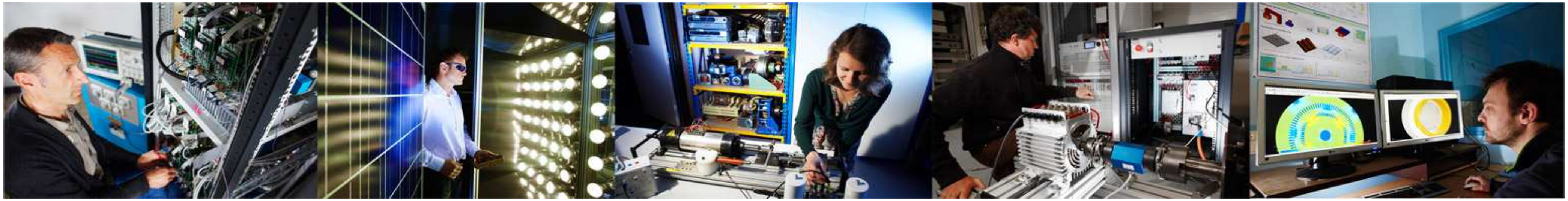

EVS'27, Barcelona, November 2013

EVS 27

« Energetic Macroscopic Representation and Inversion-Based control of a CVT-based HEV »

…………………

M. Chouhou, F. Grée, C. Jivan, A. Bouscayrol, T. Hofman

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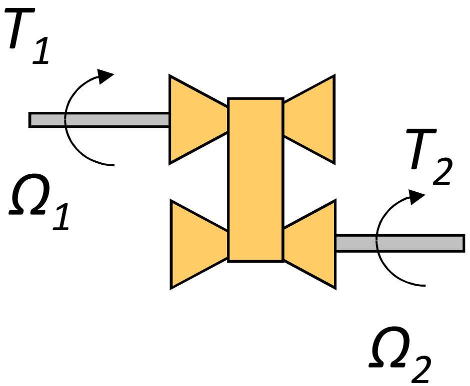
Université Lille1 Sciences et Technologies

TU/e Technische Universiteit Eindhoven University of Technology

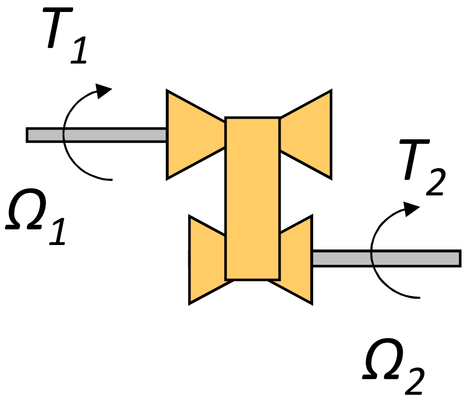
Objective: definition of the control scheme of a Hybrid Electric Vehicle (HEV) using a Continuously Variable Transmission (CVT)

1. **Studied CVT-based Hybrid Electric Vehicle**
2. **Energetic Macroscopic Representation of the CVT-based HEV**
3. **Inversion-based control of the CVT-based HEV**
4. **Simulation results**

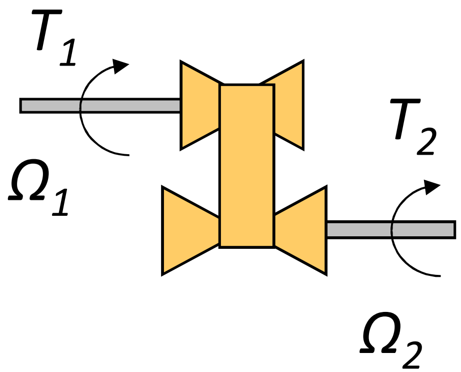
CVT = gearbox with continuous evolution of the gear ratio



$\Omega_1=\Omega_2$



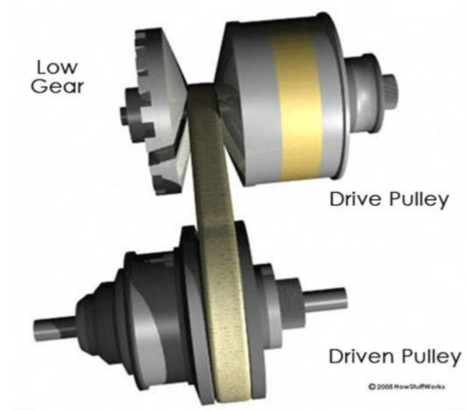
$\Omega_1>\Omega_2$



$\Omega_1<\Omega_2$

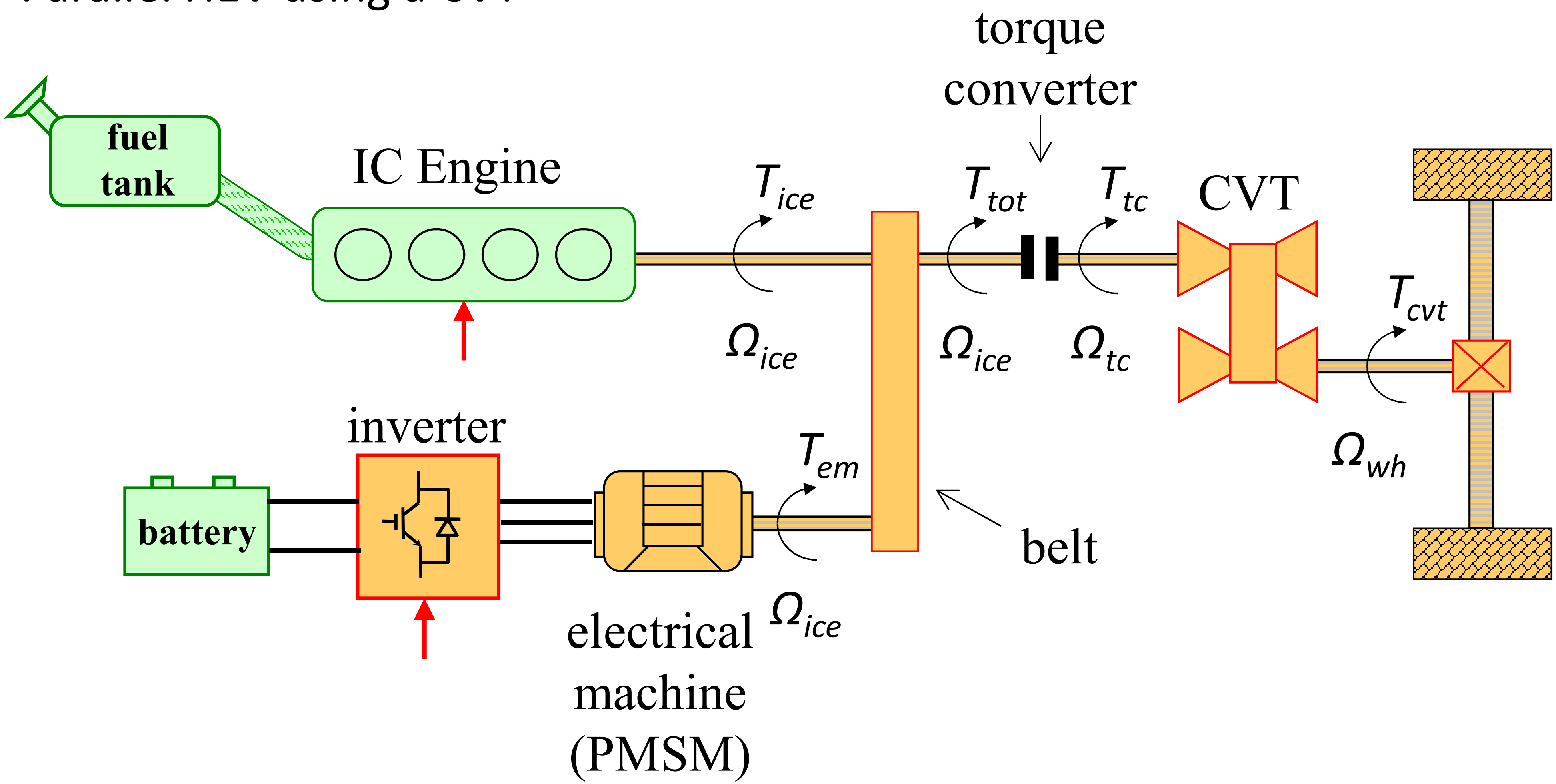
Different (friction-based) technologies of CVT:

- pulley-based CVT
- roller-based CVT
- cone-based CVT
- etc.



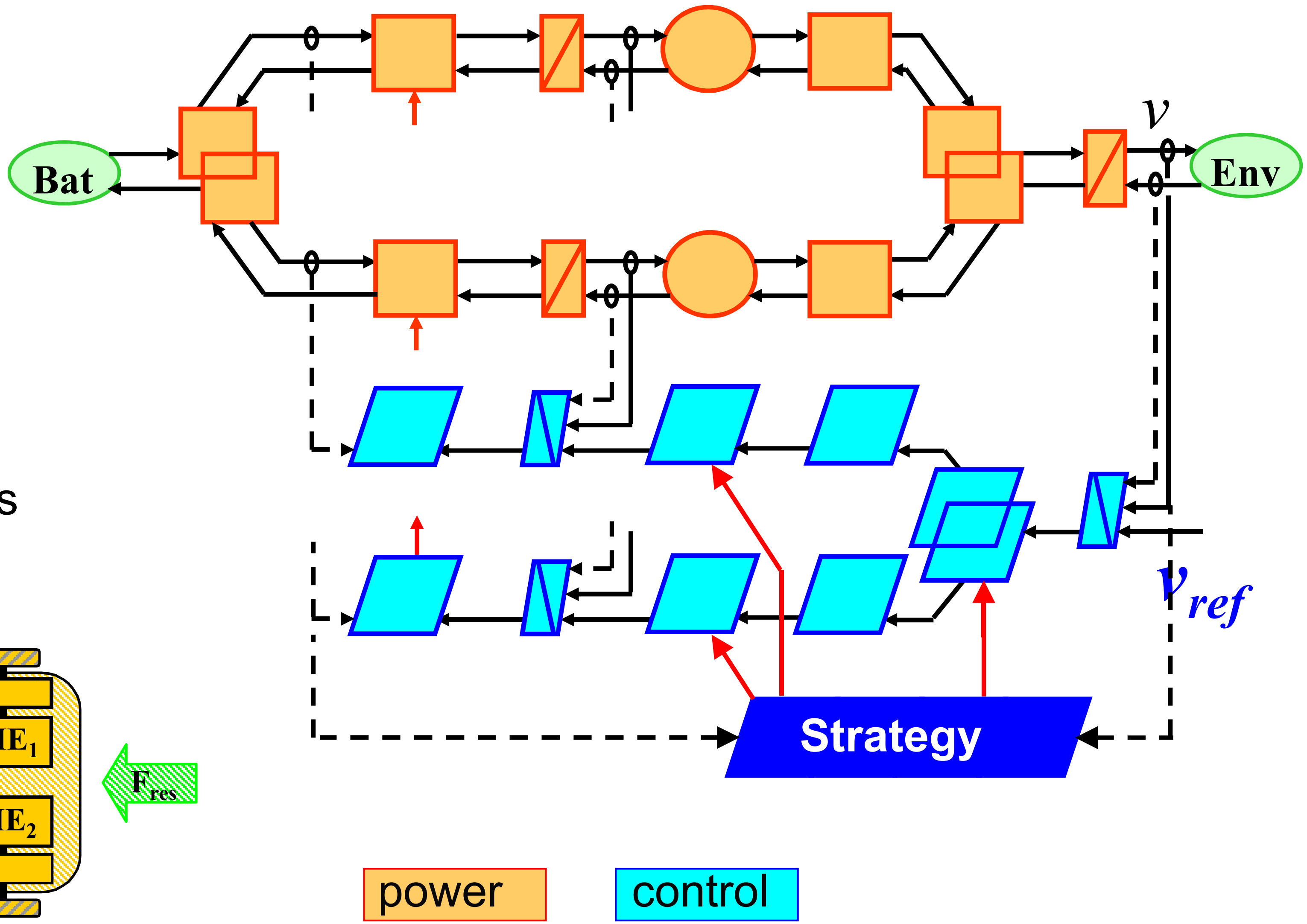
Example of pulley based CVT

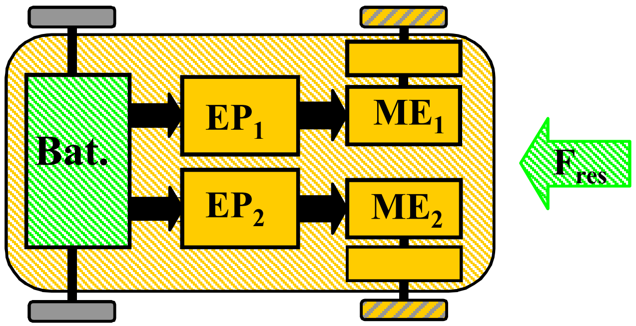
Parallel HEV using a CVT



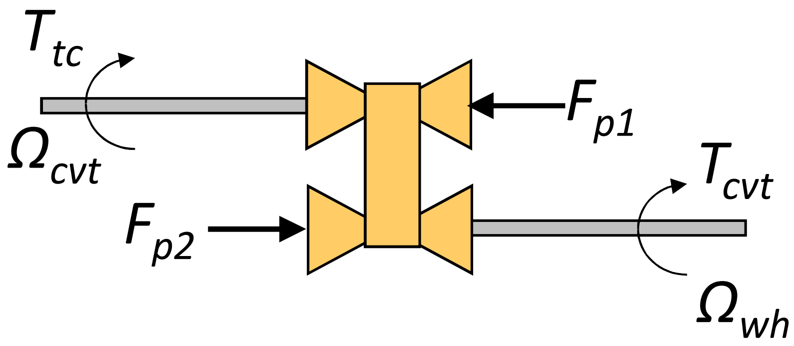
Energetic
Macroscopic
Representation
(EMR)

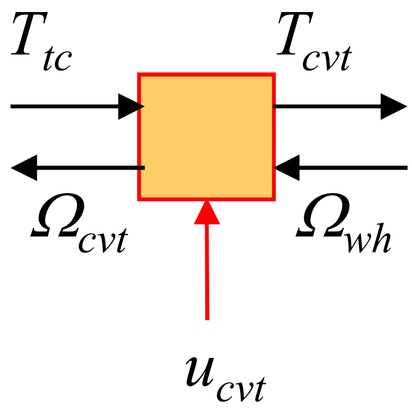
Organisation of
control schemes
of complex systems





CVT = gearbox with continuous evolution of the gear ratio





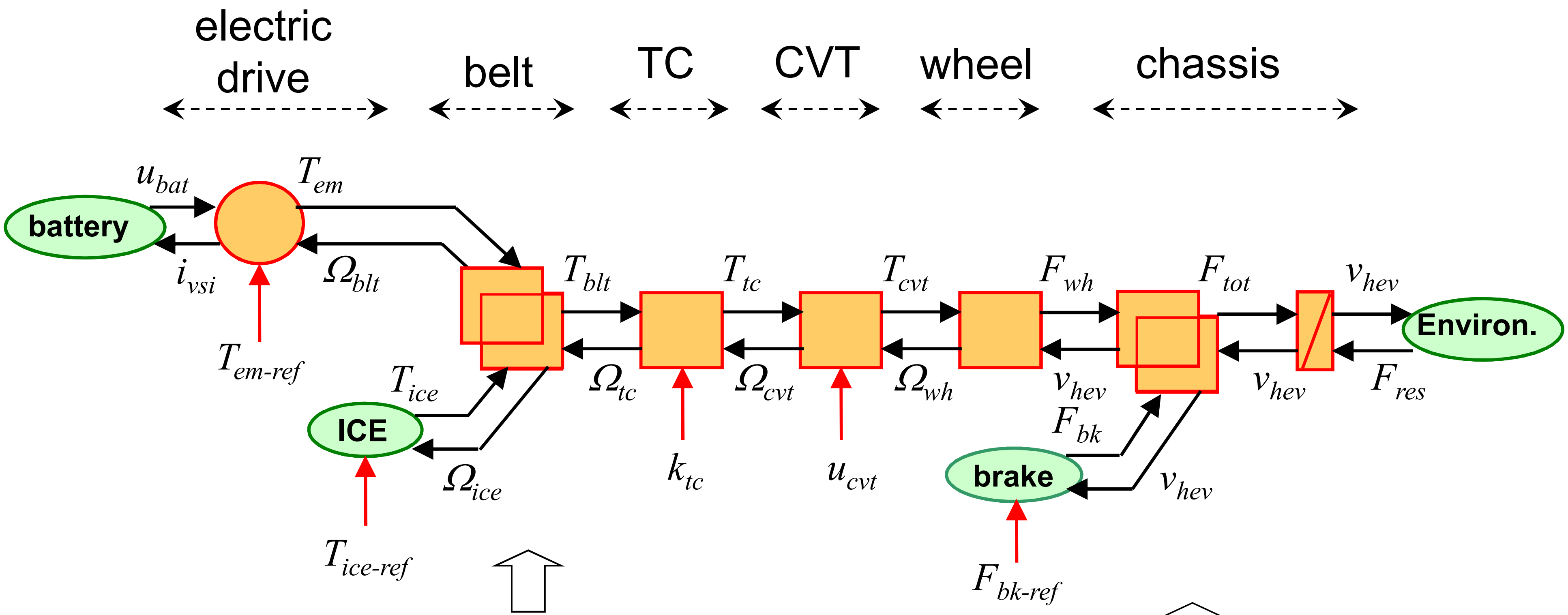
EMR of the CVT

CVT model:

$$\begin{cases} T_{cvt} = k_{cvt}\,\eta_{cvt}^{j}\,T_{tc} \\ \Omega_{cvt} = k_{cvt}\,\Omega_{wh} \end{cases} \qquad \begin{cases} j = 1 \text{ if } P_{cvt} > 0 \\ j = -1 \text{ if } P_{cvt} < 0 \end{cases}$$

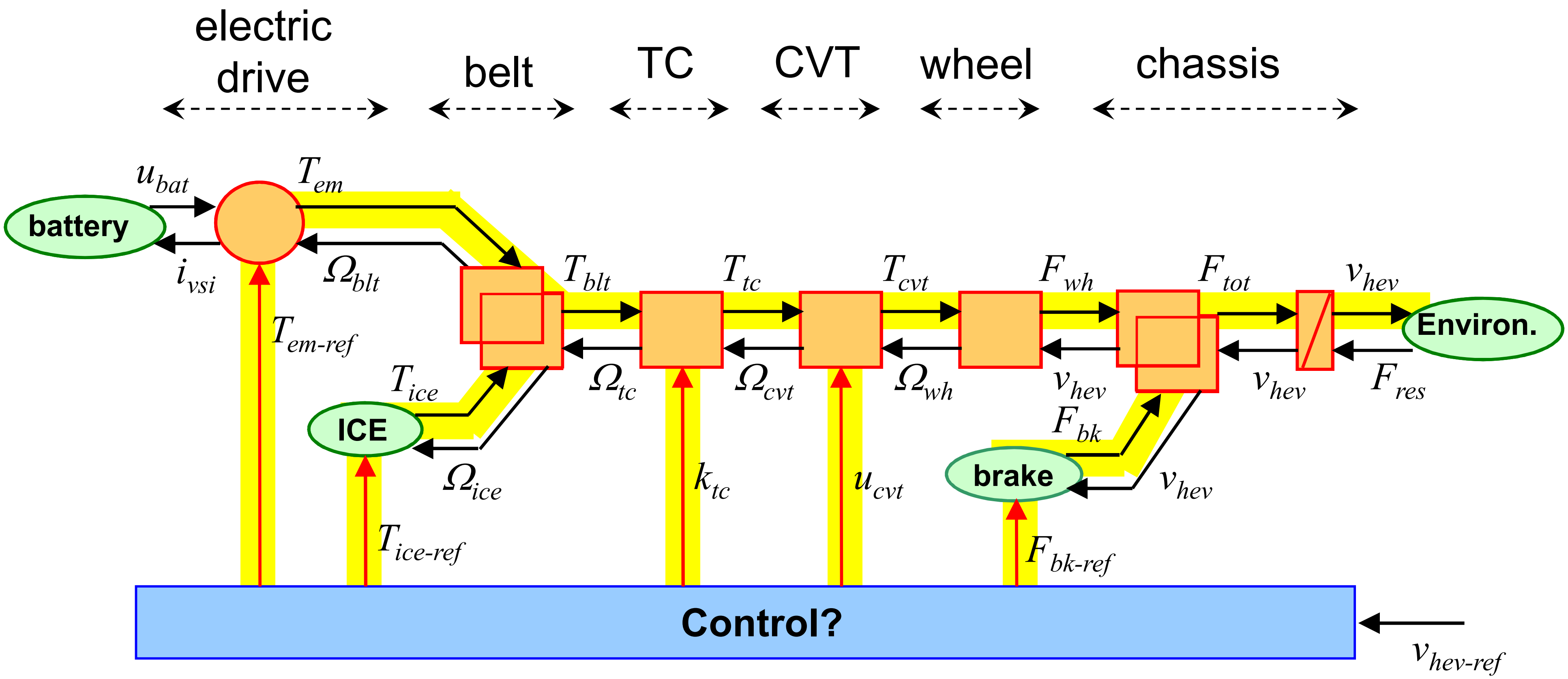
$$\frac{d}{dt} k_{cvt} = u_{cvt}\,\Omega_{tc}\,(F_{p1} - F_{p2})$$

Assumptions: constant efficiency and no stiffness and dynamic shift

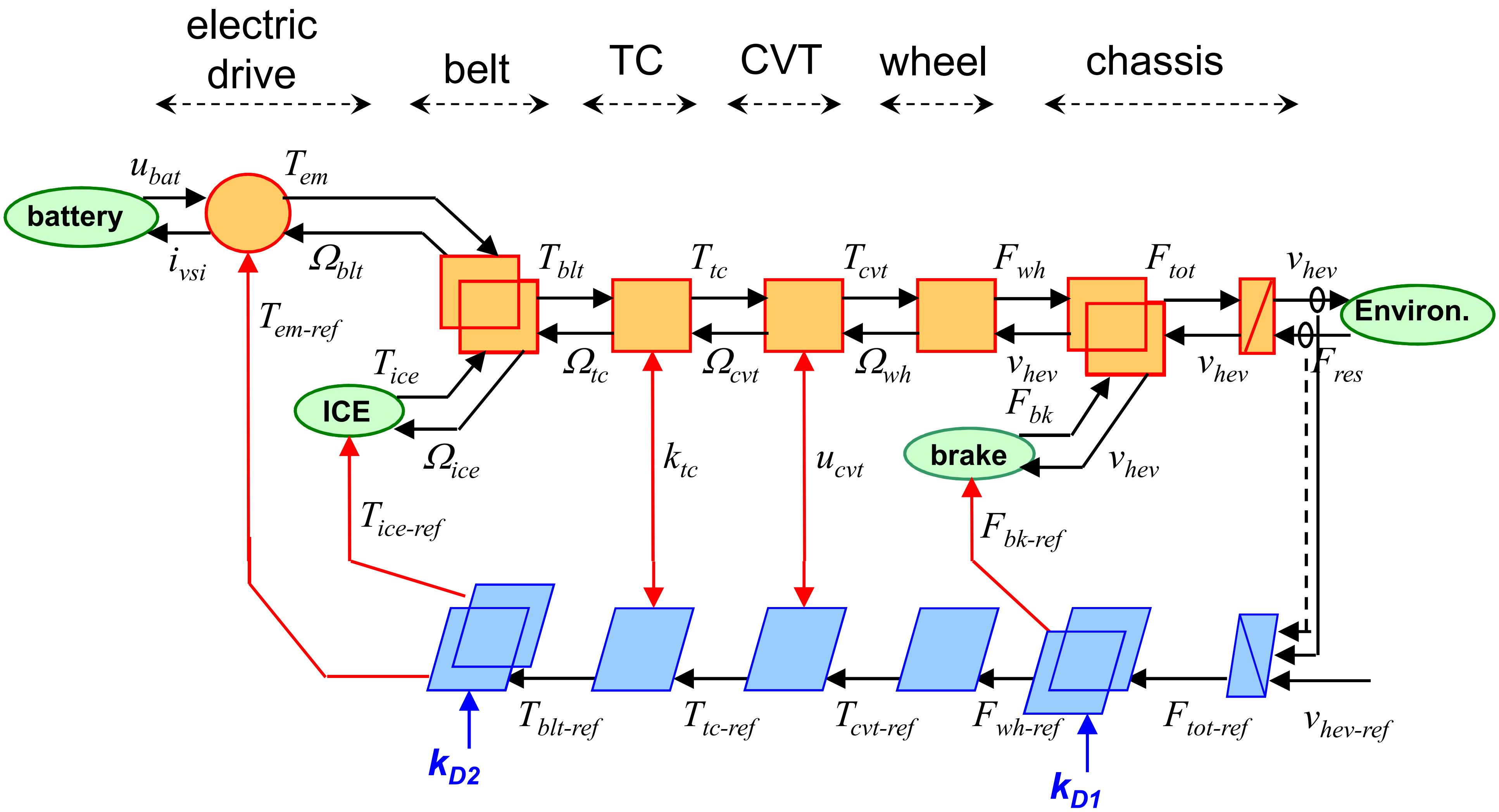


distribution of energy
between e-drive and ICE
(when traction)

distribution of energy
between electric and mechanical
brake (when deceleration)

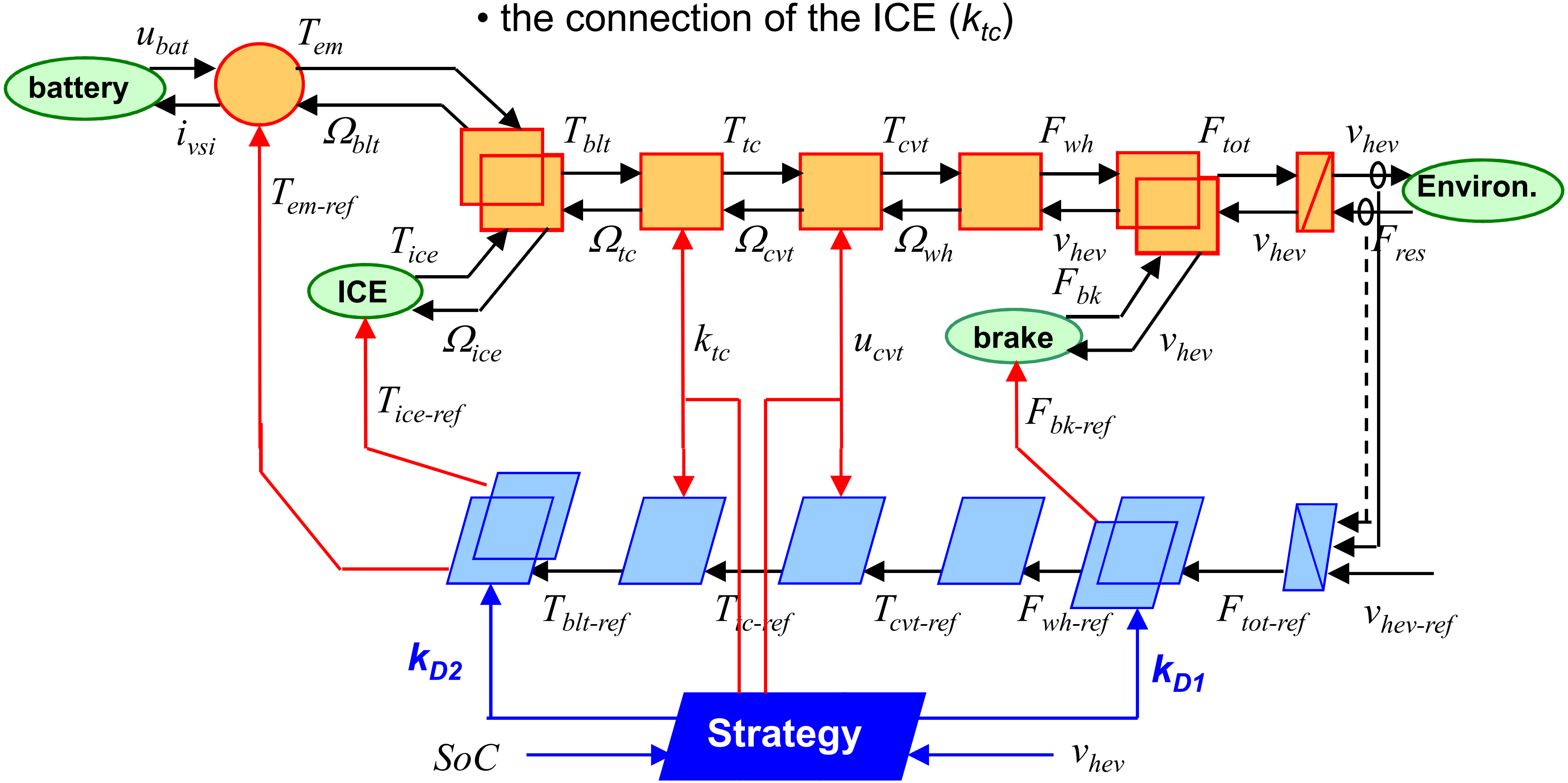


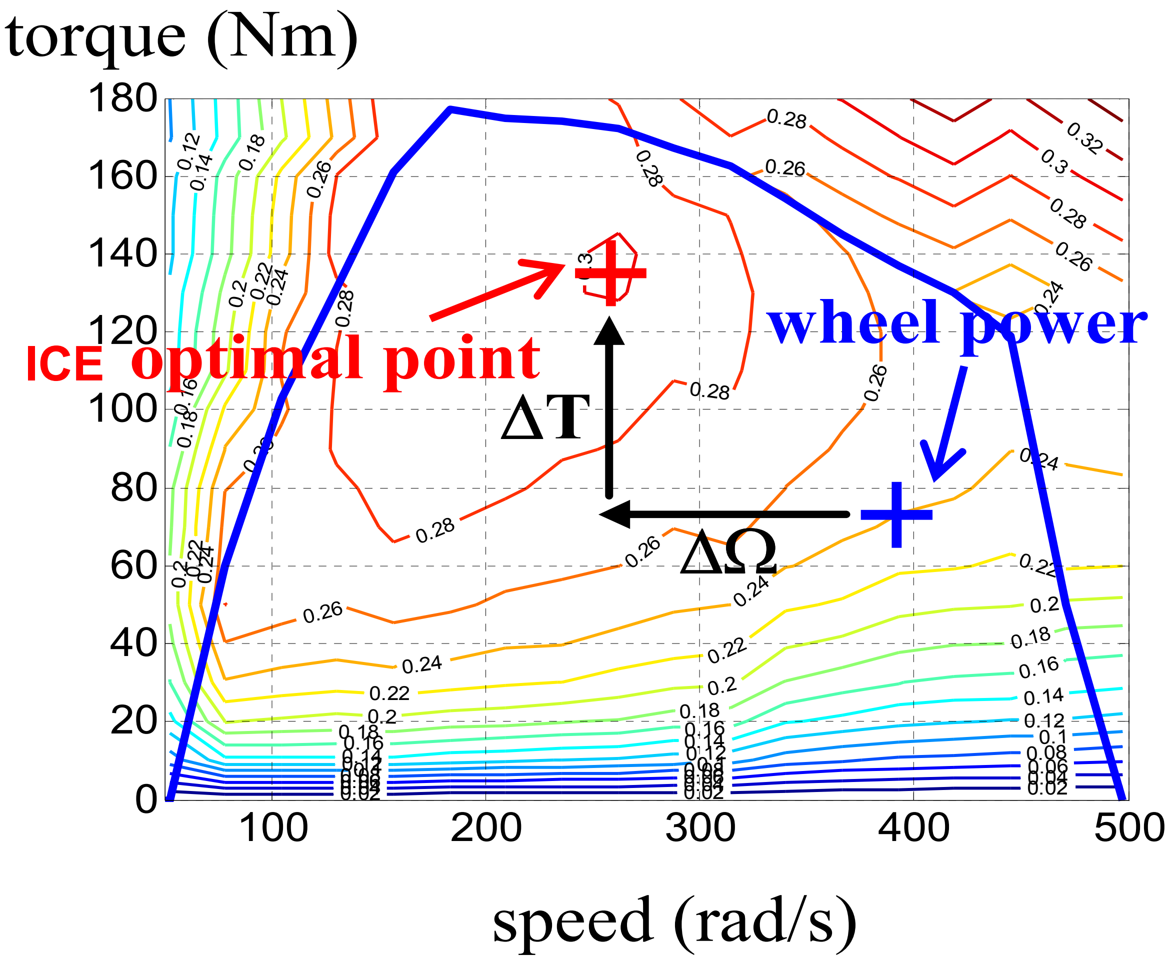
The control has to define all tuning variables to impose the desire velocity $v_{hev\text{-}ref}$


electric drive
belt
TC
CVT
wheel
chassis
battery
u bat
T em
i vsi
Ω blt
T blt
T tc
T cvt
F wh
F tot
v hev
Environ.
T em-ref
T ice
ICE
Ω tc
Ω cvt
Ω wh
v hev
v hev
F res
F bk
Ω ice
k tc
u cvt
brake
v hev
T ice-ref
F bk-ref
T blt-ref
T tc-ref
T cvt-ref
F wh-ref
F tot-ref
v hev-ref
k D2
k D1

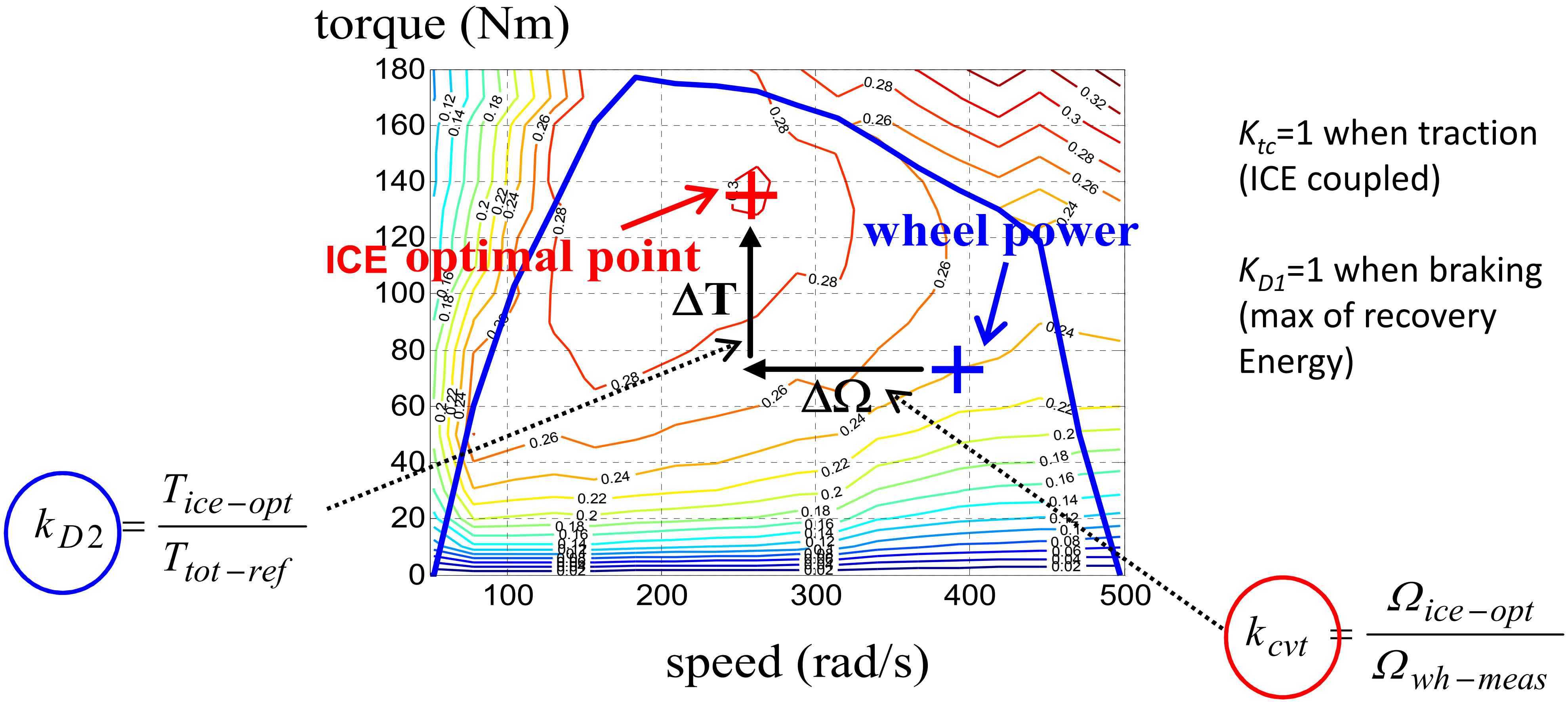
The strategy aims to reduce the fuel consumption by:

- the energy distribution between e-drive and ICE (k_{D2})
- the brake distribution between e-brake and m-brake (k_{D1})
- the choice of the CVT ratio (u_{cvt})
- the connection of the ICE (k_{tc})



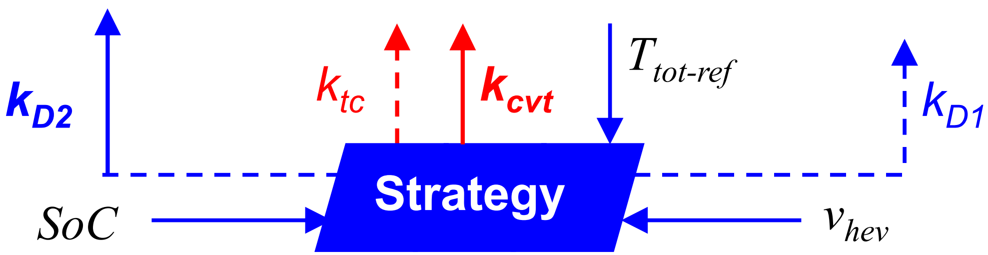


The strategy aims to put the ICE in its best consumption area

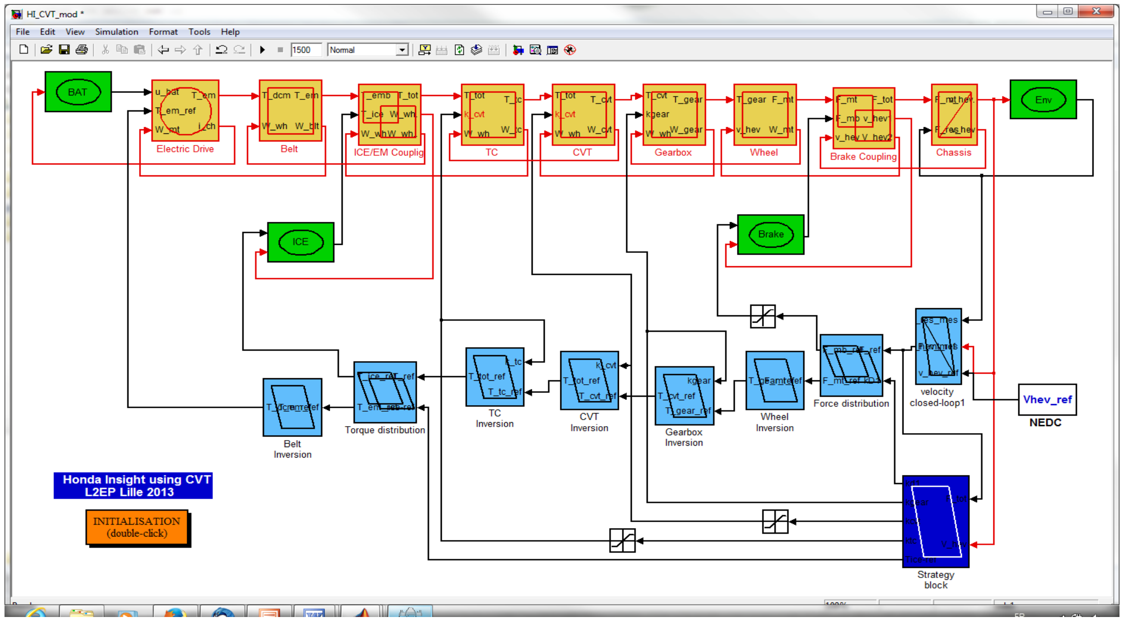


K_{tc}=1 when traction (ICE coupled)

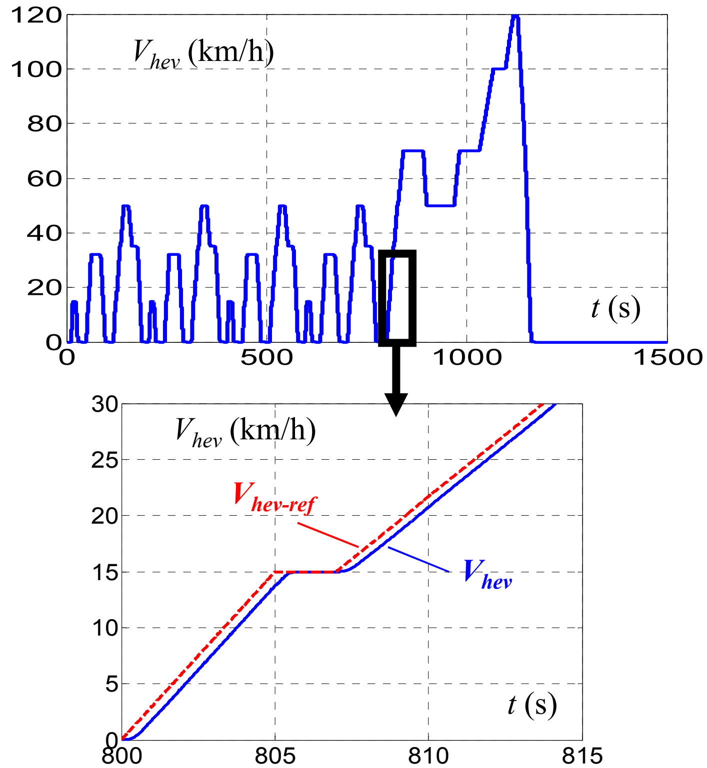
K_{D1}=1 when braking (max of recovery Energy)



Matlab-Simulink© + EMR Libary

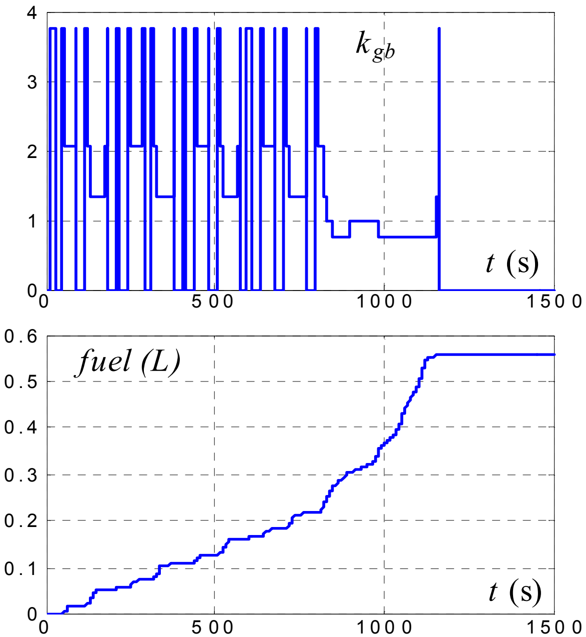


New European Drive Cycle



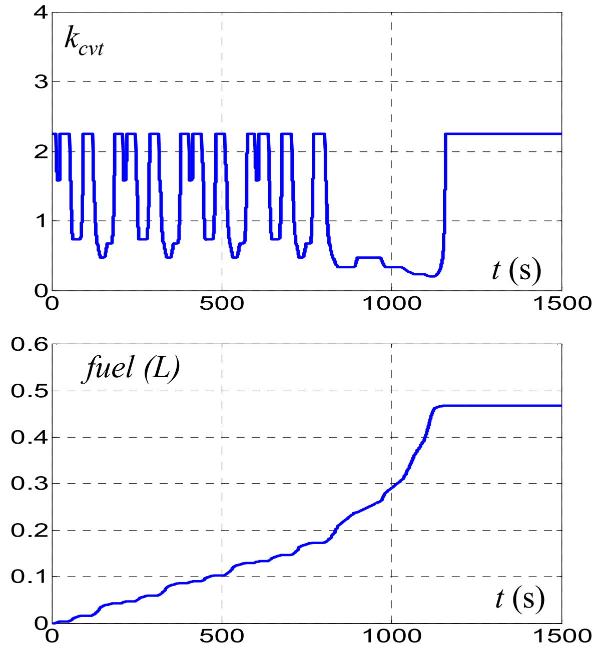
the requested velocity
is wheel achieved

Thermal vehicle with a 4-speed gearbox



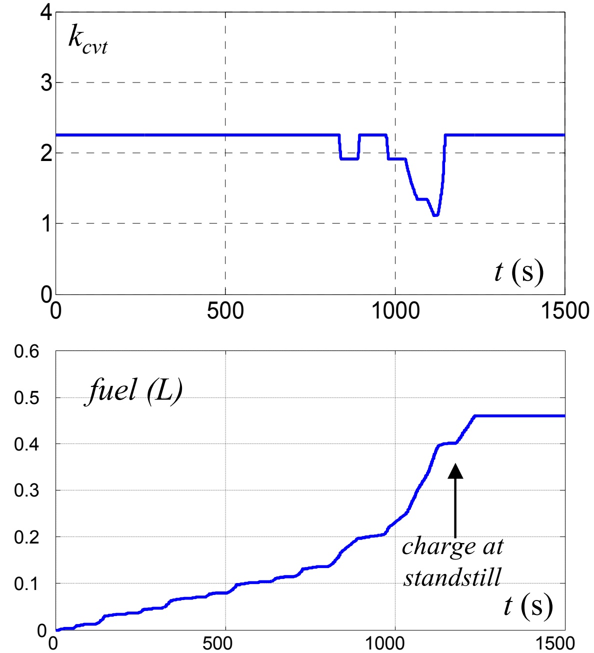
5.04 L/100 km

Thermal vehicle with CVT



4.32 L/100 km

Hybrid vehicle with CVT



4.018 L/100 km

but k_{CVT} often limited and recharge at standstill

CONCLUSION

- A CVT-based HEV is a complex vehicle to manage because of the high number of tuning variable to achieve the velocity by reducing the fuel consumption

- EMR and the deduced inversion-based control is a valuable way to organize the control of this complex vehicle

- The interest of the CVT has been demonstrated in term of fuel consumption but the gain between a CVT thermal vehicle and a CVT hybrid vehicle is not relevant using a rule-based strategy for energy management

⇩

A **optimal energy management** should now be used to develop a more efficient strategy and to improve the fuel saving for a CVT-based HEV

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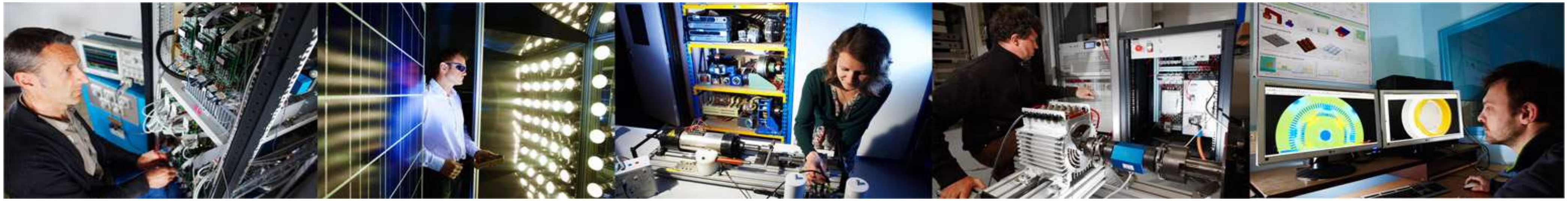

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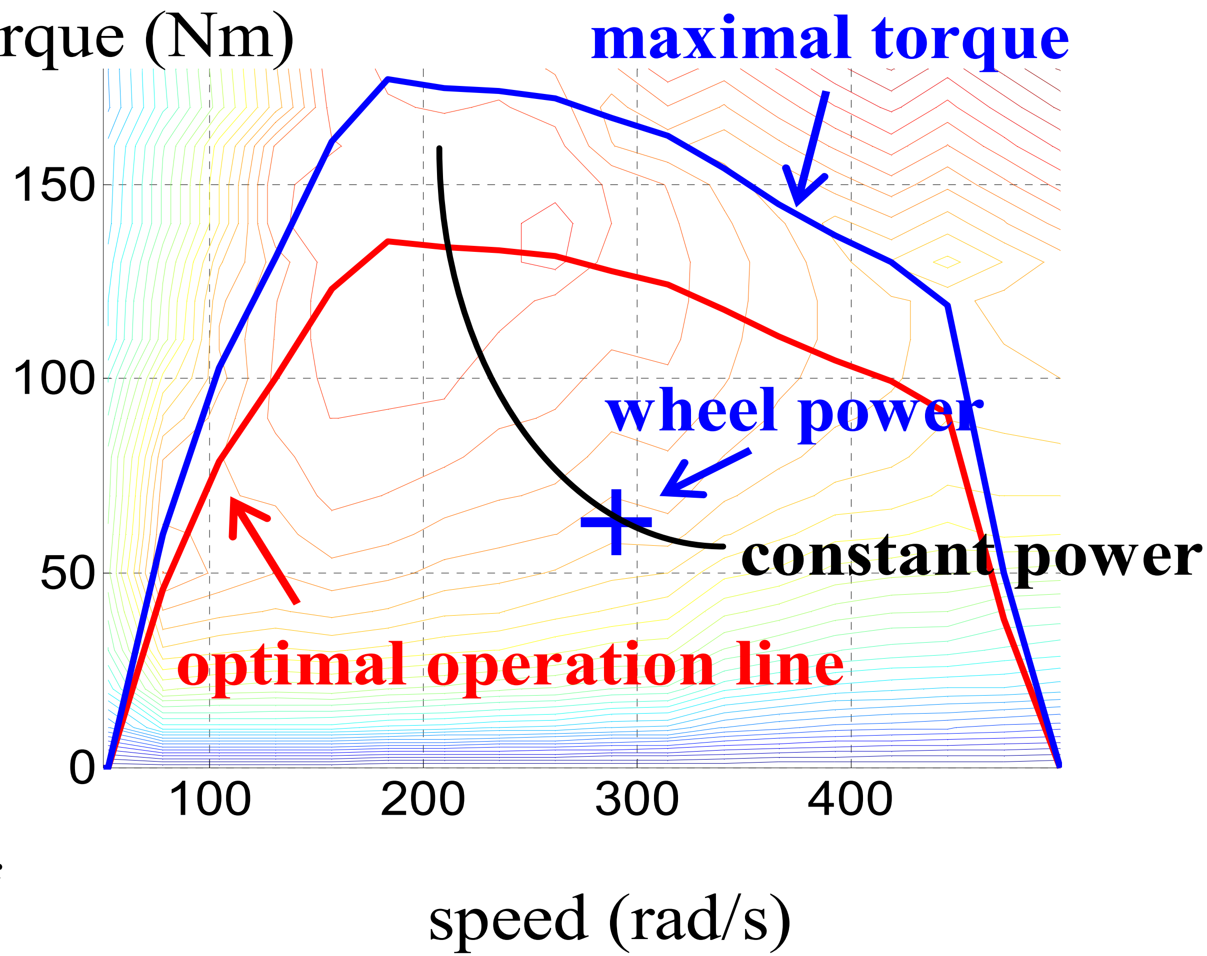

$$\begin{cases} T_{cvt} = k_{cvt}\eta_{cvt}^{j}T_{tc} \\ \Omega_{cvt} = k_{cvt}\Omega_{wh} \end{cases}$$

As a CVT can only act on torque ratio **OR** speed ratio,
the optimal operation line is the preferable operation line