EV2019

ELECTRIC VEHICLES INTERNATIONAL
CONFERENCE & SHOW

Powerful Advanced N-Level Digital Architecture
for models of electrified vehicles and their components

Workshop PANDA

Energetic macroscopic representation

Eduard-Edis RACLARU
Siemens Industry Software

SIEMENS
Ingenuity for life

www.project-panda.eu

Complex systems

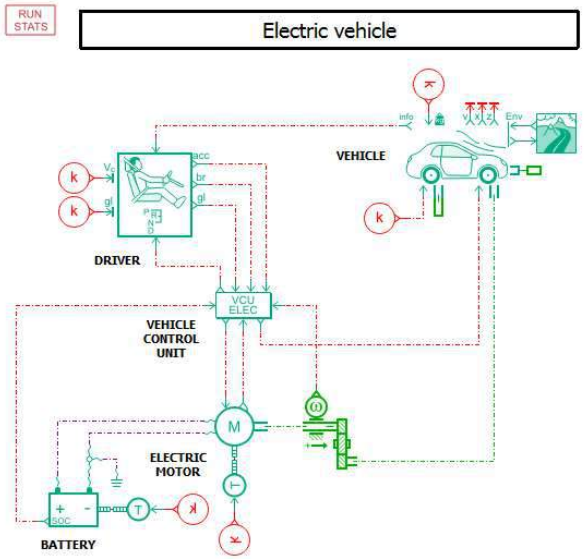
- Complex multi-physical systems : Electric vehicles

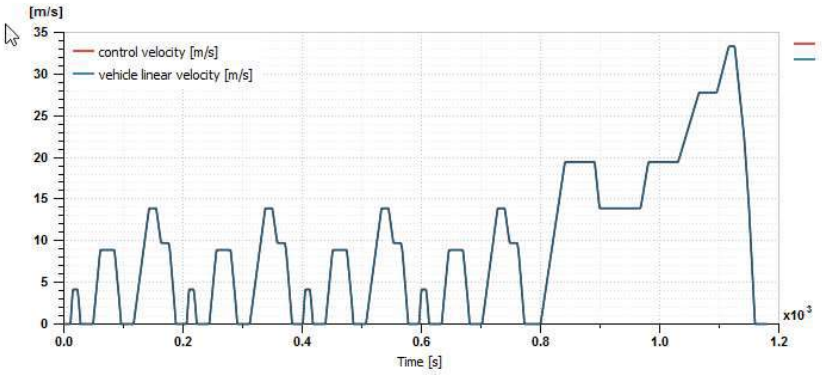
Renault Zoe powertrain
Credit: Renault

Renault Zoe
Credit: Renault

- How to manage the various power flows?
- How to optimize the energy consumption?

System simulation





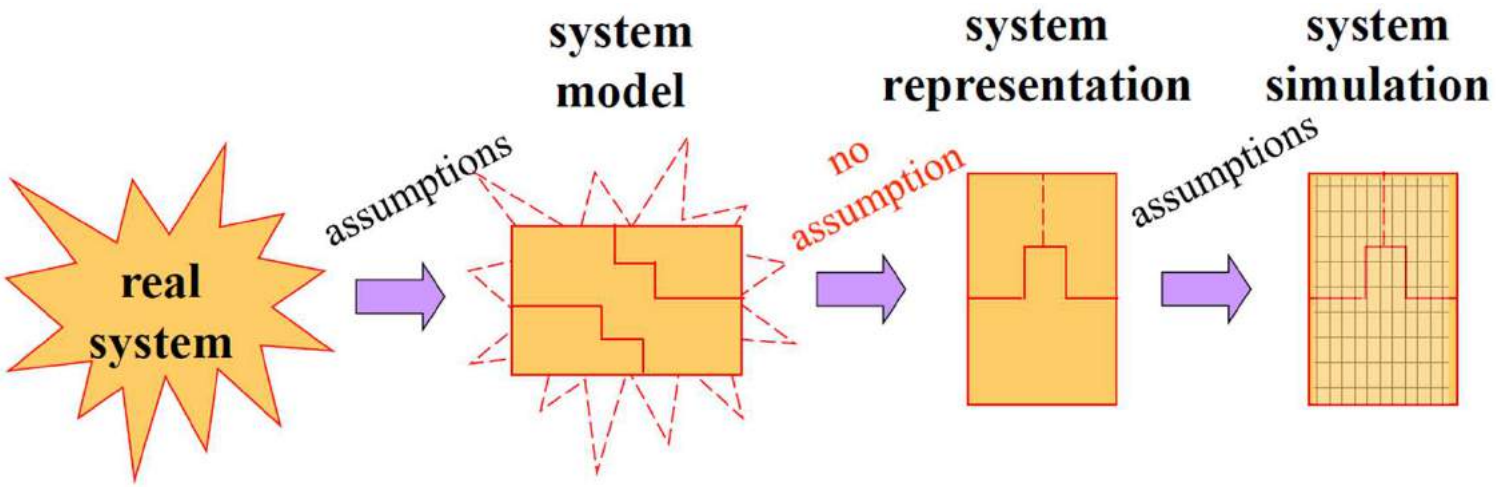
- How to build a performant and accurate simulation?
- How to reduce the development time?

Outline

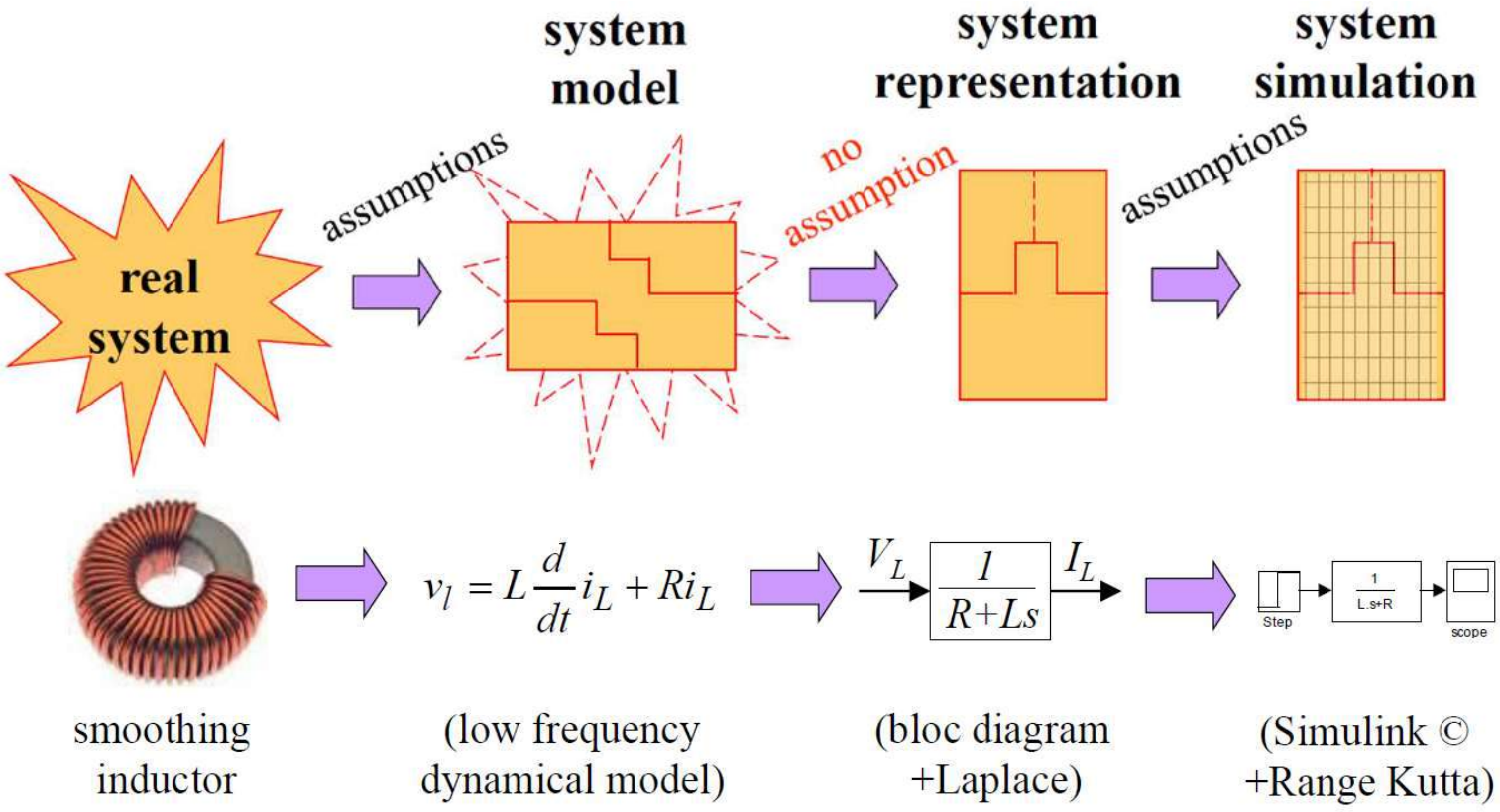
1. **Multi-physics systems**
2. **Energetic macroscopic representation**
3. **Control strategy based on the EMR**
4. **Conclusions**

« Multi-physics systems »

System, model, representation, simulation

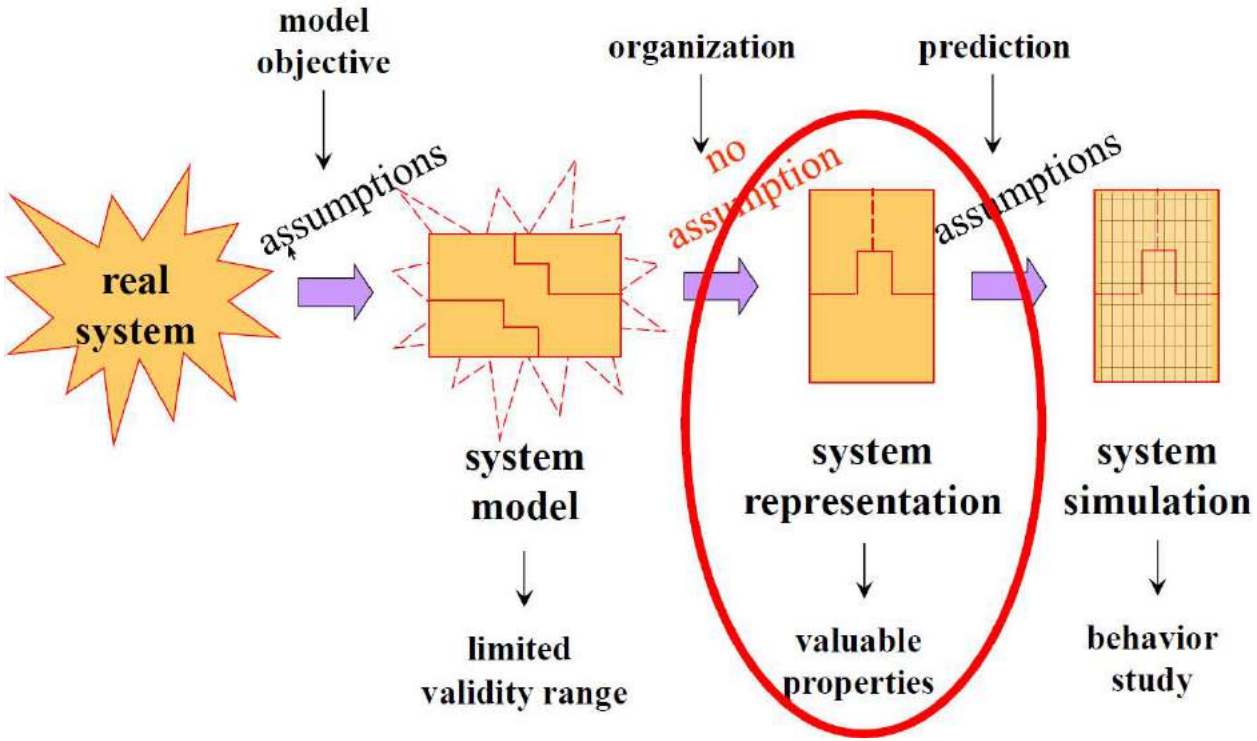


System, model, representation, simulation



Energetic macroscopic representation

EMR is a Graphical description / Model organization



Graphical system representations

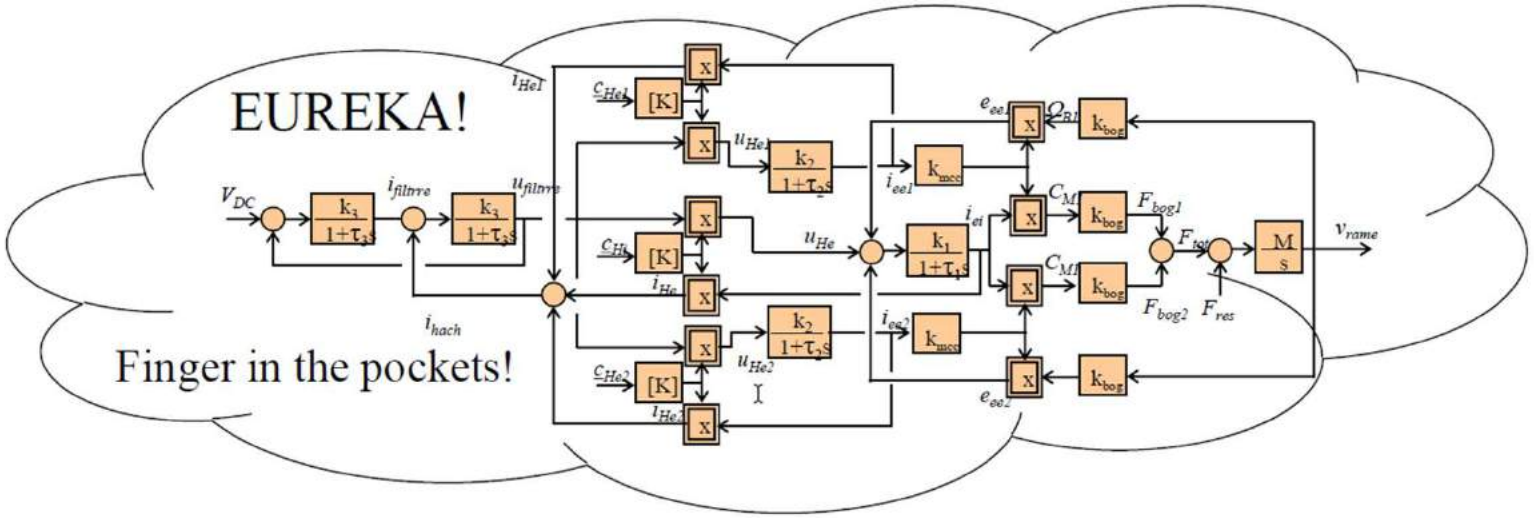
Structural descriptions for analysis and design:

- Bond graphs
- Power orientated graphs
- Signal flow diagrams

Functional descriptions for simulation and control:

- Block diagrams
- Causal orientated graphs
- Energetic macroscopic representation

Limitations of block diagrams



Block diagrams:

- Do not highlight energy properties.
- Do not highlight interactions between subsystems.
- Can be confusing for complex multi-physics systems.

Systems and interactions

How to structure complex multi-physics systems?

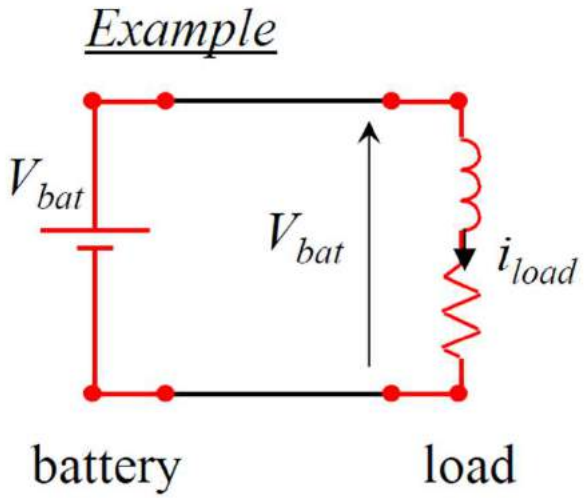
Renault Zoe powertrain
Credit: Renault

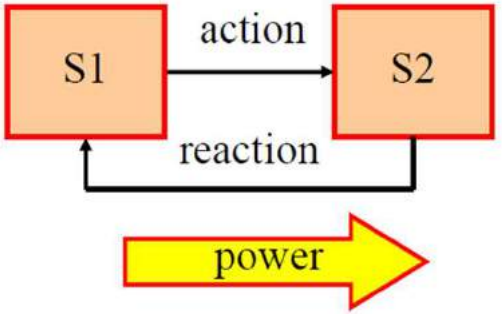
Renault Zoe
Credit: Renault

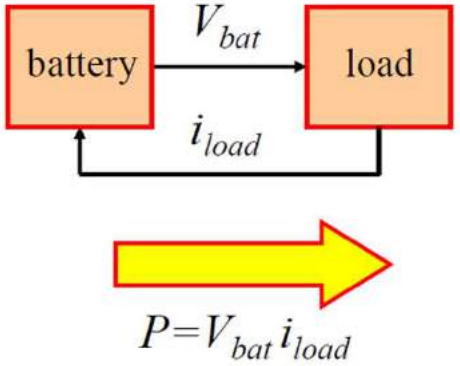
System = interconnected subsystems, organized for a common objective

Holistic property = new global property induced by association of subsystems

Physical interaction

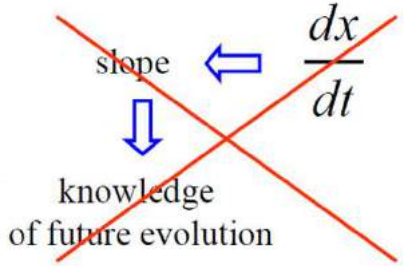


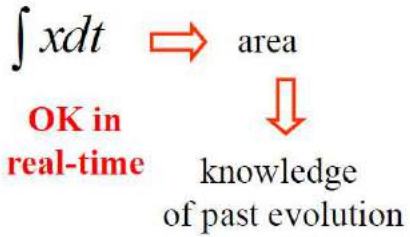




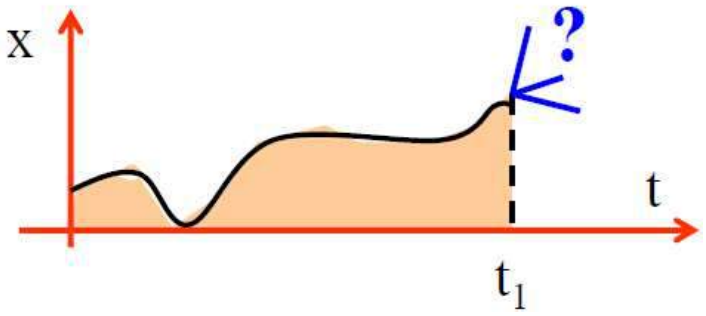
Energy and causality

Choice of input/output roles for the interconnection variables:



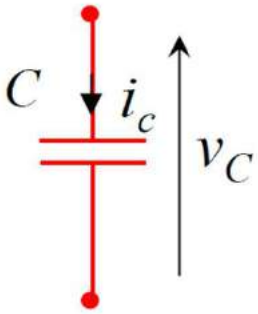


Physical causality integral.



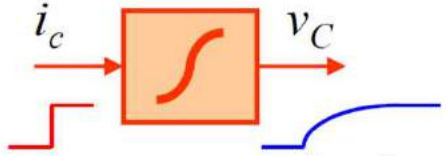
Energy and causality

Example:

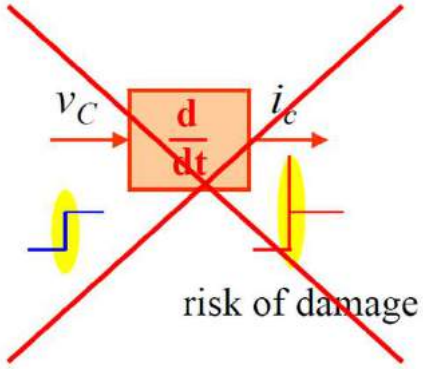


$$i_c = C\frac{d}{dt}v_c + \frac{v_c}{R}$$

$$E_c = \frac{1}{2}v_c^{\,2}$$



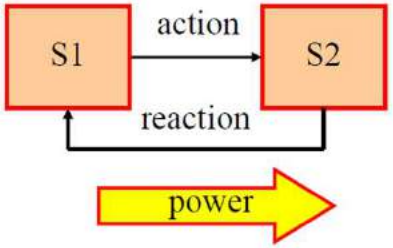
delay
no energy disruption



risk of damage

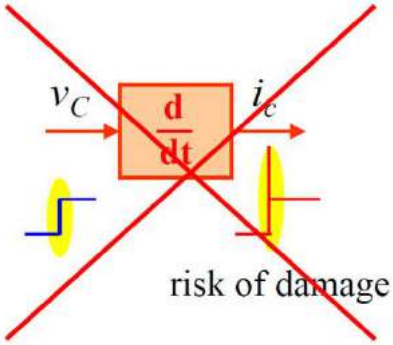
EMR

- Highlights energy properties.



- Highlights interaction between systems.

- Respects physical causality.



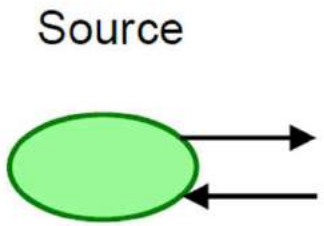
« Energetic macroscopic Representation »

EMR basic elements

EMR uses only 4 functions to describe energy conversion systems:

- Energy sources.
- Energy accumulation.
- Energy conversion.
- Energy distribution.

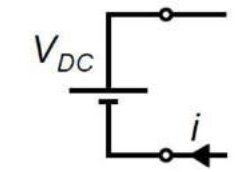
Energy sources

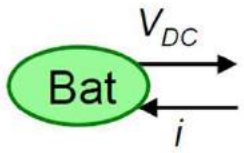


Terminal element which represents the environment of the studied system.

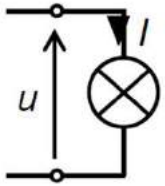
Generator and/ or receptor of energy

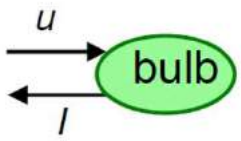
Example: Voltage source





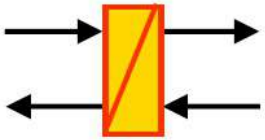
Lightning bulb





Accumulation elements

Accumulator

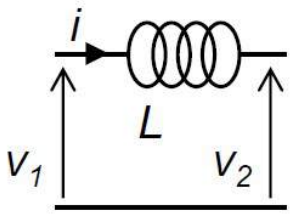


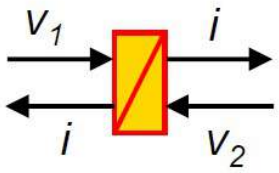
Internal accumulation of energy
(with or without losses)

Output(s) = Integral Input(s)

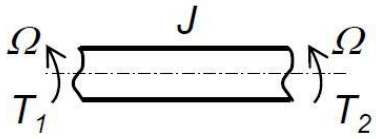
Fixed I/O (causal description)

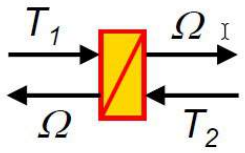
inductor



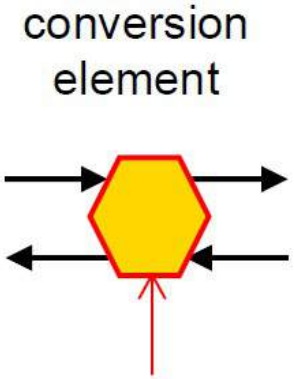


inertia





Energy sources

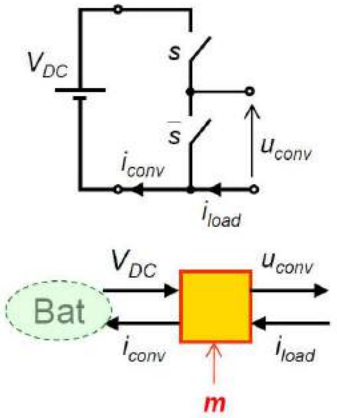


Conversion of energy without accumulation (with or without losses)

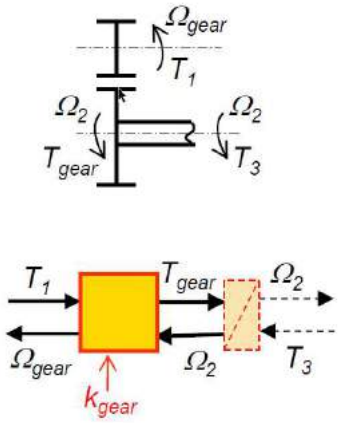
I/O can be permuted (floating I/O)

Possible tuning input variable

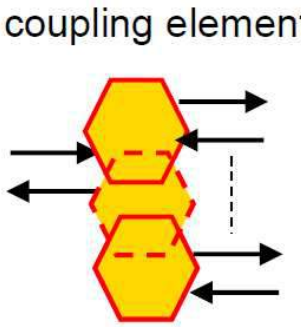
Chopper



Gearbox



Energy sources



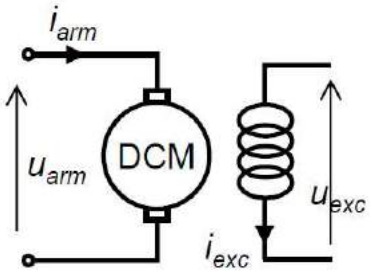
Distribution of energy

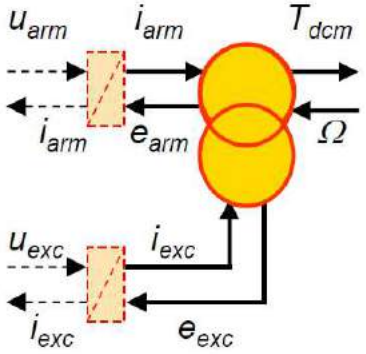
without energy accumulation,

without tuning variable,

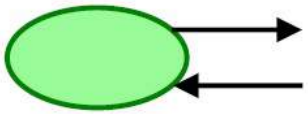
with or without losses

Field winding DC machine

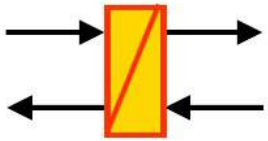




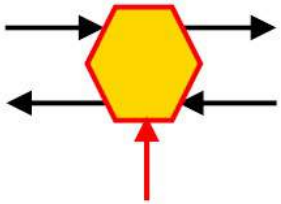
EMR properties



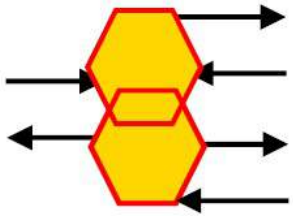
Energy source



Energy accumulation



Energy conversion (potential tuning)



Energy distribution

The diagram of the entire system is made by interconnecting the components.

- Highlight energetic functions
- All elements are connected by action/reaction (power link) (systemic approach)
- All power I/O are defined by accumulation elements (causality)
- Only conversion elements can have tuning inputs

⇩

Valuable for control design

« Control strategy based on the EMR »

Control strategy based on the EMR

How operate for performance (speed, comfort)?

How to efficiently manage different power flows?

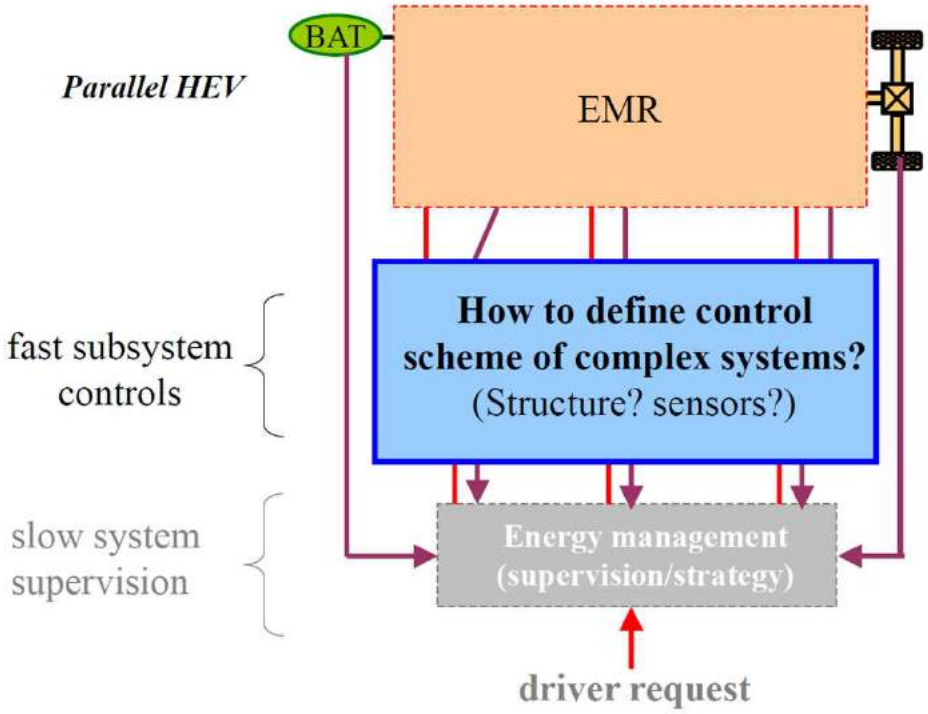
} Multi-objective control

Control strategy based on the EMR

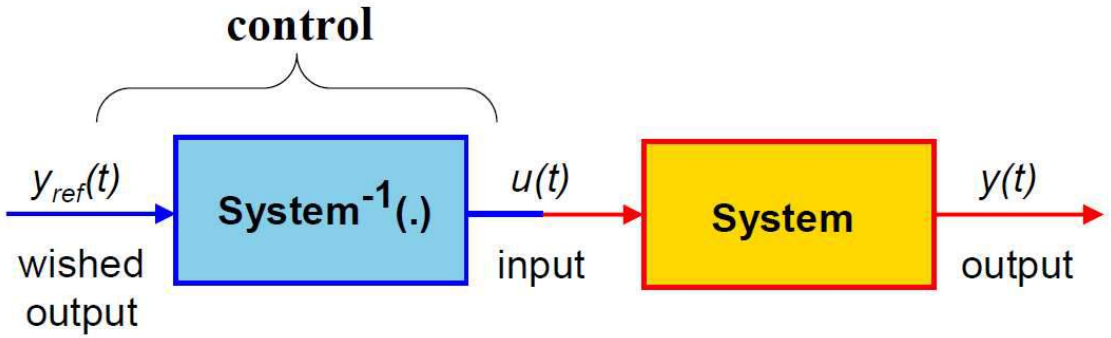
How operate for performance (speed, comfort)?

How to efficiently manage different power flows?

Hierarchical control



Open-loop control

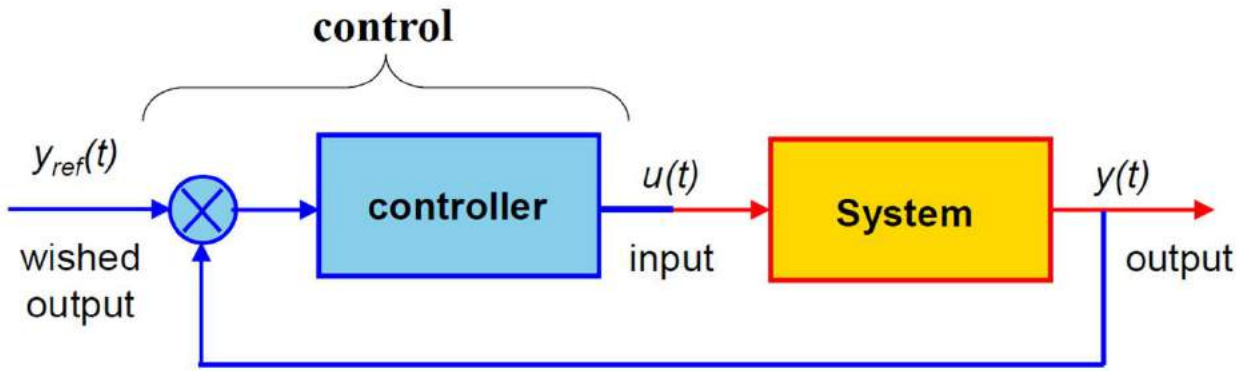


Not appropriate for plant control, if used by its own.

Could prove to be efficient, when used in combination with closed-loop control.

Helpful for linearizing nonlinear systems.

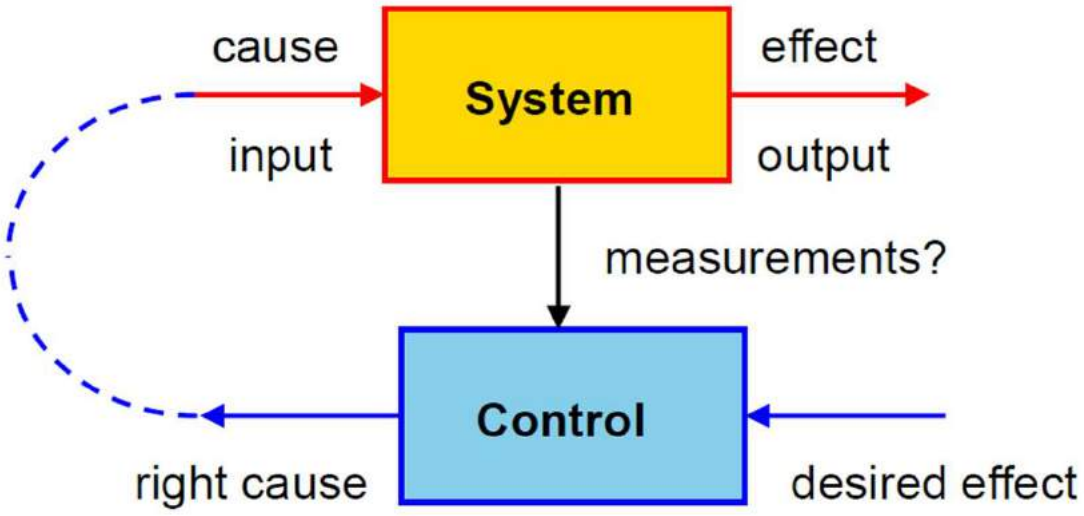
Closed-loop control



Control objectives:

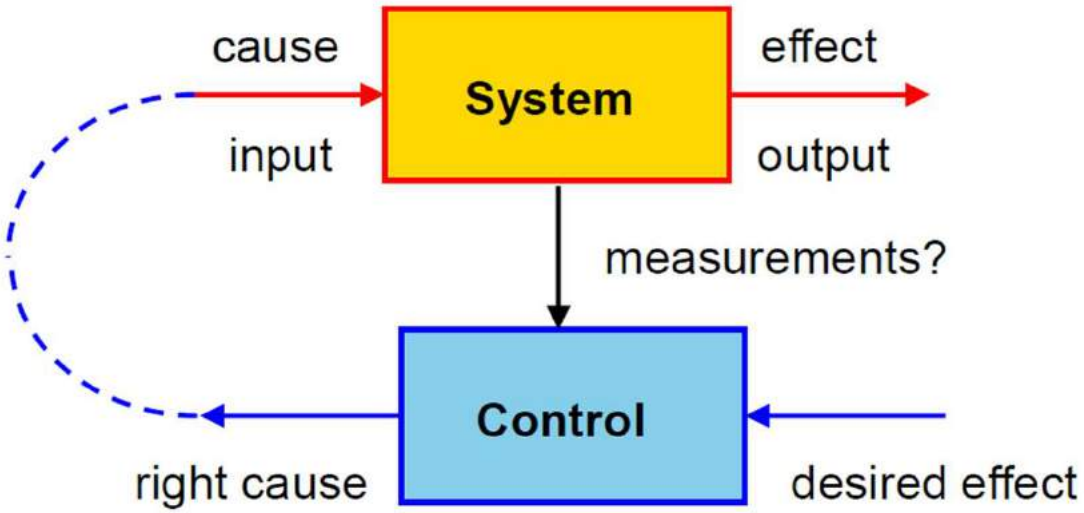
- Ensure stability
- Track references
- Reject disturbances
- Handle model uncertainties

Inversion based control (principle)



control = inversion of the causal path

Inversion based control (principle)

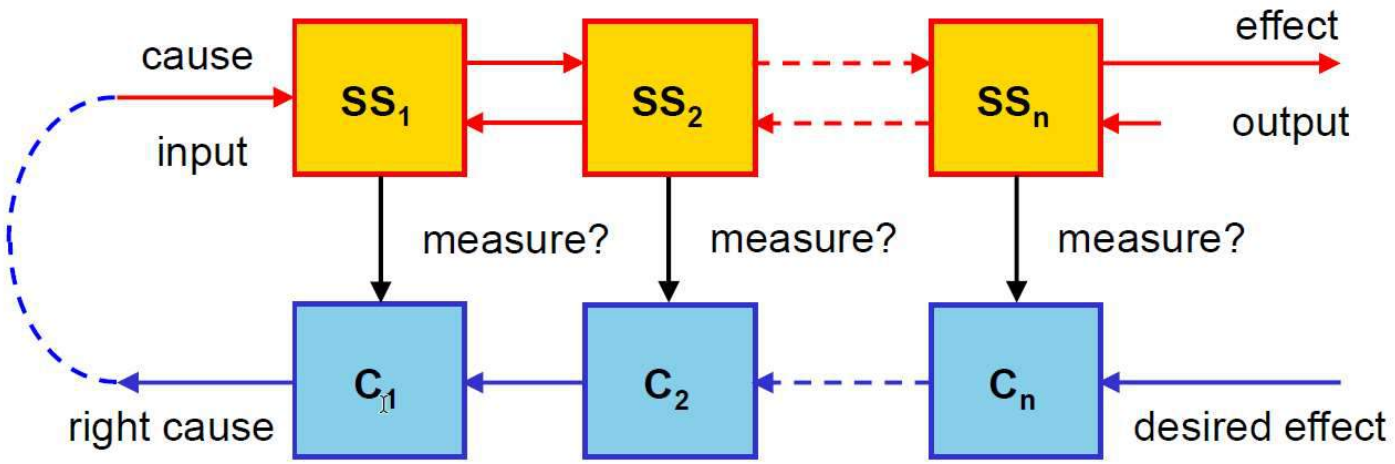


control = inversion of the causal path

Which control structure?

Which variables to measure?

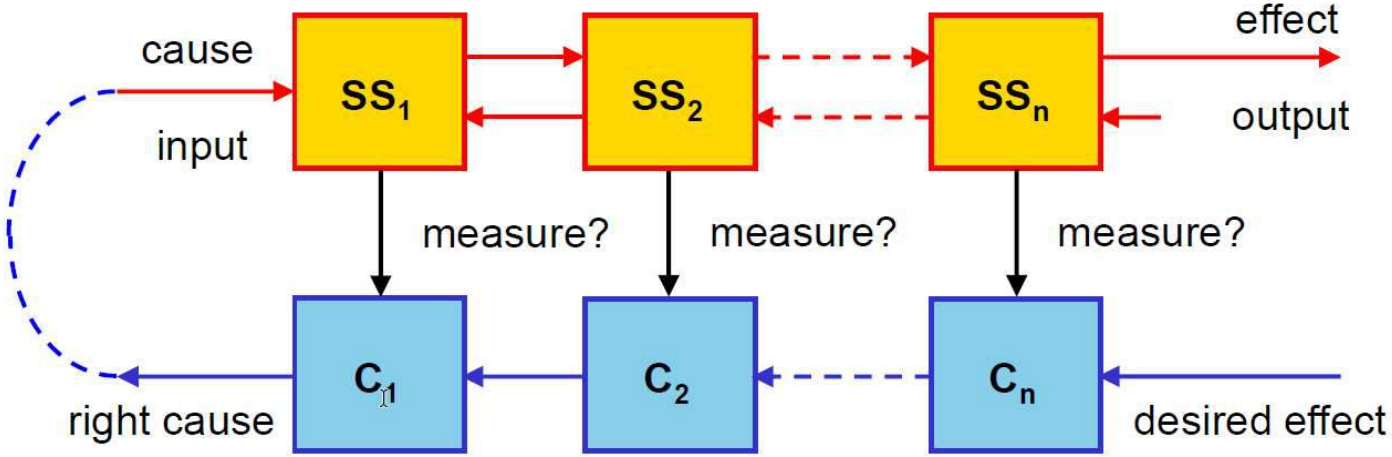
EMR properties



Systemics approach (EMR): look at the structure of the system.

Construct a reference signal chain for the causal path (cascaded control) step by step.

EMR properties



Inversion based control: systematic inversion of each subsystem using open-loop and closed-loop control.

Divide and conquer!

When to use open-loop or closed-loop control?

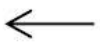
Which variables to measure?

Inversion of EMR elements

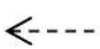
direct inversion

indirect inversion

sensor

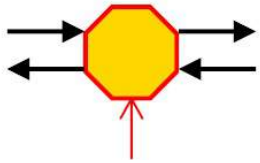


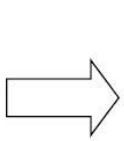
mandatory link



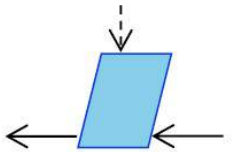
facultative link

conversion element

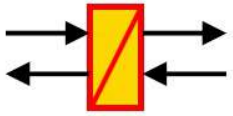


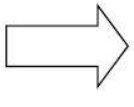


direct inversion + disturbance rejection

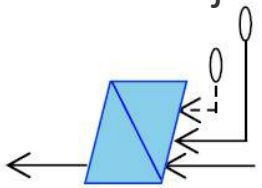


accumulation element

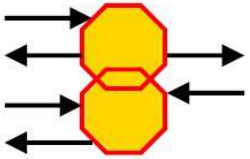


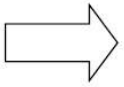


controller + disturbance rejection

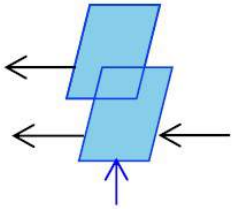


coupling element

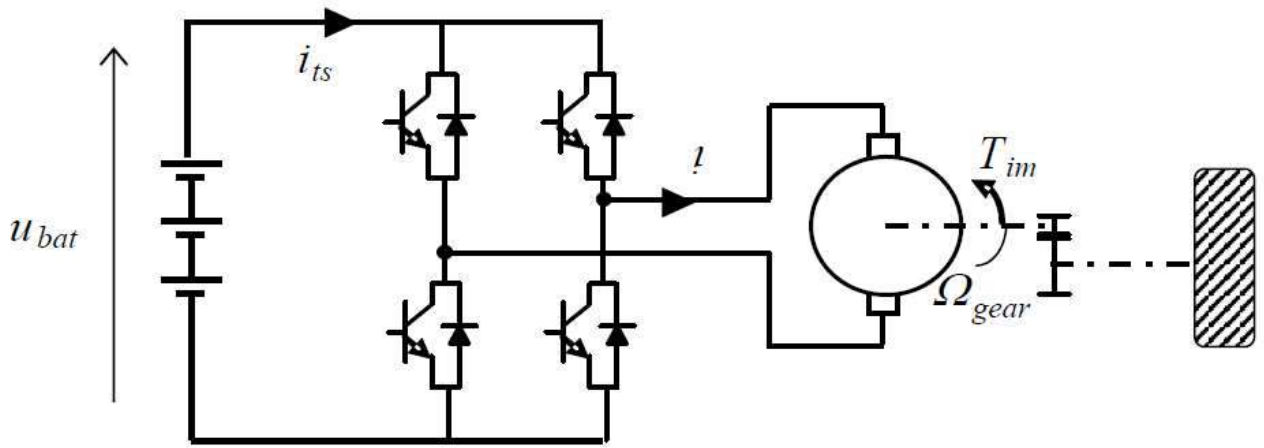




distribution criteria

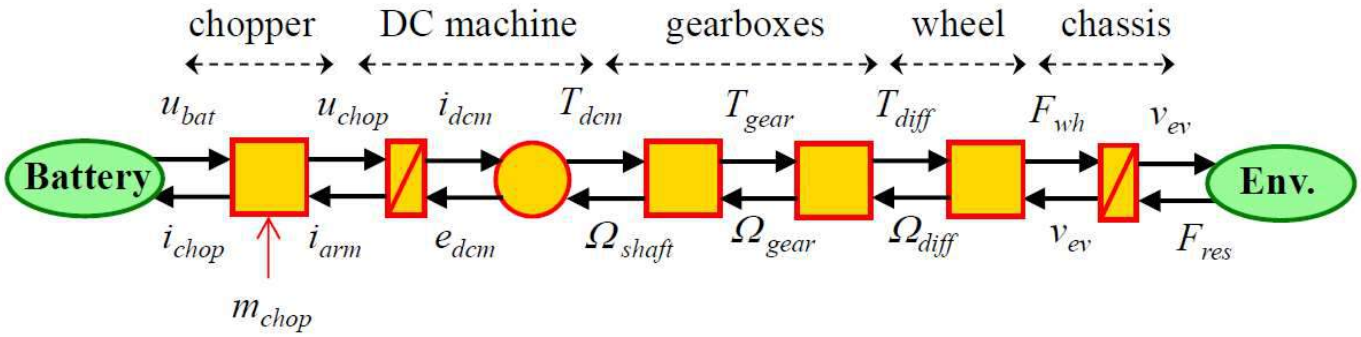


Electric vehicle example



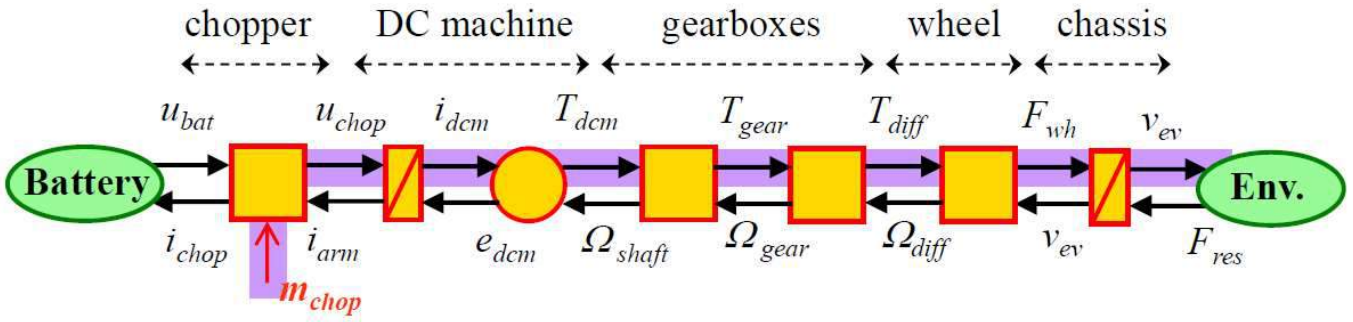
Electric vehicle example

1. EMR of the system



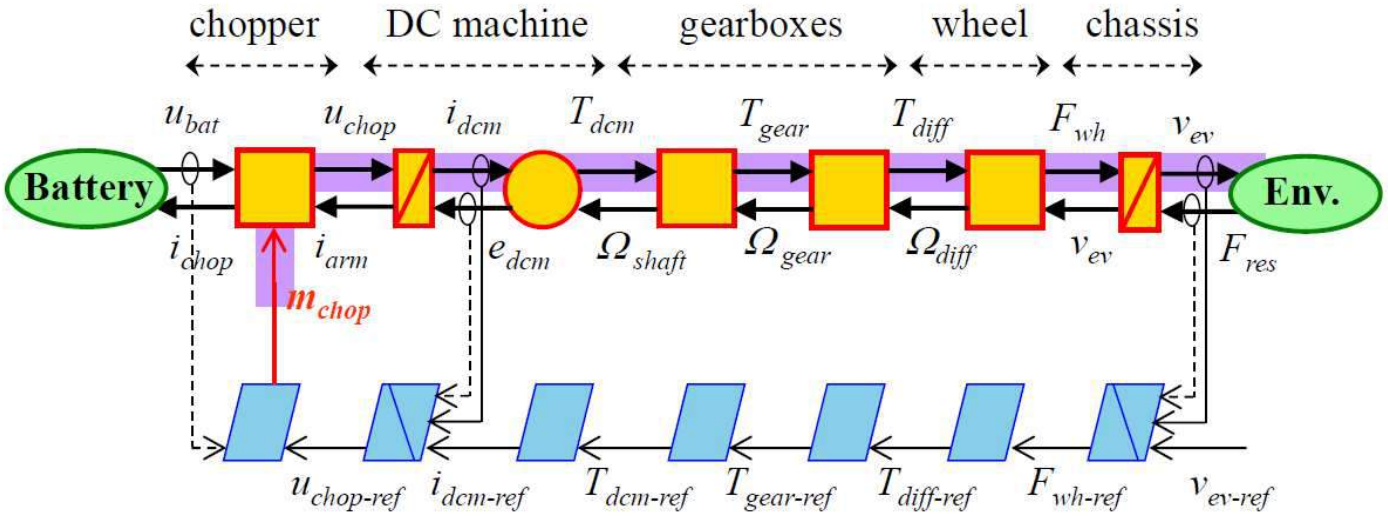
Electric vehicle example

1. EMR of the system
2. Tuning path



Electric vehicle example

1. EMR of the system
2. Tuning path
3. Inversion-based control



« Conclusions »

Conclusions

- Better analysis of simulation results, e.g. than with block diagram, for multi-physics systems.
- Helpful for clients to model/test/design etc., their products.
- Supports efficient energy use designs according to customer specifications.
- Provides a distributed (cascaded) control strategy for complex systems.

« BIOGRAPHIES AND REFERENCES »

References

[1] A. Bouscayrol, J.-P. Hautier, and B. Lemaire-Semail, “Graphic formalism for the control of multi-physiscal energetic systems: COG and EMR,” in *Systemic Design Methodologies for Electrical Energy Systems*, New York, NY, USA, Wiley, ch. 3 2012.
[2] J.P. Hautier, P.J. Barre, « The causal ordering graph – A tool for modeling and control law synthesis”, *Studies in Informatics and Control Journal*, vol. 13, no. 4, pp. 265-283, 2004.
[3] EMR. [Online], available: http://www.emrwebsite.org/

End of presentation

www.project-panda.eu

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824256.