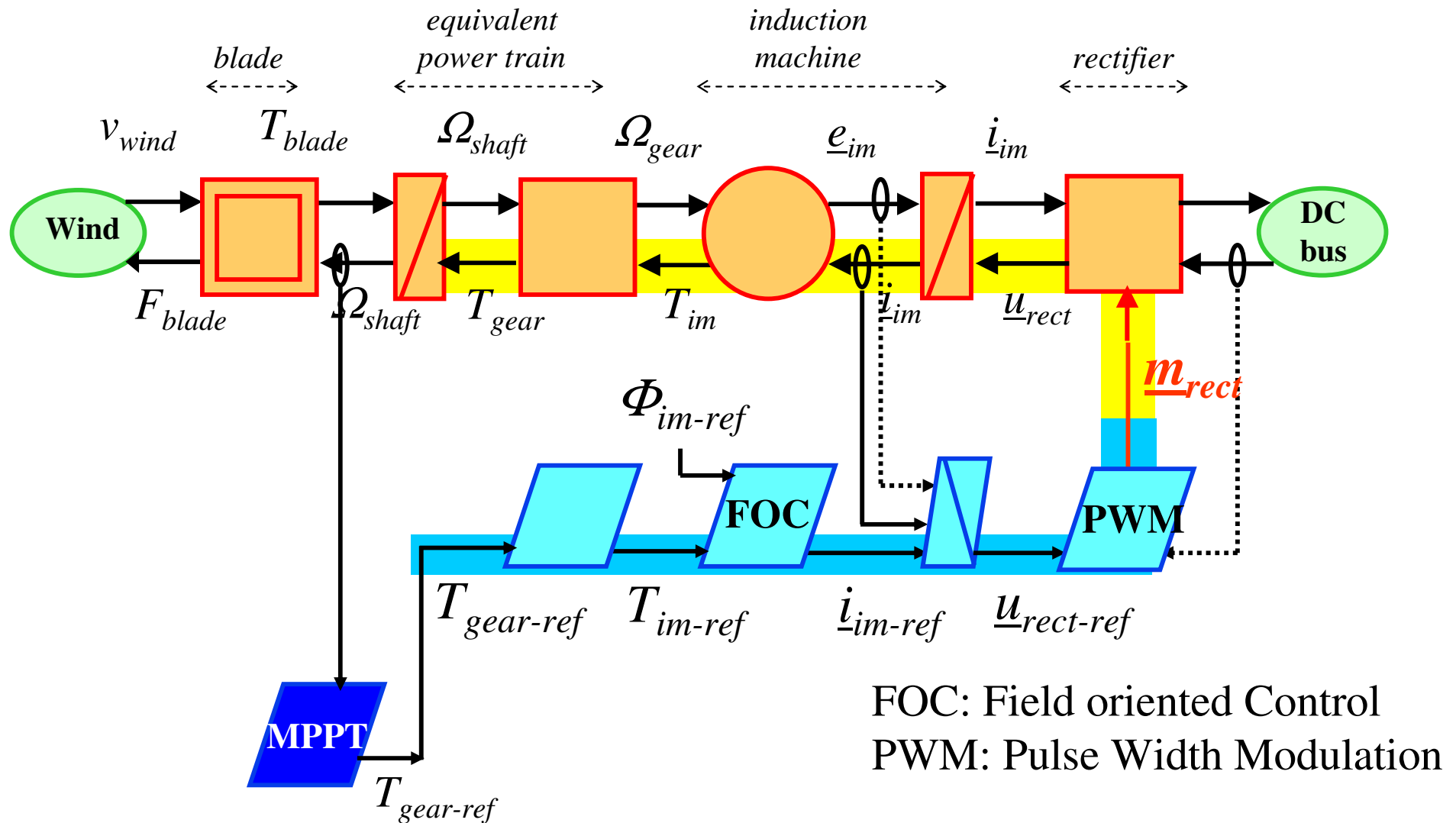


objectives: active power P
reactive power Q

constraints: capacitor voltage
machine flux

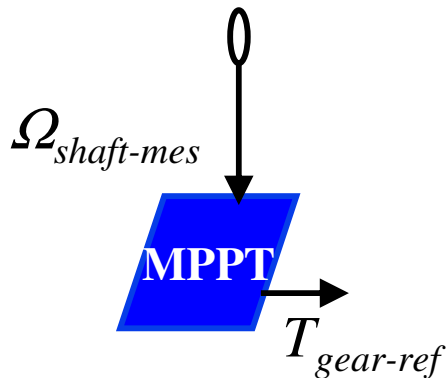
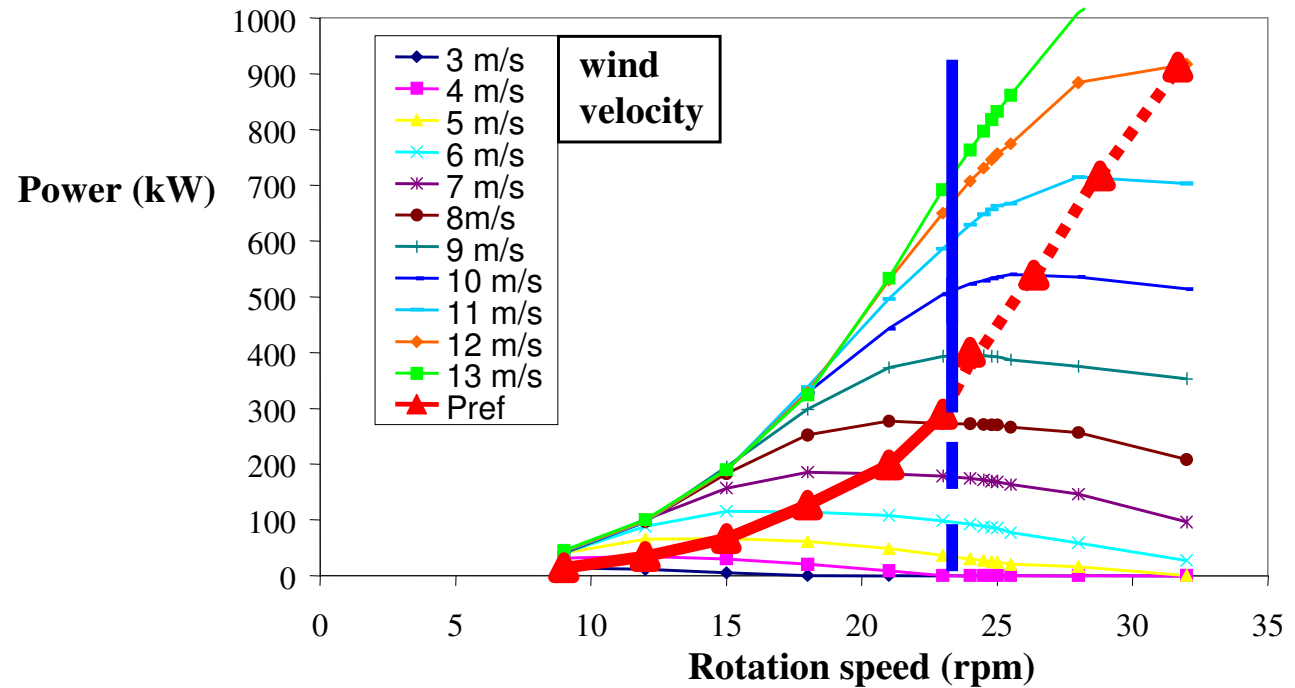
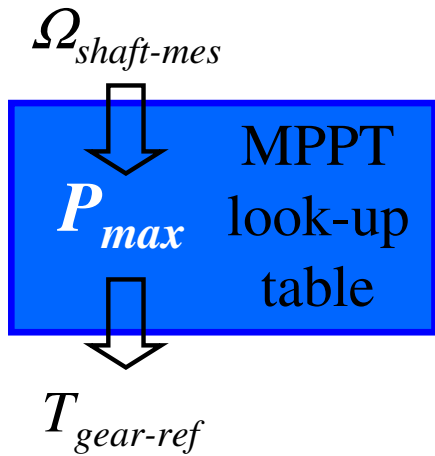
$$\underline{m}_{rect} = \begin{bmatrix} m_{13} \\ m_{23} \end{bmatrix} \Rightarrow 2 \text{ freedom degrees}$$

$$\underline{m}_{inv} = \begin{bmatrix} m'_{13} \\ m'_{23} \end{bmatrix} \Rightarrow 2 \text{ freedom degrees}$$



FOC: Field oriented Control
 PWM: Pulse Width Modulation

MPPT = Maximum Power Point Tracking



$P_{max} \# T_{gear} \Omega_{shaft}$

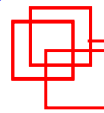
Ω_{max}

MPPT = Maximum Power Point Tracking

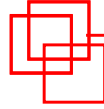
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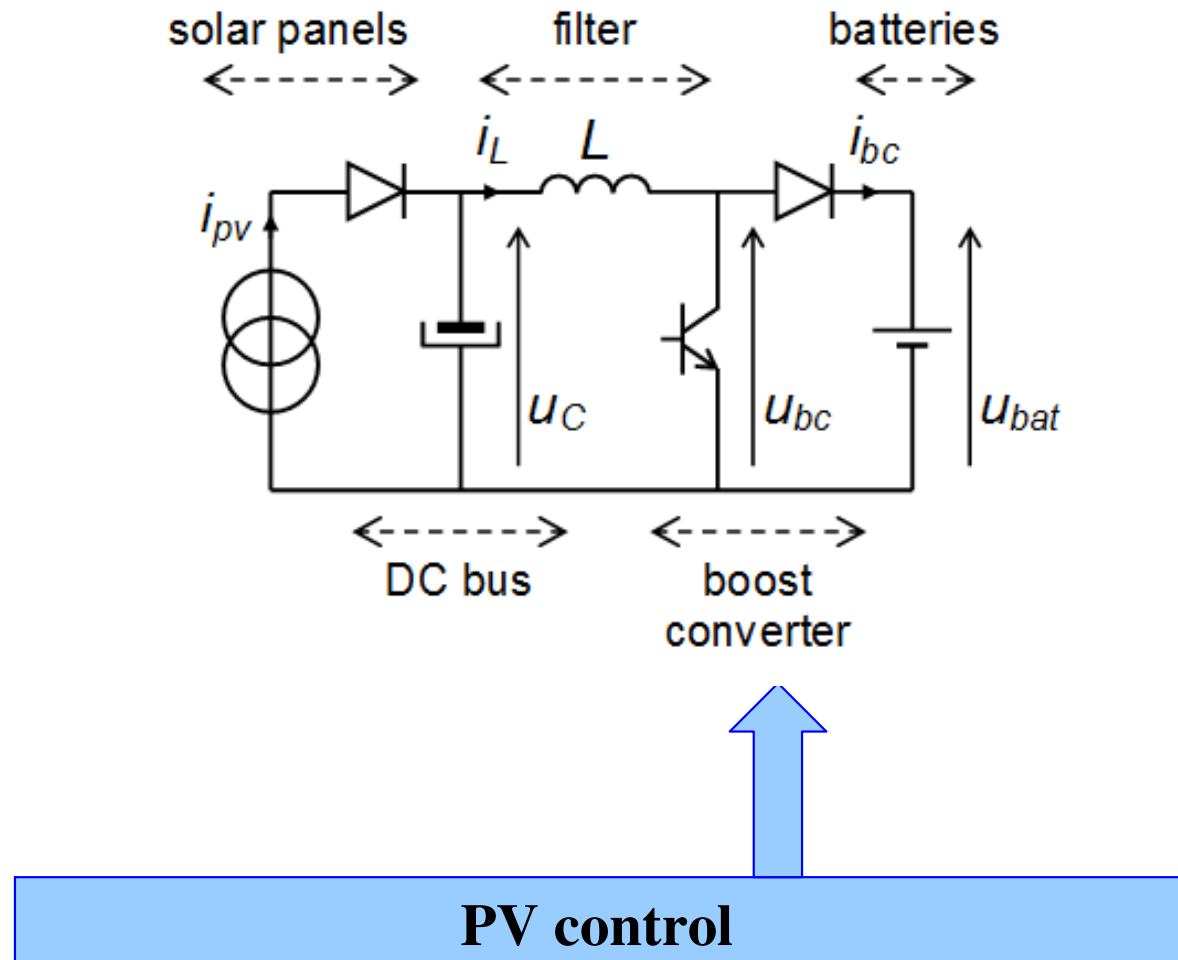
« PHOTO -VOLTAIC CONVERSION SYSTEM »

*Dr. W. Lhomme, Dr. P. Delarue, Prof. A. Bouscayrol,
(University of Lille 1, France)*



Université
Lille1
Sciences et Technologies

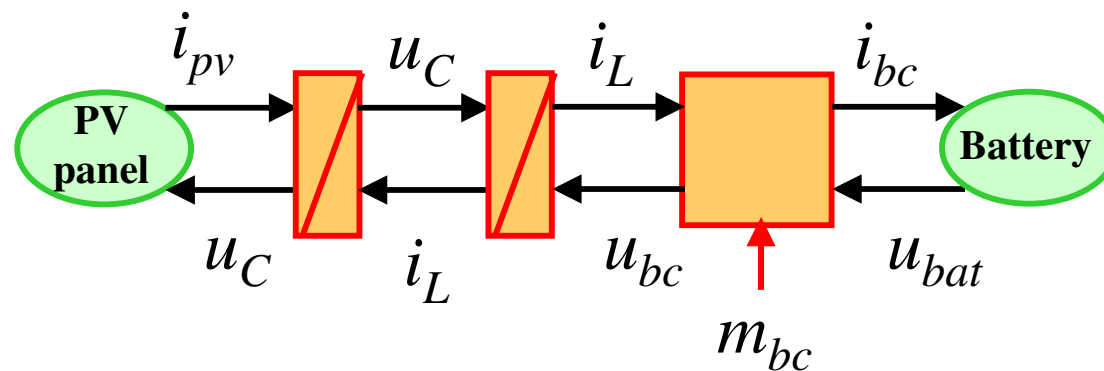
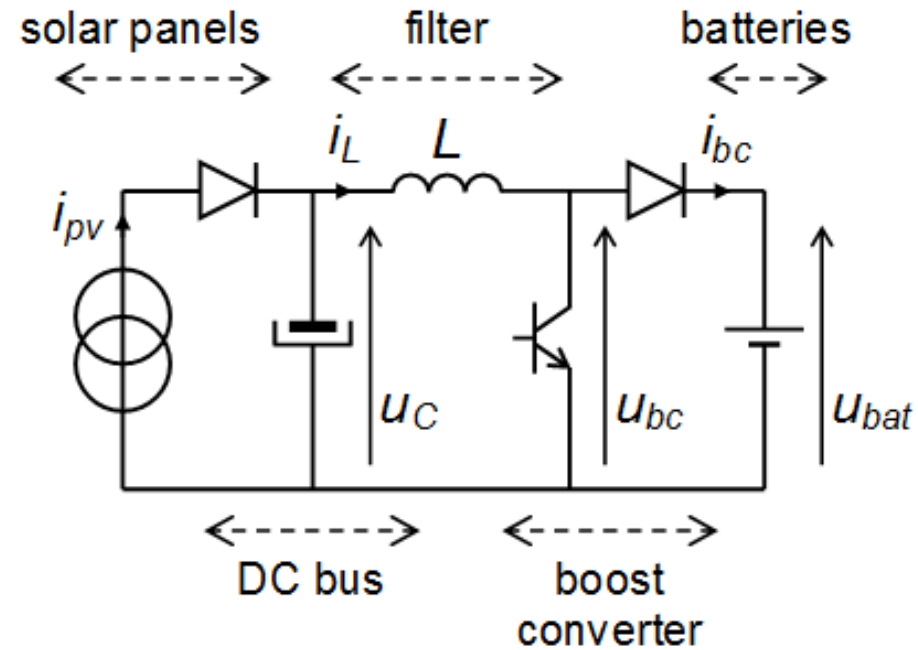




Technical requirements: provide the maximum active power P

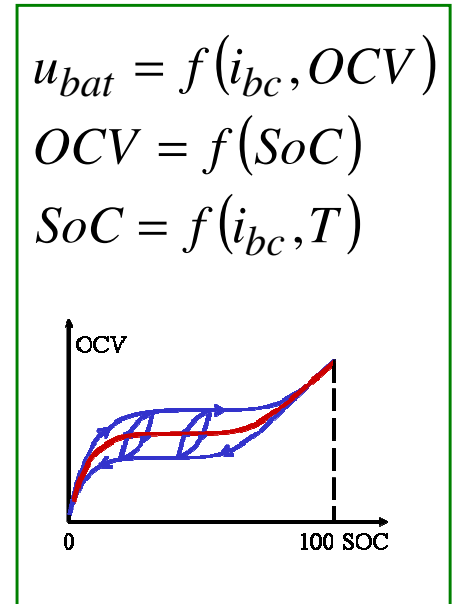
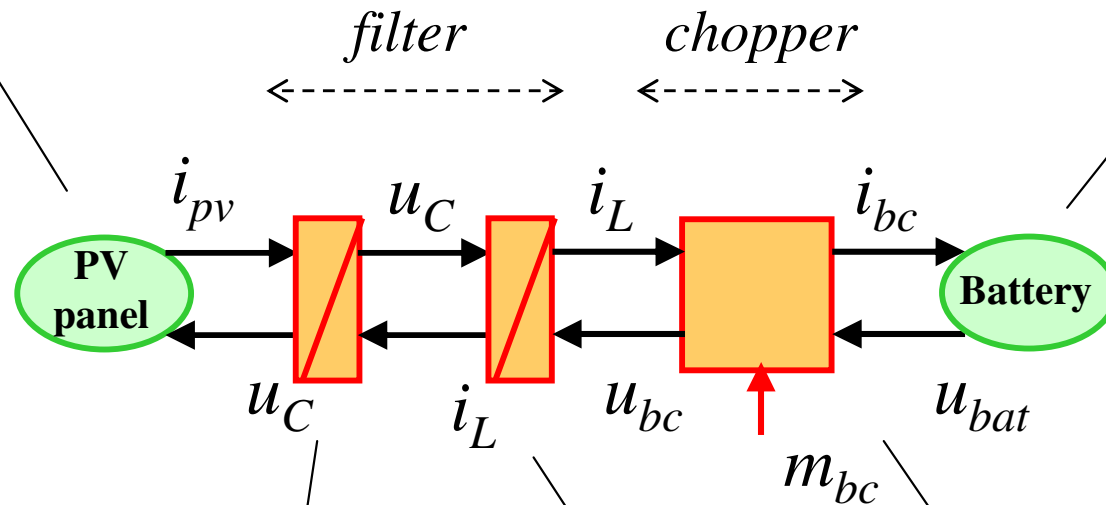
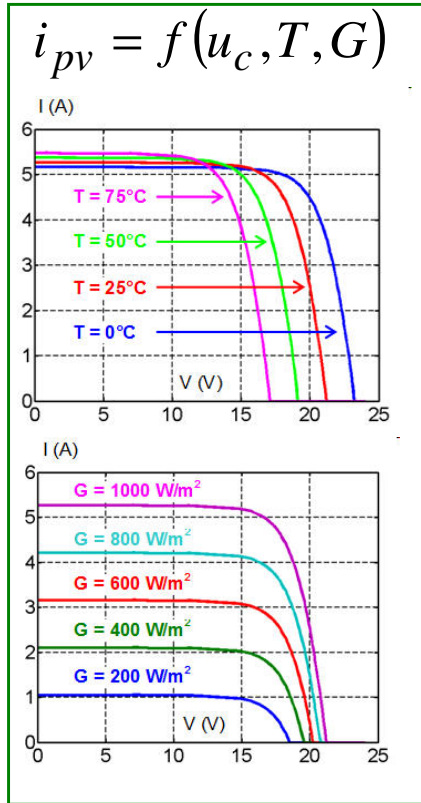
- EMR of the PV System -

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- EMR of the PV System -

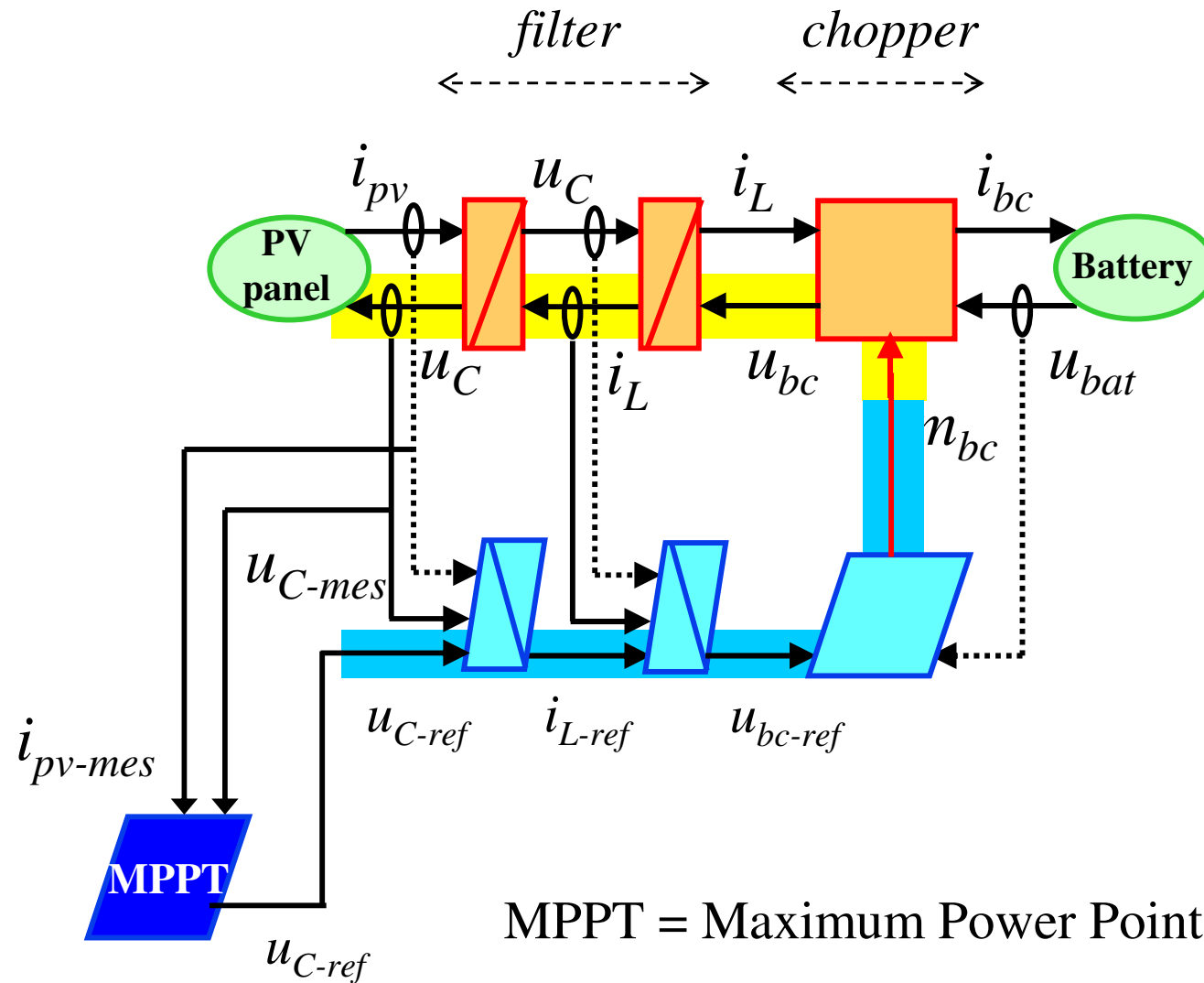
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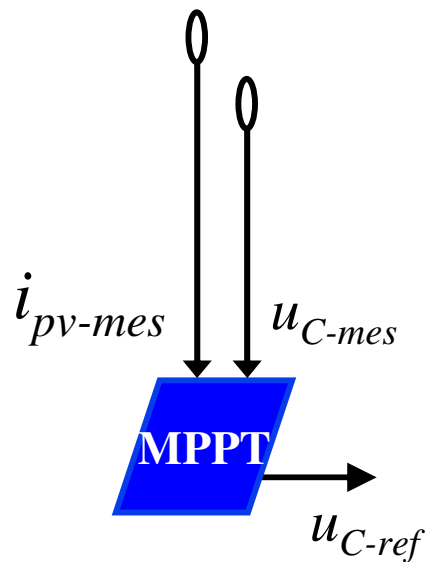
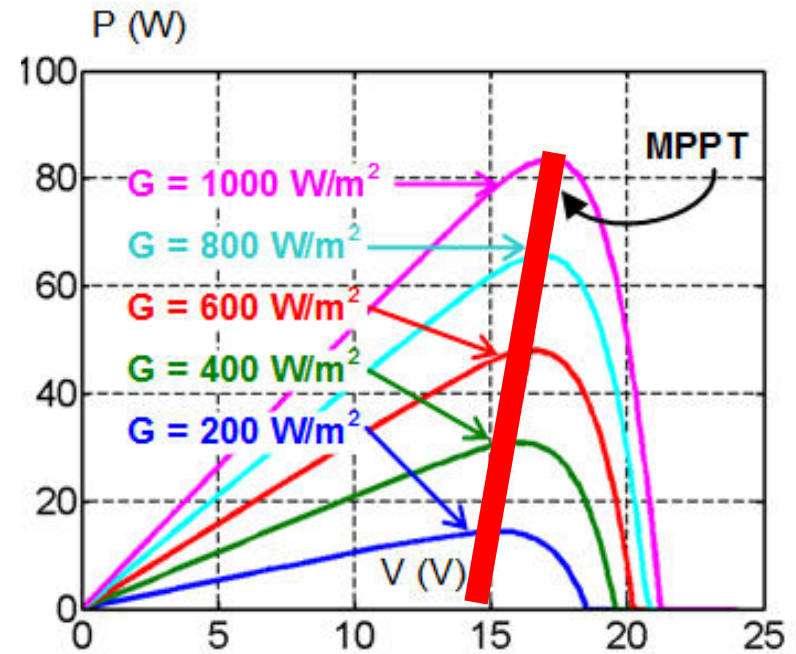
$$C \frac{d}{dt} u_c + \frac{u_c}{R_C} = i_{pv} - i_L$$

$$\begin{cases} i_{bc} = m_{bc} i_L \\ u_{bc} = m_{bc} u_{bat} \end{cases}$$

$$L \frac{d}{dt} i_L + R_L i_L = u_c - u_{bc}$$



MPPT = Maximum Power Point Tracking

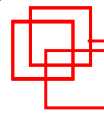


MPPT = Maximum Power Point Tracking

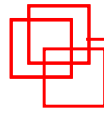
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- A. Bouscayrol, X. Guillaud, R. Teodorescu, P. Delarue, W. Lhomme, "Hardware-in-the-loop simulation of different wind turbines using Energetic Macroscopic Representation", IEEE-IECON'06, Paris, November 2006, (common paper of L2EP and University of Aalborg).
- A. Bouscayrol, X. Guillaud, P. Delarue, B. Lemaire-Semail, "Energetic Macroscopic Representation and inversion-based control illustrated on a wind energy conversion systems using Hardware-in-the-loop simulation", IEEE transactions on Industrial Electronics, to be published in 2009, available on Xplore