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Multi-scale modeling of a high performance fuel cell powered highway bus

Marion Georges
Liangfei Xu
Bingkun Cai
Jiayi Hu
Jianqiu Li
Minggao Ouyang

CentraleSupélec

Tsinghua University

Powertrain Control Research Group

School of Vehicle and Mobility
Powertrain System Research Group

Professor
Liangfei Xu

Professor
Jianqiu Li

Professor
Minggao Ouyang

2004-2011
Exploration and demonstration

EXPO 2010 SHANGHAI CHINA
FOTON
UNDP
Beijing 2008
Singapore 2010

1st Gen fuel cell engine

2012-2015
Technological breakthrough

2st Gen fuel cell engine

2016~
Early commercialization

YUTONG
FOTON
GOLDEN DRAGON 金旅客车
DFM
ZEV

3st Gen fuel cell engine

2017
New generation fuel cell engine

3st Gen fuel cell engine

Fuel cell engine from Tsinghua-Sinohytec

亿华通 SinoHytec

清華大學 Tsinghua University

清華大學 Tsinghua University
Powertrain Control Research Group

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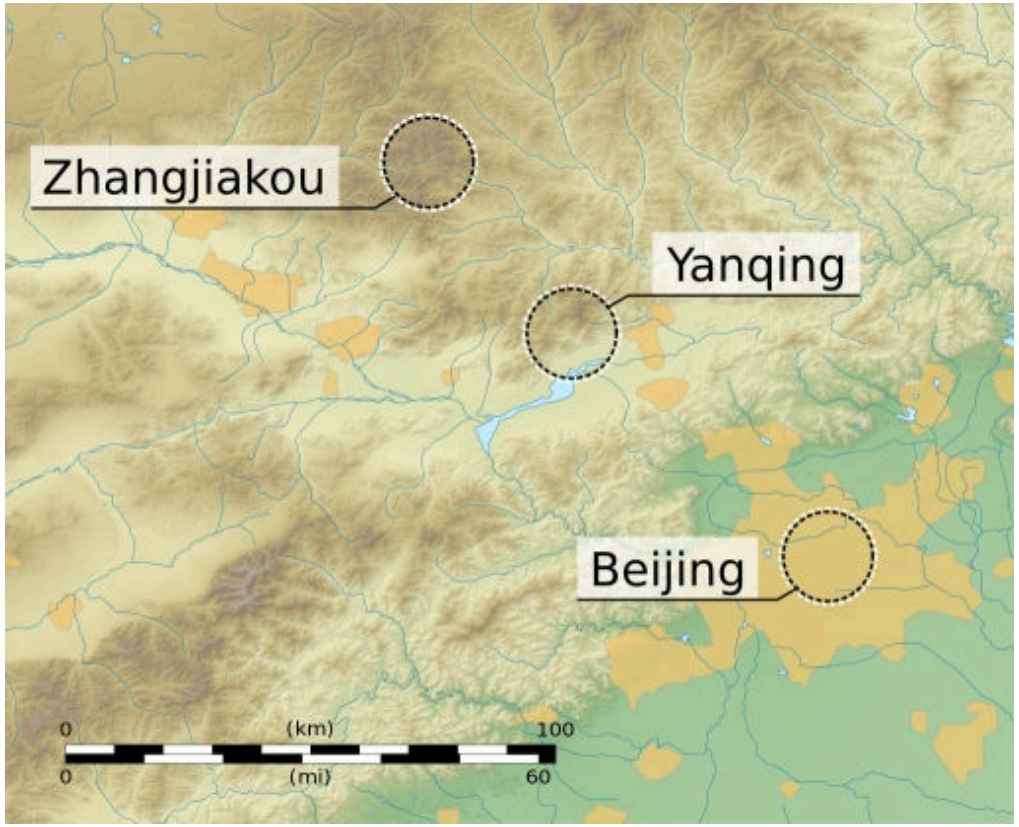
Background

An intercity transportation

Bus prototypes for 2022 Beijing Olympic Games

- Longer mileage (500km)
- Higher speed (100km/h)
- Better climbing ability (max 20%)
- Starting up at lower temperature (-30°C)

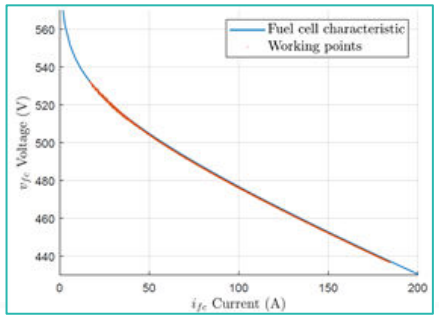
80kW polymer electrolyte membrane fuel cell engine

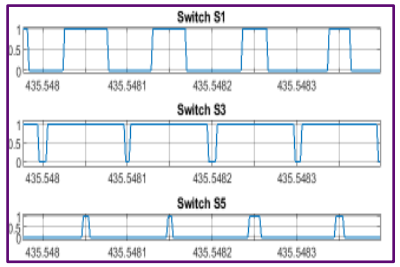


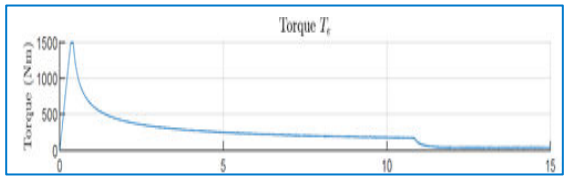
亿华通 SinoHytec

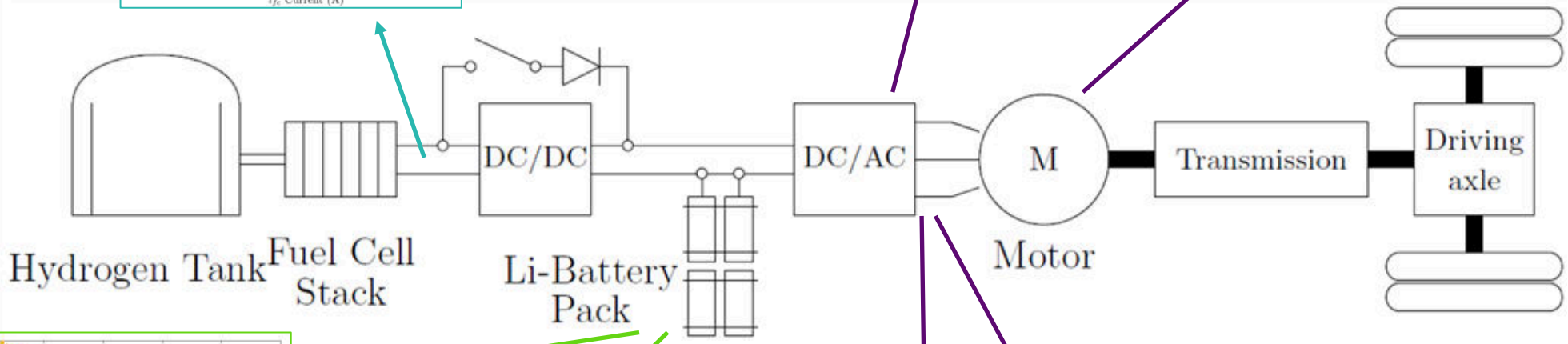
Modeling

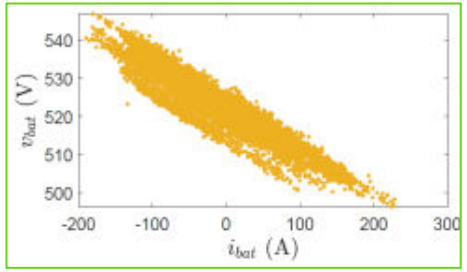
Matlab
Simulink

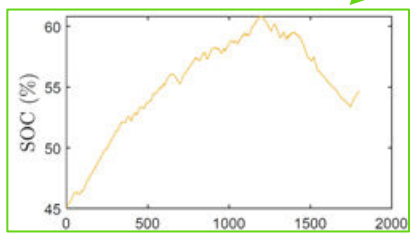


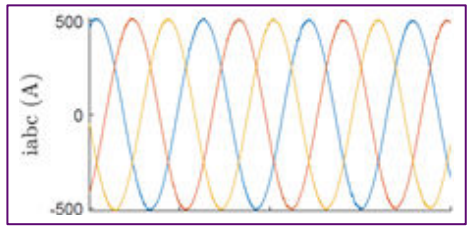


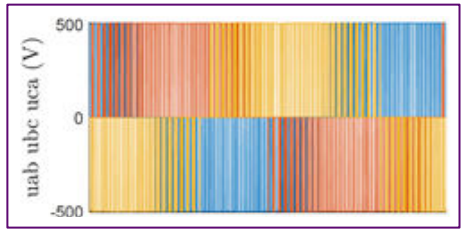






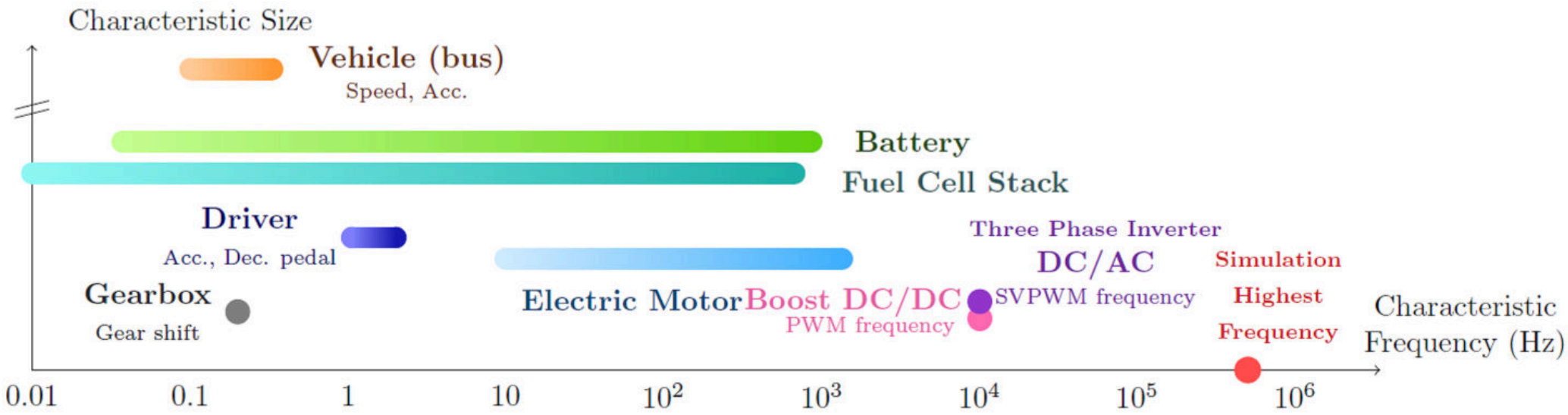




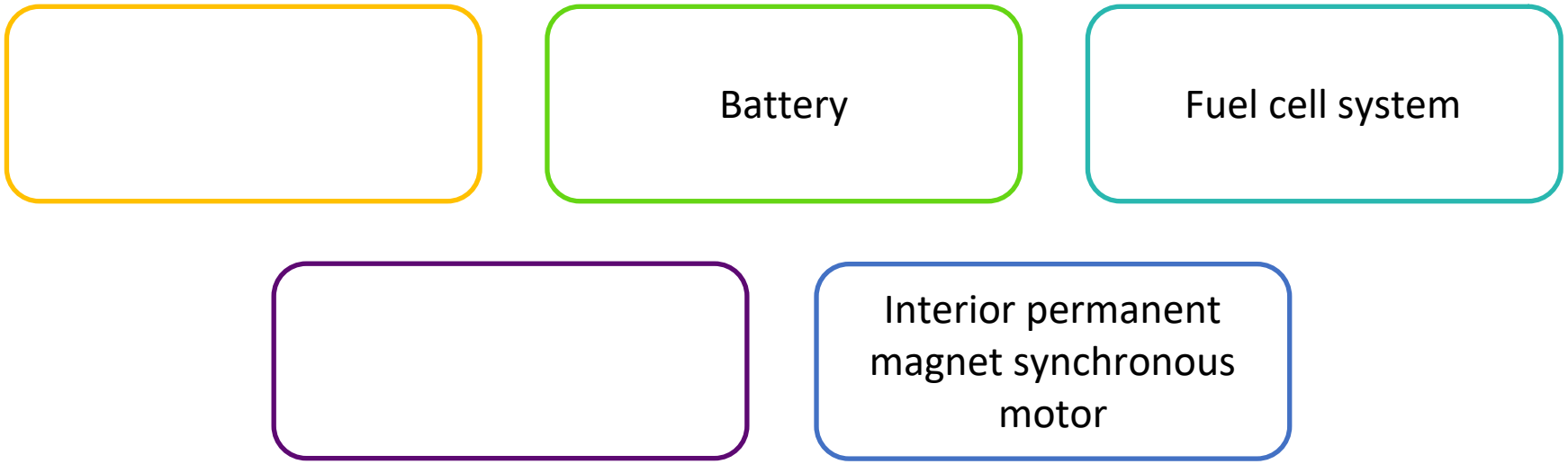


Objective

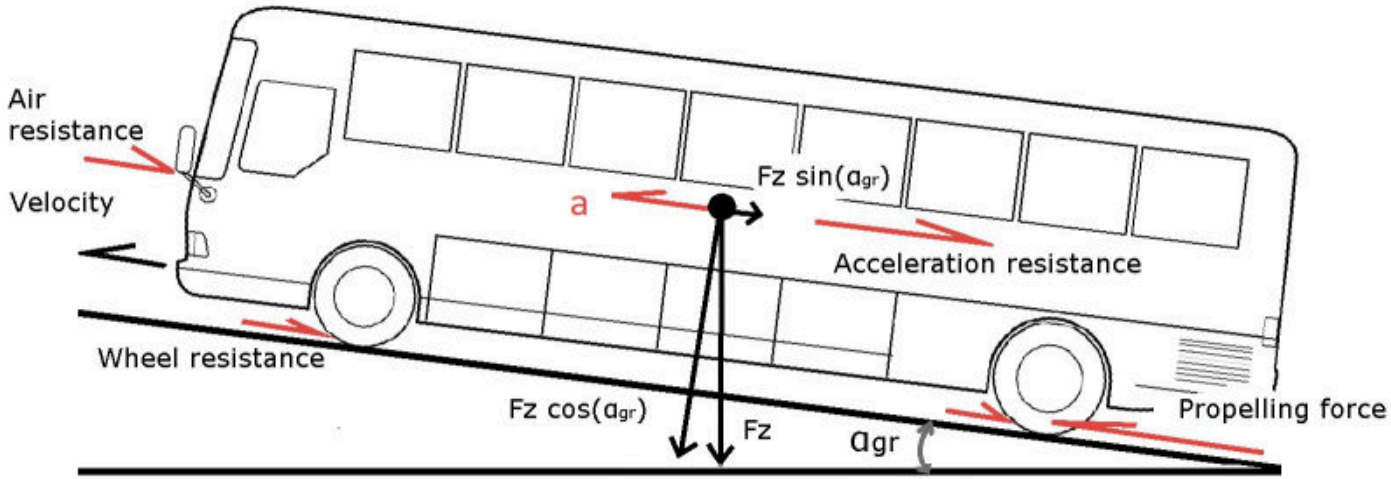
Several scales : several sizes, several frequencies



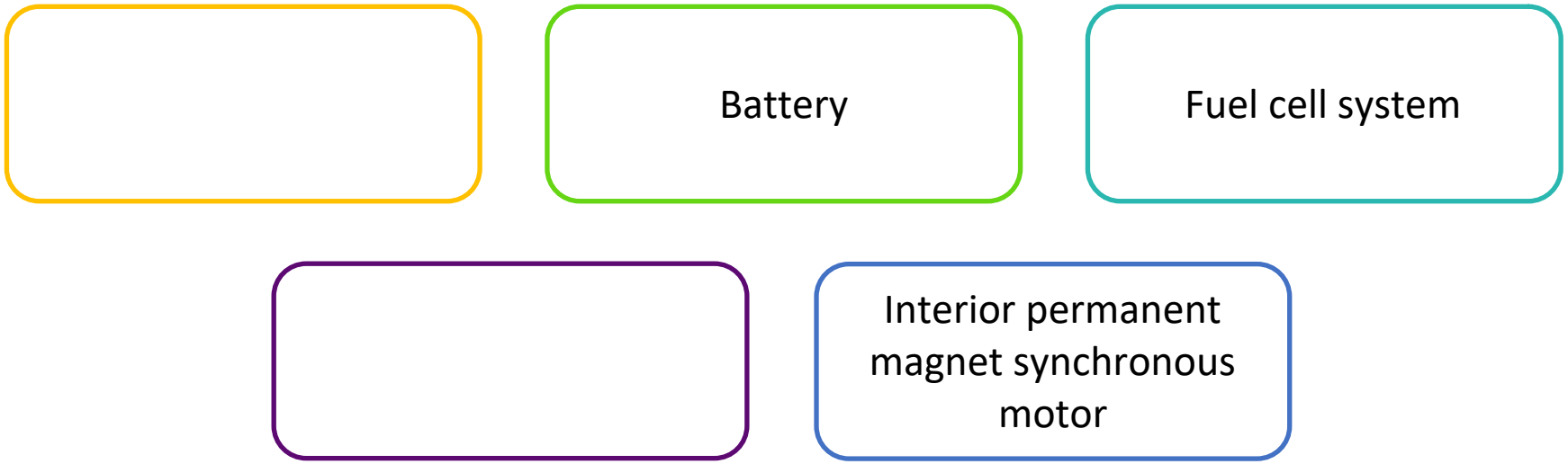
System and models



System and models

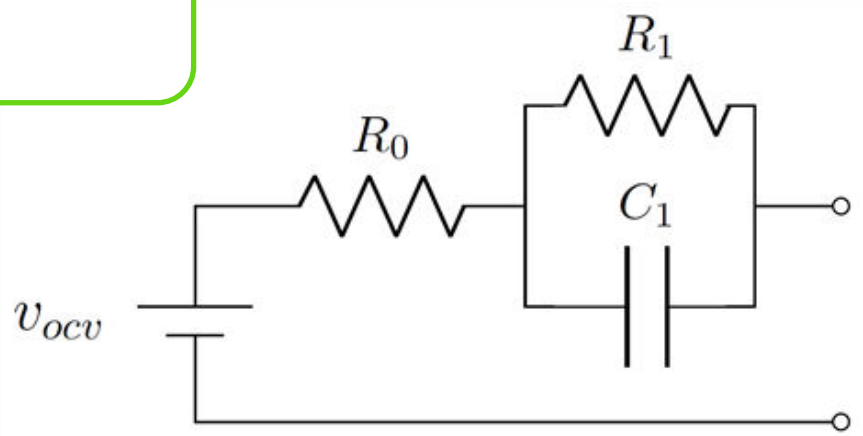


System and models



System and models

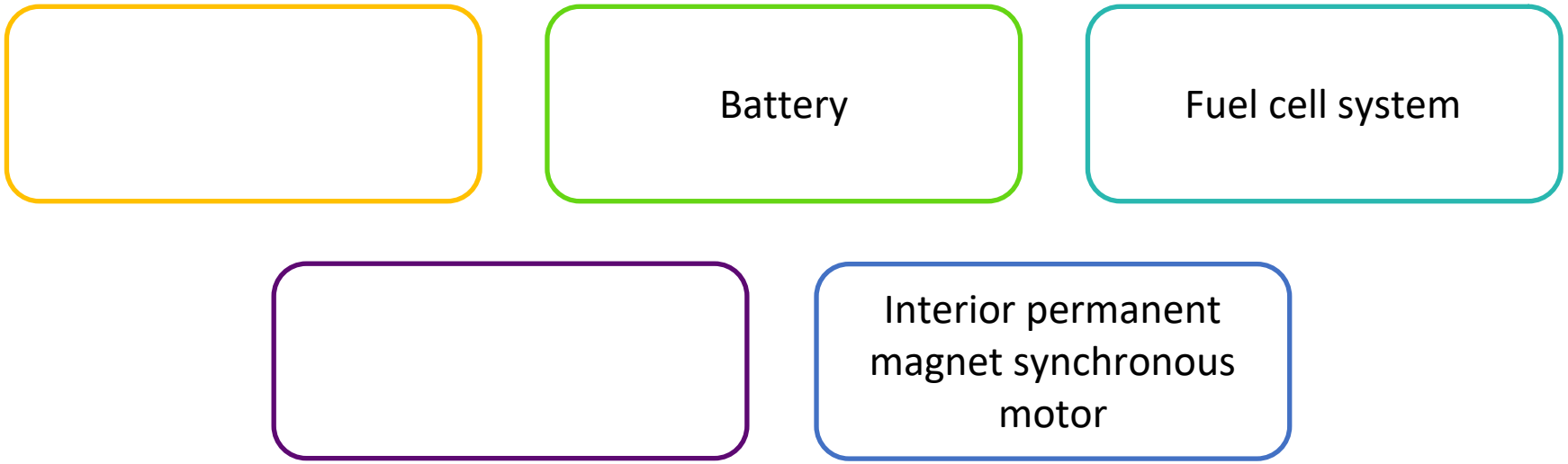
Battery



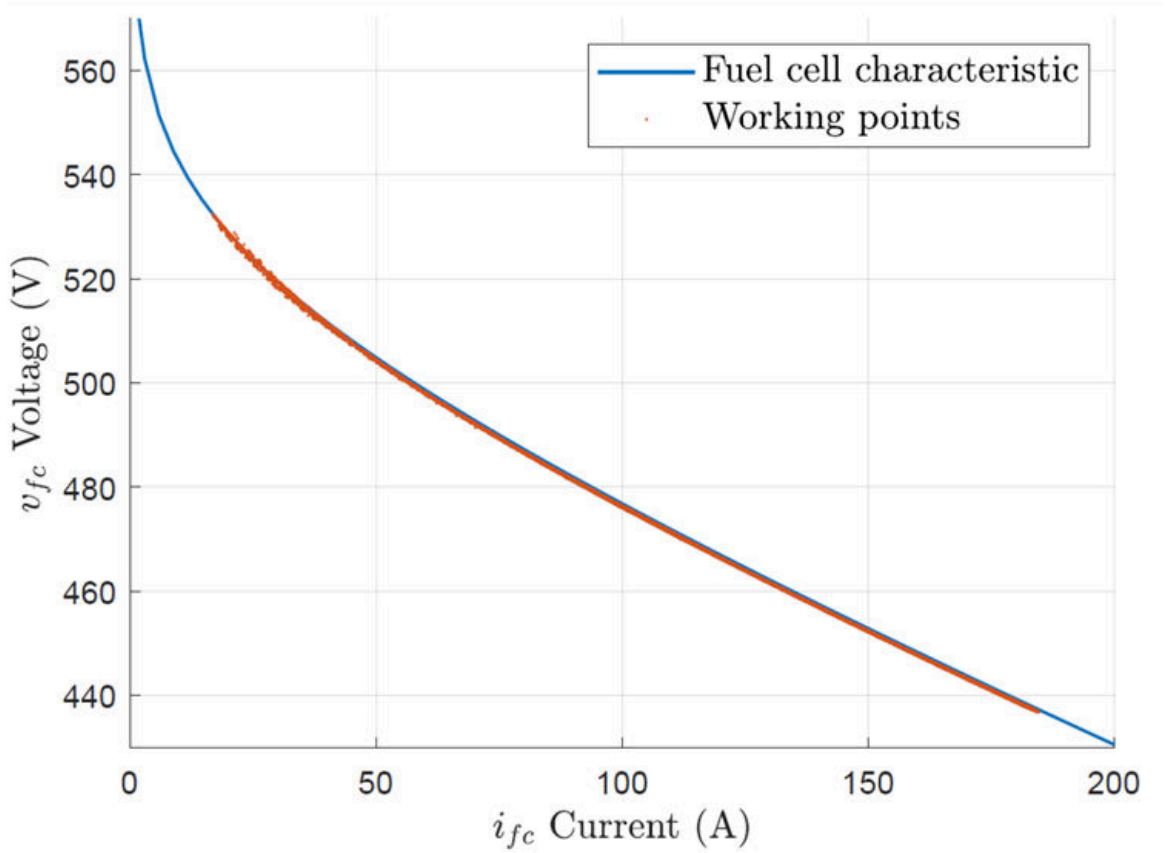
1st order Thevenin battery model

look up tables for v_{OCV}, R_0, R_1, C_1

System and models

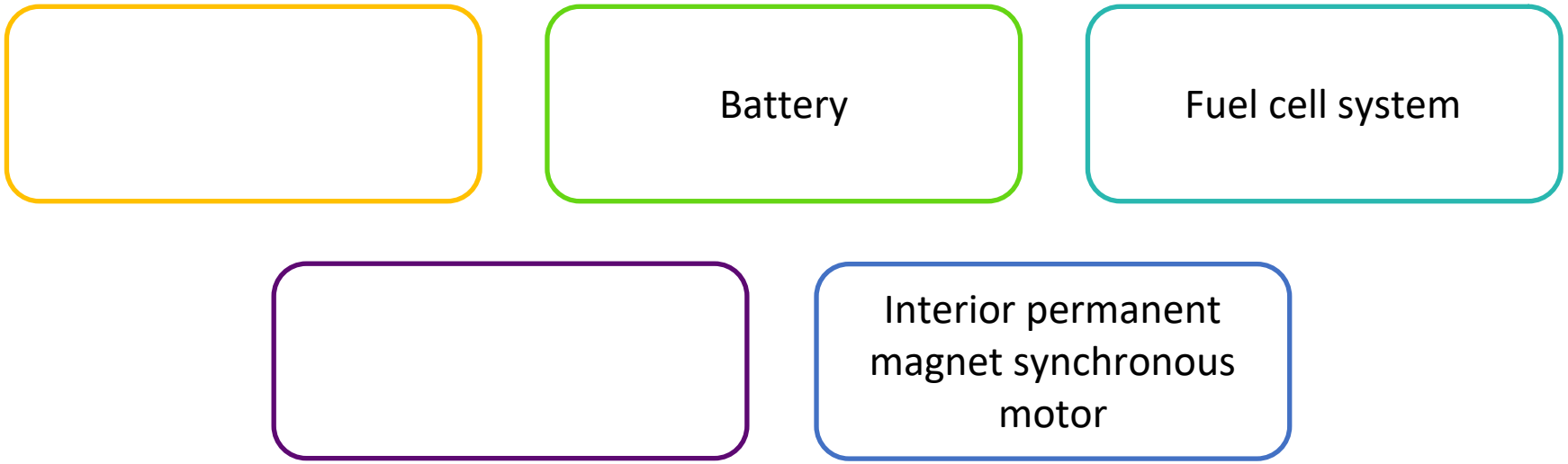


System and models

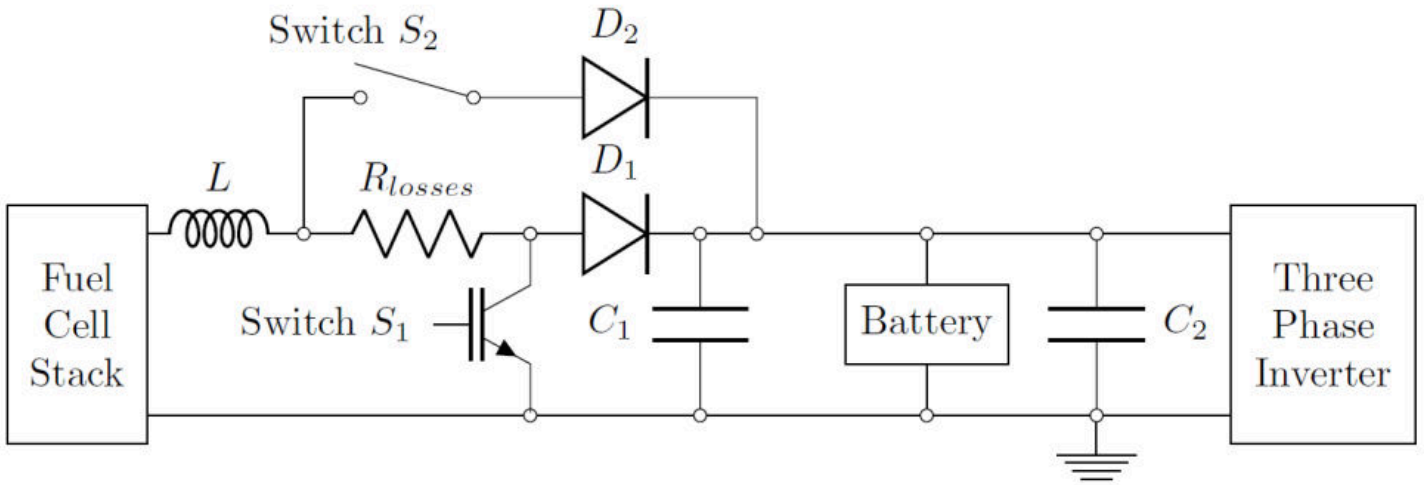


Fuel cell system

System and models

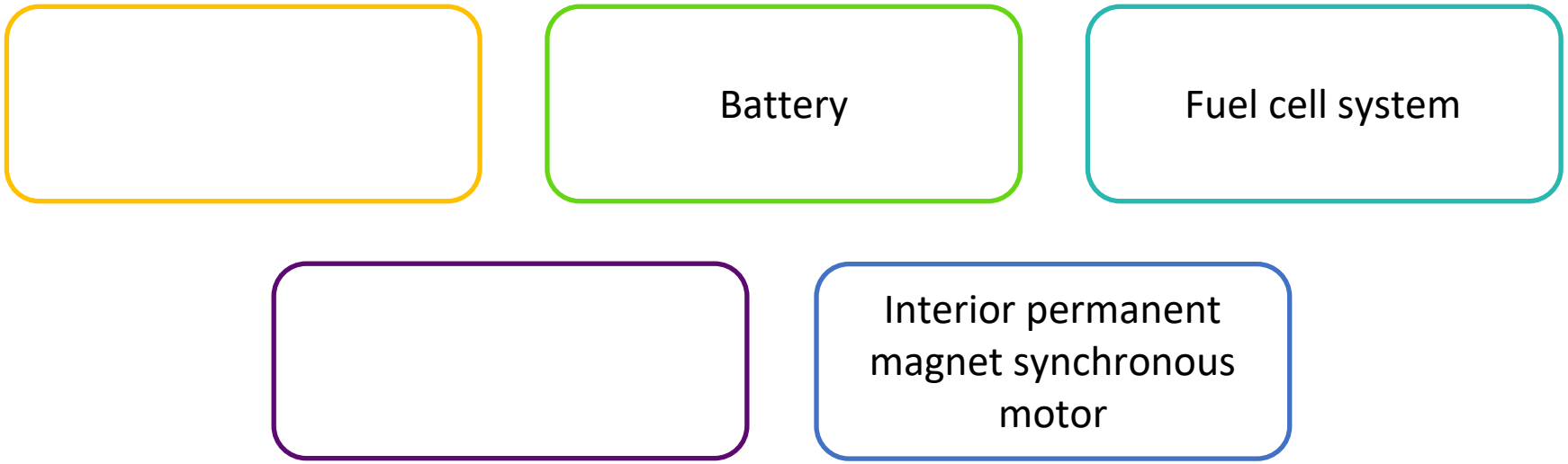


System and models



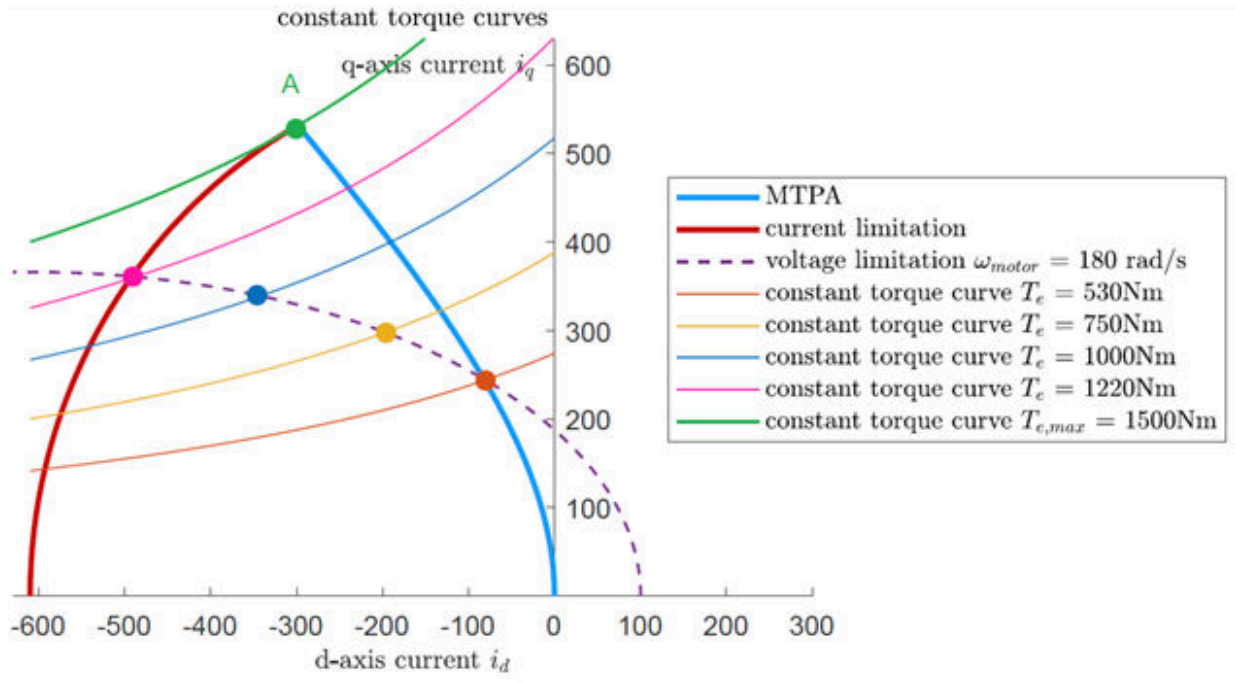
- Load-following mode
- DC/DC mode

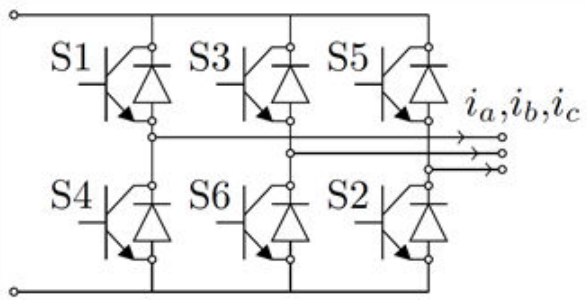
System and models



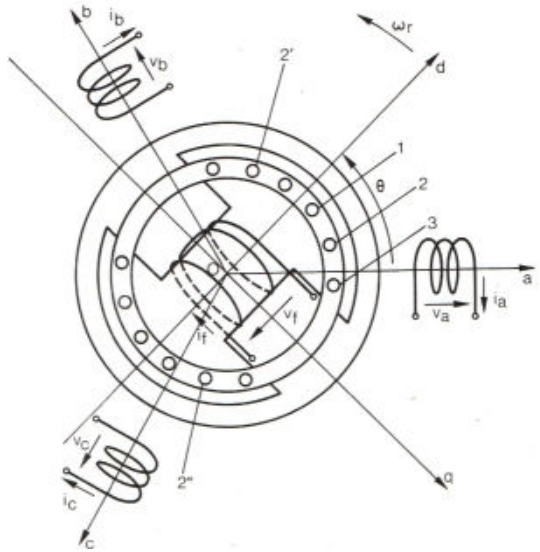
System and models

a, ib, ic → dq0 transform





Interior permanent magnet synchronous motor



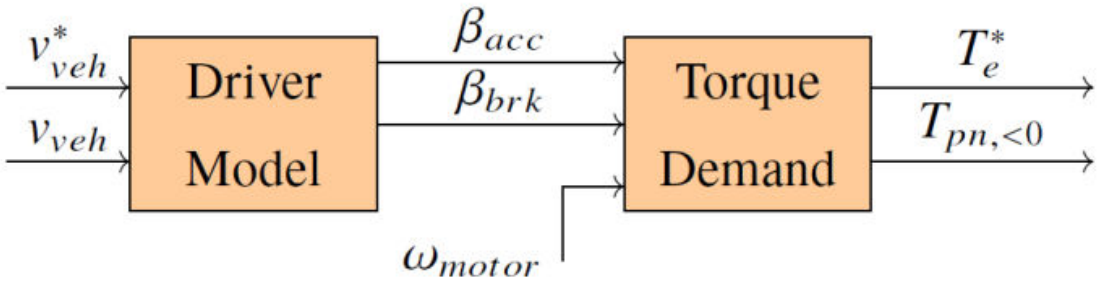
Structure and control

Main control loop

Energy management

Structure and control

Main control loop

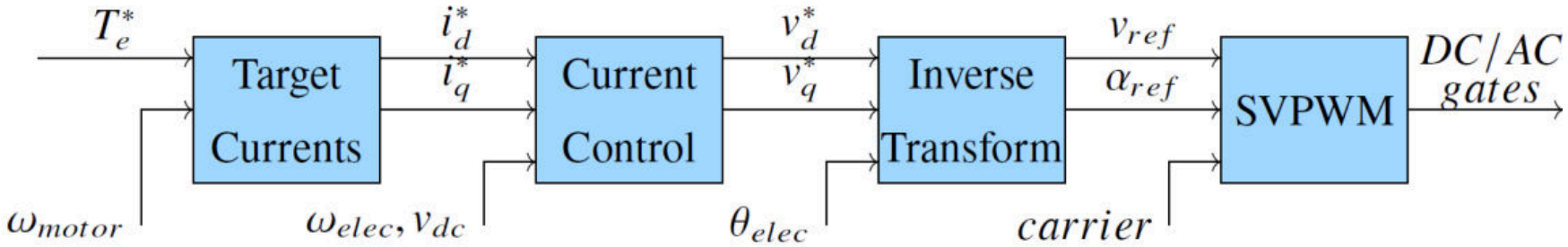


Structure and control

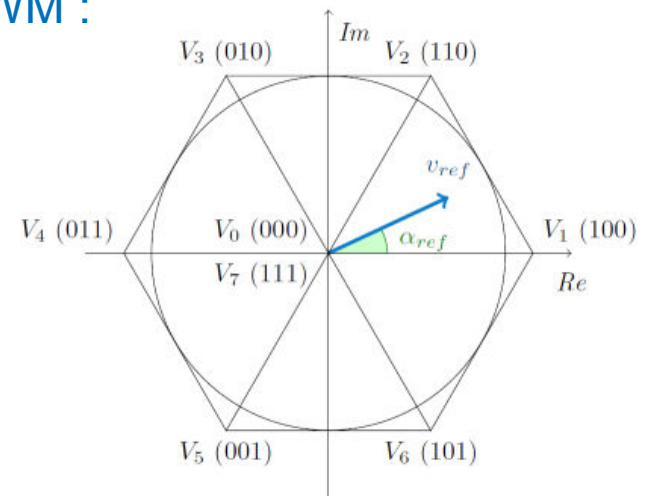
Main control loop

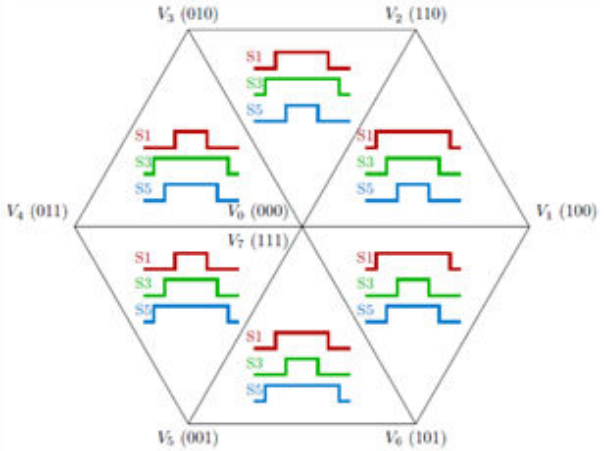
Energy management

Structure and control



SVPWM :



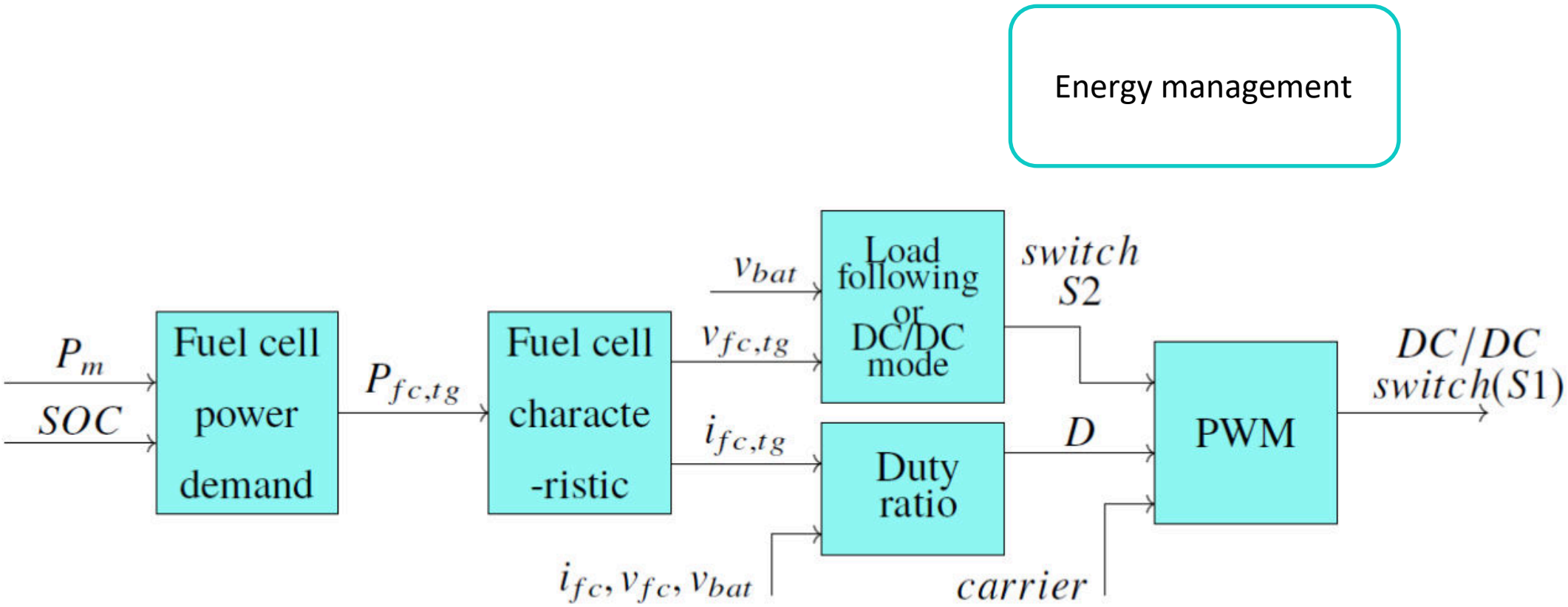


Structure and control

Main control loop

Energy management

Structure and control



Battery

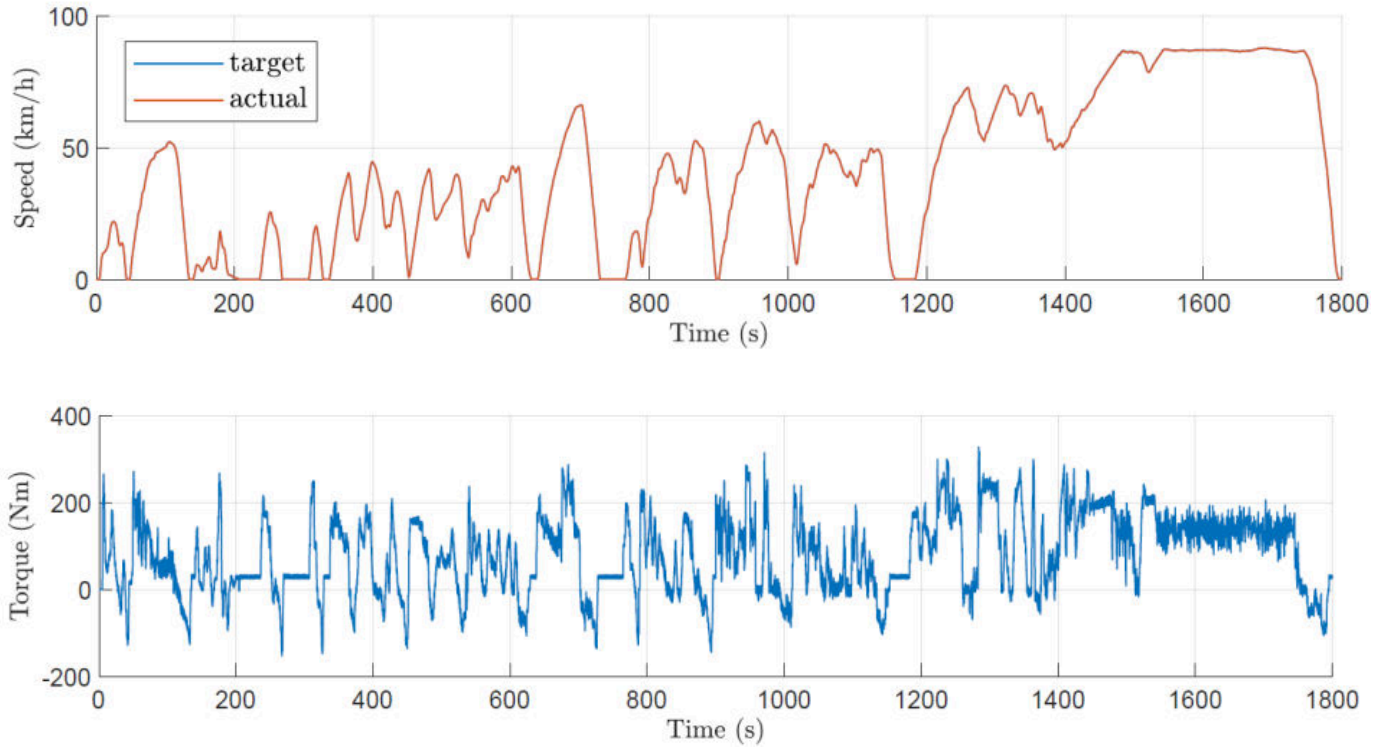
Fuel cell system

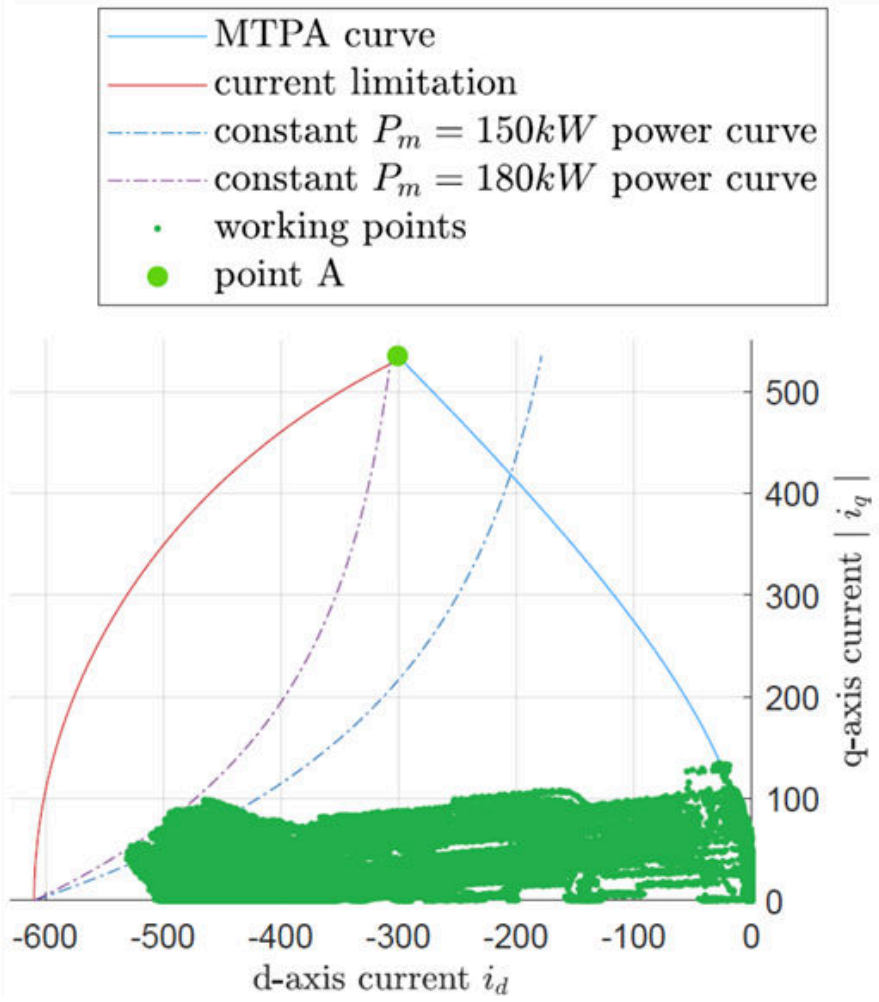
Interior permanent magnet synchronous motor

Main control loop

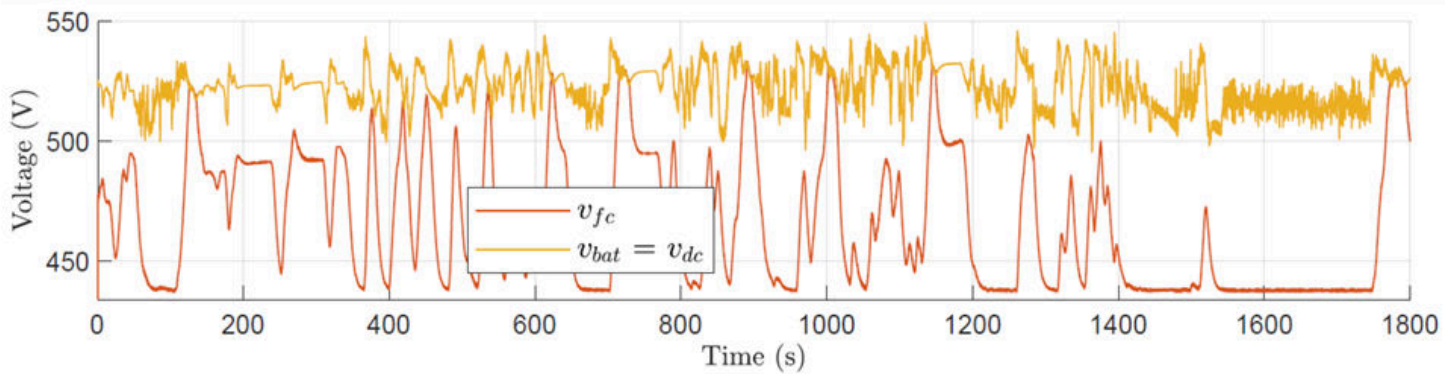
Energy management

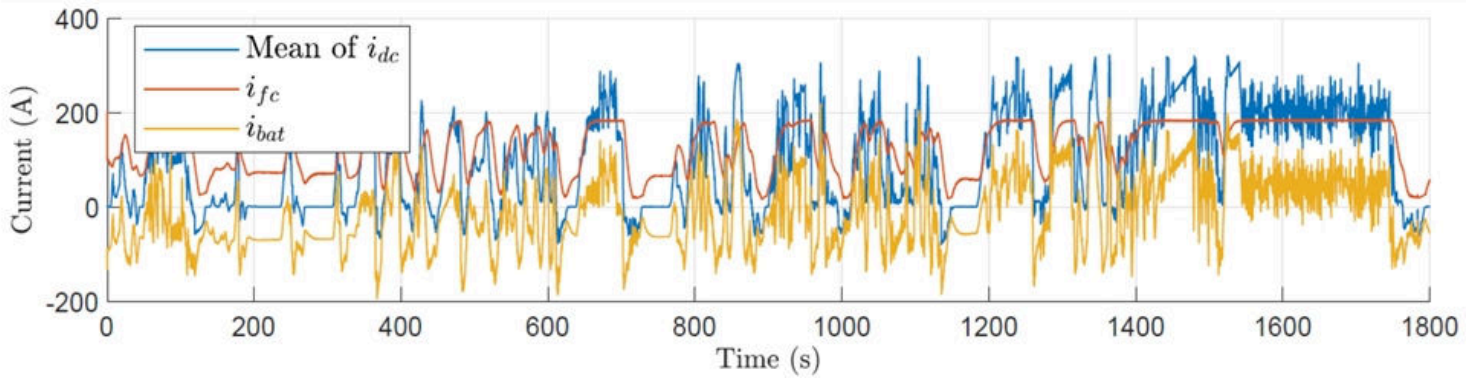
Results

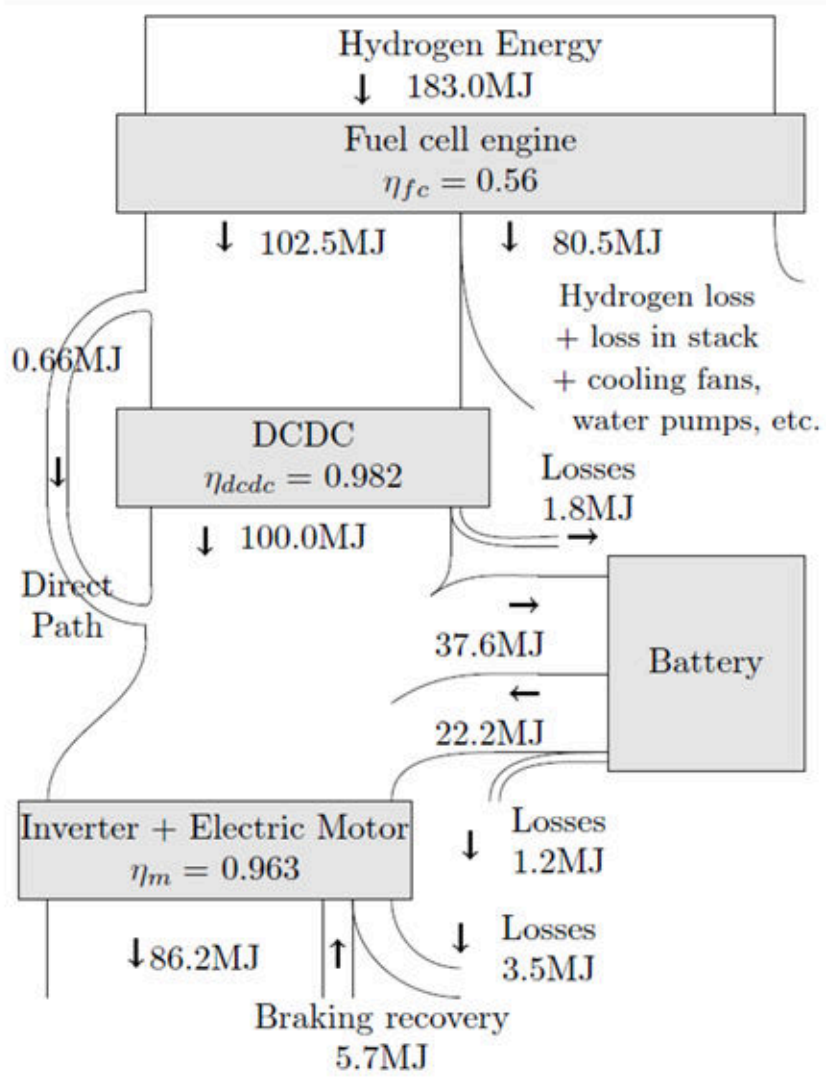

target
actual
Speed (km/h)
Time (s)
Torque (Nm)
Time (s)


MTPA curve
current limitation
constant $P_m = 150kW$ power curve
constant $P_m = 180kW$ power curve
working points
point A
q-axis current i_q
d-axis current i_d

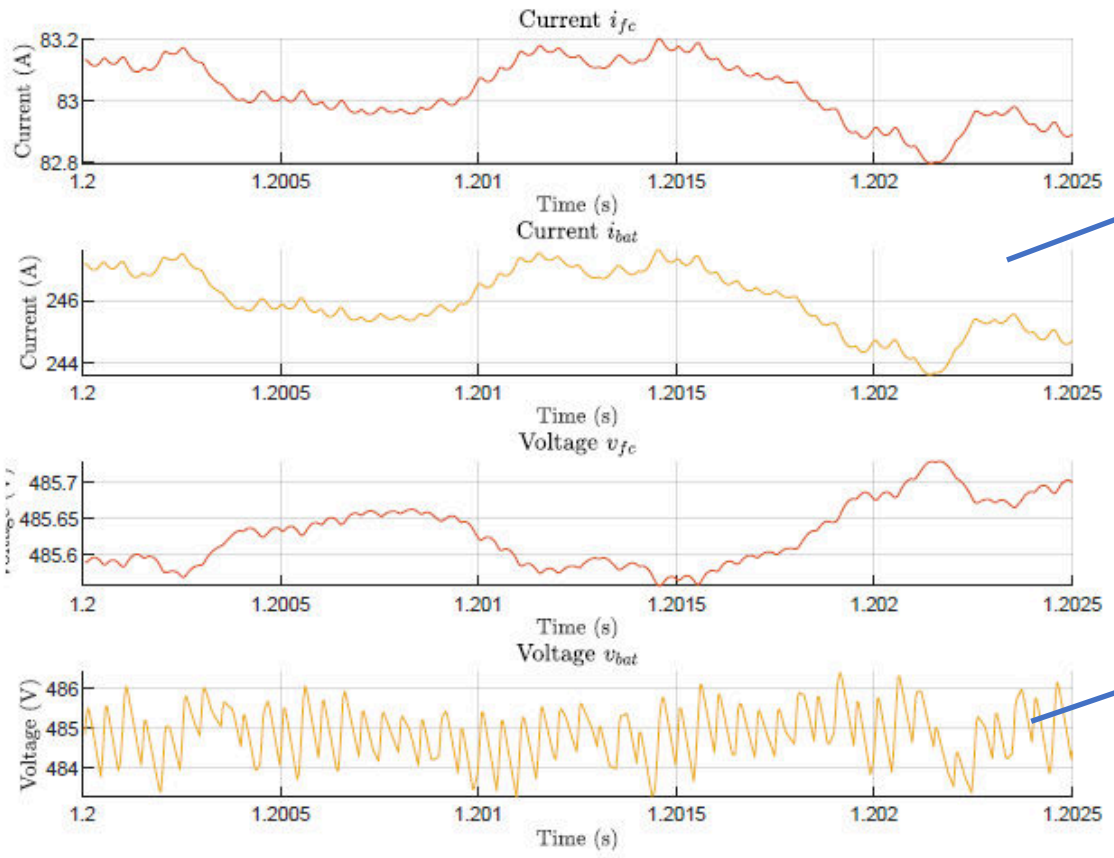
Results

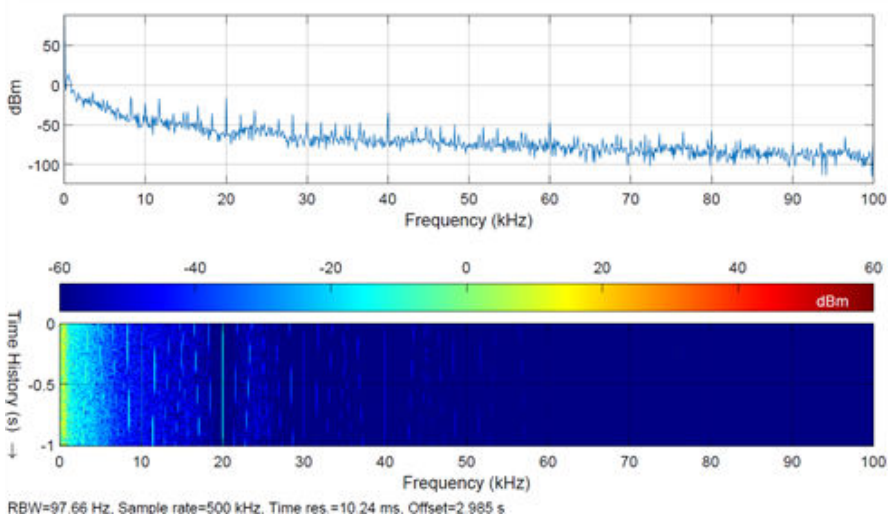

Voltage (V)
550
500
450
0
200
400
600
800
1000
1200
1400
1600
1800
Time (s)
v_{fc}
$v_{bat} = v_{dc}$

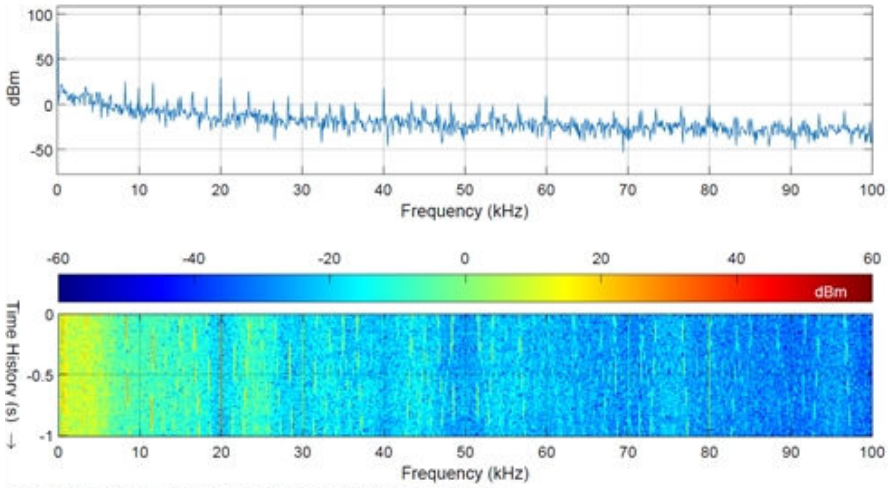

Current (A)
400
200
0
-200
0
200
400
600
800
1000
1200
1400
1600
1800
Time (s)
Mean of i_{dc}
i_{fc}
i_{bat}


Hydrogen Energy
183.0MJ
Fuel cell engine
$\eta_{fc} = 0.56$
102.5MJ
80.5MJ
Hydrogen loss
+ loss in stack
+ cooling fans,
water pumps, etc.
0.66MJ
DCDC
$\eta_{dcdc} = 0.982$
Losses
1.8MJ
100.0MJ
Direct
Path
37.6MJ
Battery
22.2MJ
Inverter + Electric Motor
$\eta_m = 0.963$
Losses
1.2MJ
86.2MJ
Losses
3.5MJ
Braking recovery
5.7MJ

Results


Current i_{fc}
Current (A)
83.2
83
82.8
1.2
1.2005
1.201
1.2015
1.202
1.2025
Time (s)
Current i_{bat}
Current (A)
246
244
Time (s)
Voltage v_{fc}
485.7
485.65
485.6
Time (s)
Voltage v_{bat}
Voltage (V)
486
485
484
Time (s)


dBm
Frequency (kHz)
Time History (s)
RBW=97.66 Hz. Sample rate=500 kHz. Time res.=10.24 ms. Offset=2.985 s

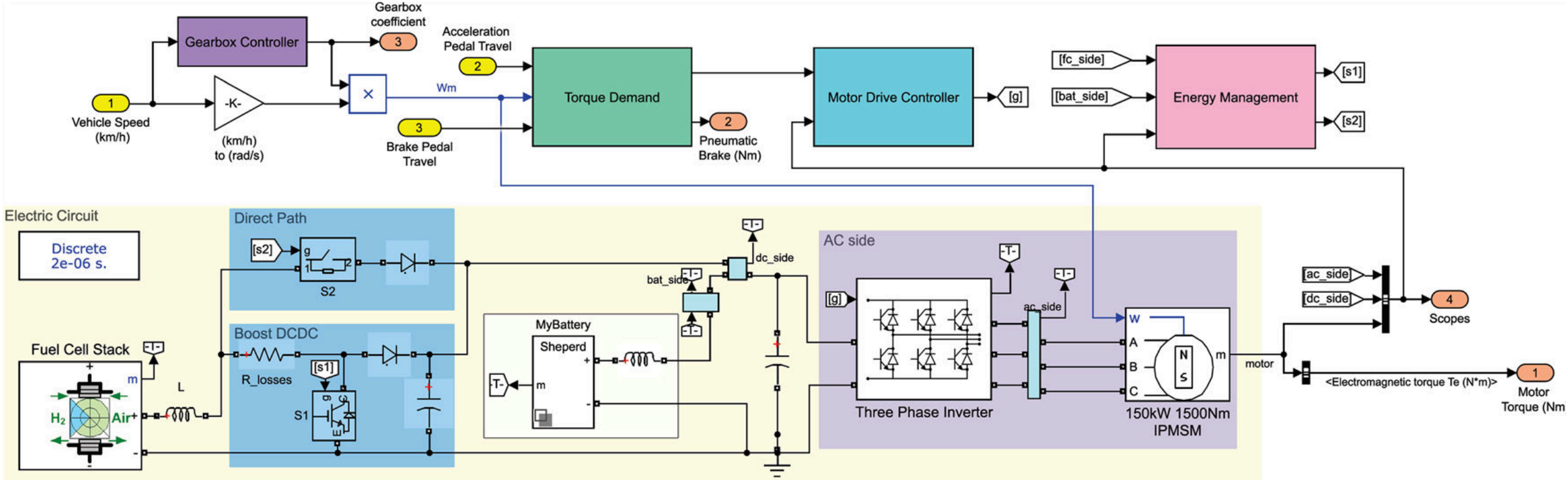

dBm
Frequency (kHz)
Time History (s)
RBW=97.66 Hz. Sample rate=500 kHz. Time res.=10.24 ms. Offset=2.985 s

Conclusion

Questions ?

Thanks !

ANNEXE 1


Gearbox Controller
Gearbox coefficient
3
Acceleration Pedal Travel
2
1
Vehicle Speed (km/h)
-K-
(km/h) to (rad/s)
×
Wm
3
Brake Pedal Travel
Torque Demand
2
Pneumatic Brake (Nm)
Motor Drive Controller
[g]
[fc_side]
[bat_side]
Energy Management
[s1]
[s2]
Electric Circuit
Discrete 2e-06 s.
Direct Path
[s2]
S2
Boost DCDC
R_losses
[s1]
S1
L
Fuel Cell Stack
m
H2
Air
MyBattery
Sheperd
dc_side
bat_side
AC side
[g]
Three Phase Inverter
ac_side
W
A
B
C
N
S
m
150kW 1500Nm IPMSM
motor
[ac_side]
[dc_side]
4
Scopes
<Electromagnetic torque Te (N*m)>
1
Motor Torque (Nm

ANNEXE 2

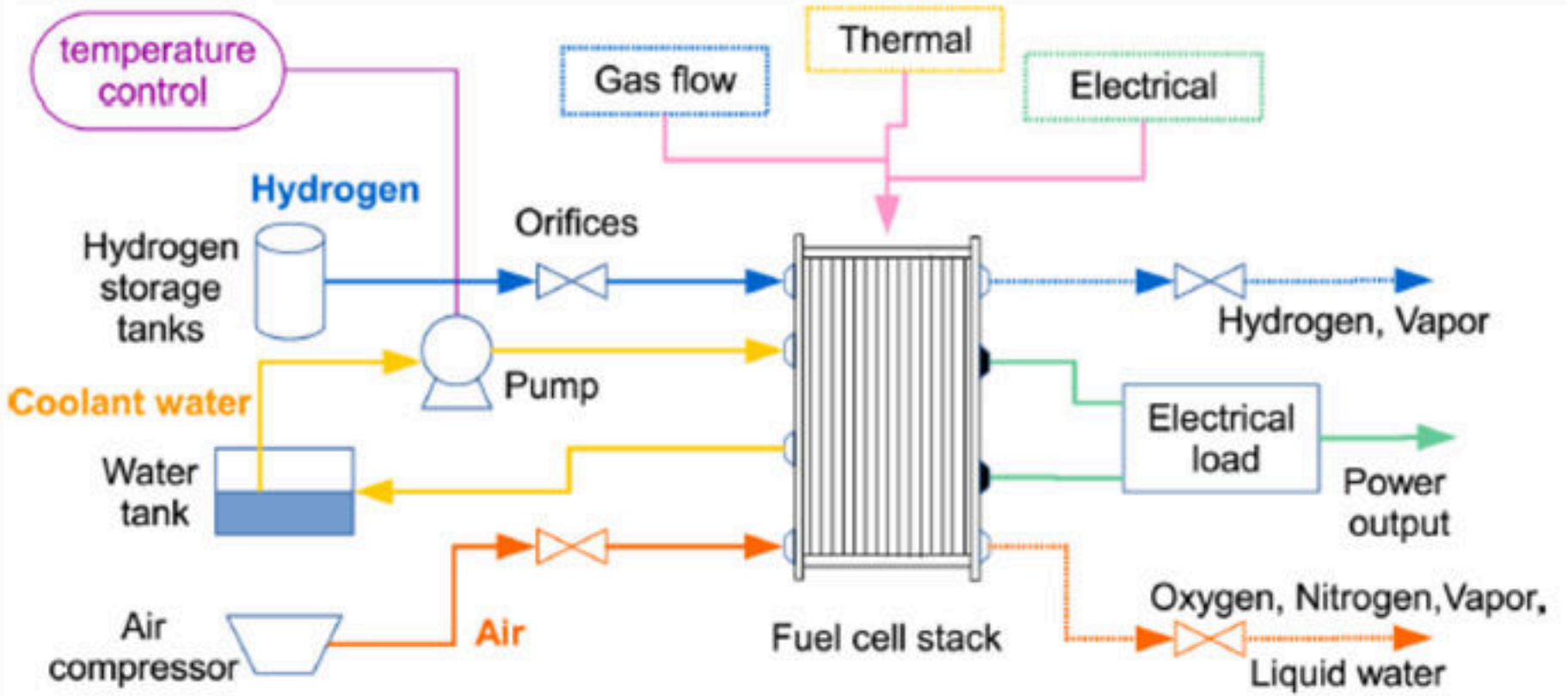


Fig. 1.13 Schematic illustration of a typical fuel cell system (from [21])

ANNEXE 3

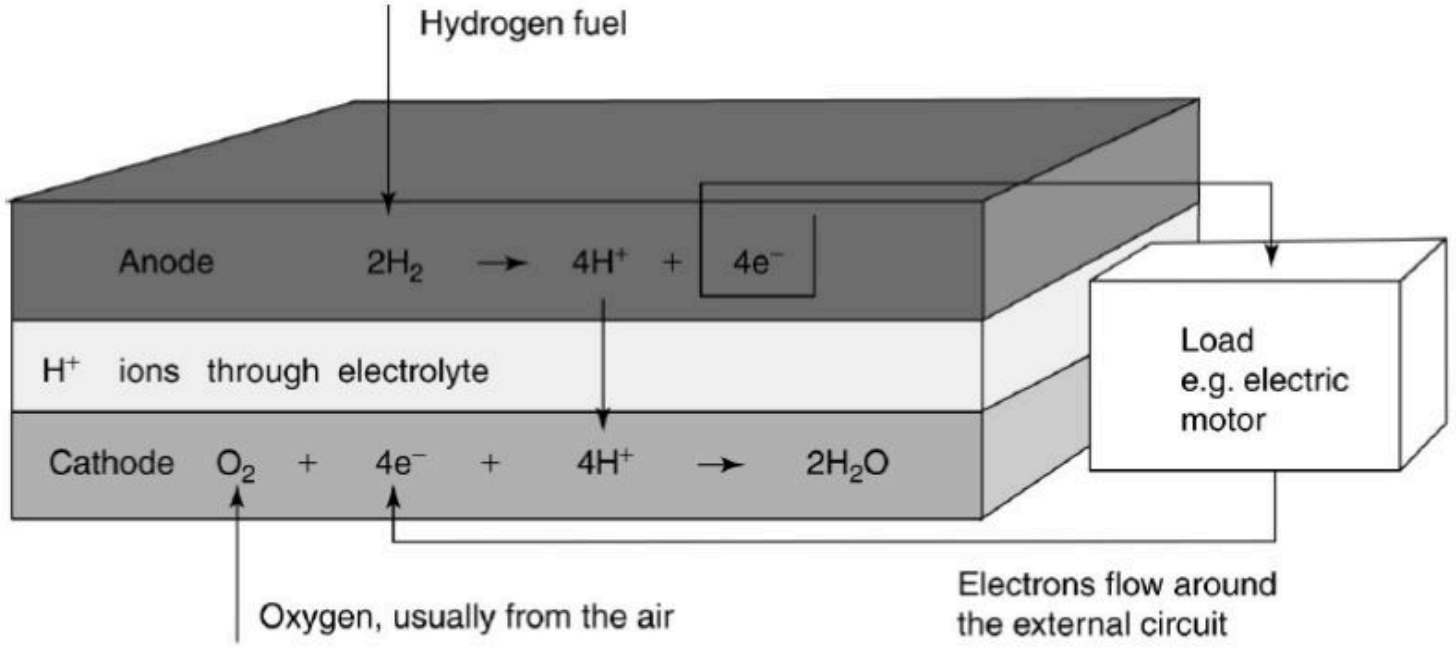


Fig. 1.9 Electrode reactions and charge flow for an acid electrolyte fuel cell (from [16])

ANNEXE 4

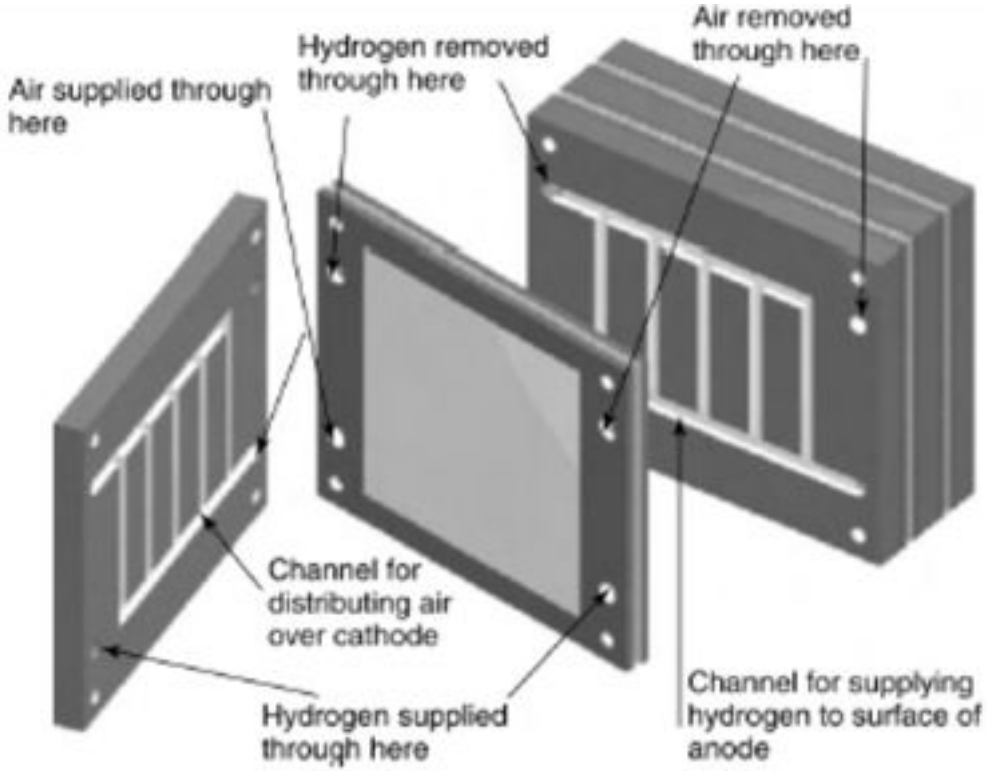


Fig. 1.11 Internal manifolding (from [16])

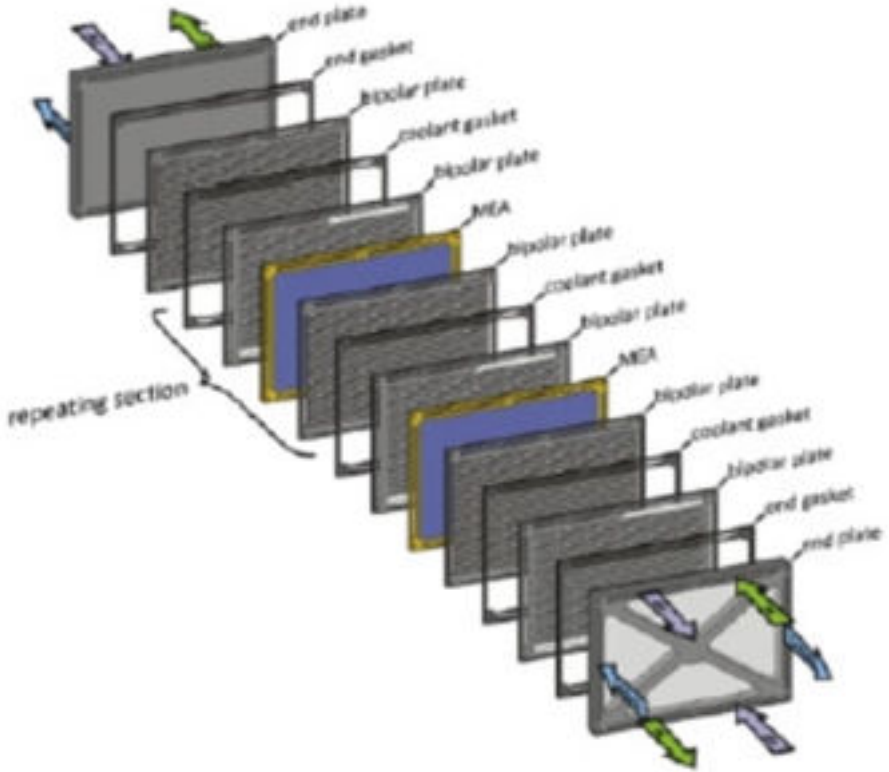


Fig. 1.12 Main components of PEMFC stack (from [20])

ANNEXE 5

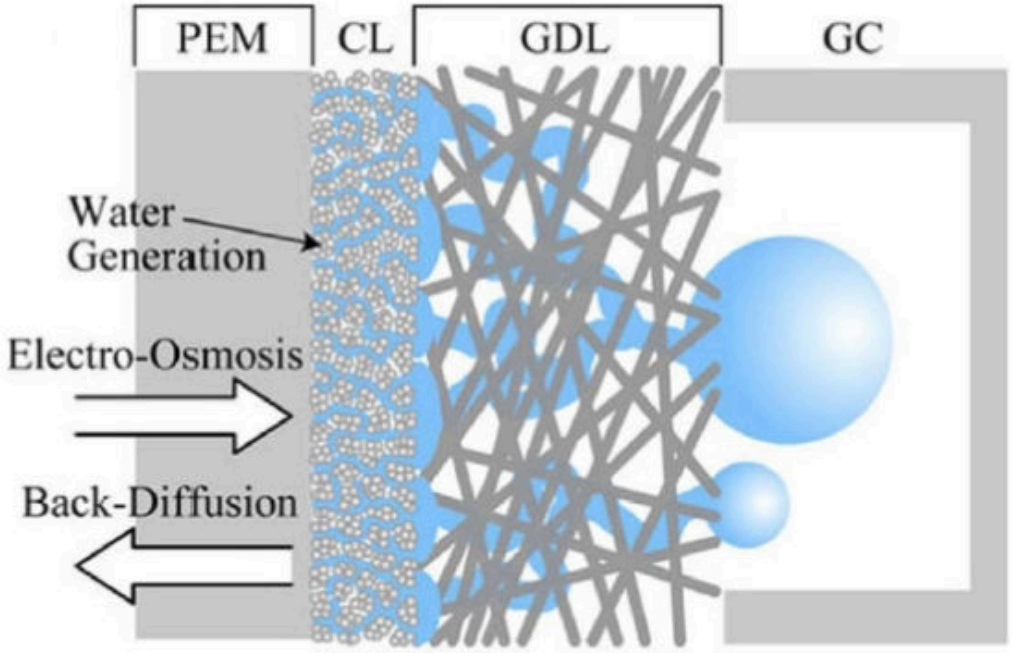


Fig. 1.10 Cathode structure with a catalyst layer and a gas diffusion layer (from [17])

References for ANNEXES

[16] J. Larmine and A. Dicks. *Fuel Cell Systems Explained*. Wiley, 2003.
[17] E. H. Majlan, D. Rohendi, W. R.W. Daud, T. Husaini, and M. A. Haque. Electrode for proton exchange membrane fuel cells: A review. *Renewable and Sustainable Energy Reviews*, 2018.
[20] A Alaswad, A Baroutaji, H Achour, J Carton, Ahmed Al, and A G Olabi. ScienceDirect Developments in fuel cell technologies in the transport sector. *International Journal of Hydrogen Energy*, 2016.
[21] Lianghui Huang, Jian Chen, Zhiyang Liu, and Mohamed Becherif. ScienceDirect Adaptive thermal control for PEMFC systems with guaranteed performance. *International Journal of Hydrogen Energy*,2017.