«EMR-based energy management of a fuel cell hybrid vehicle »

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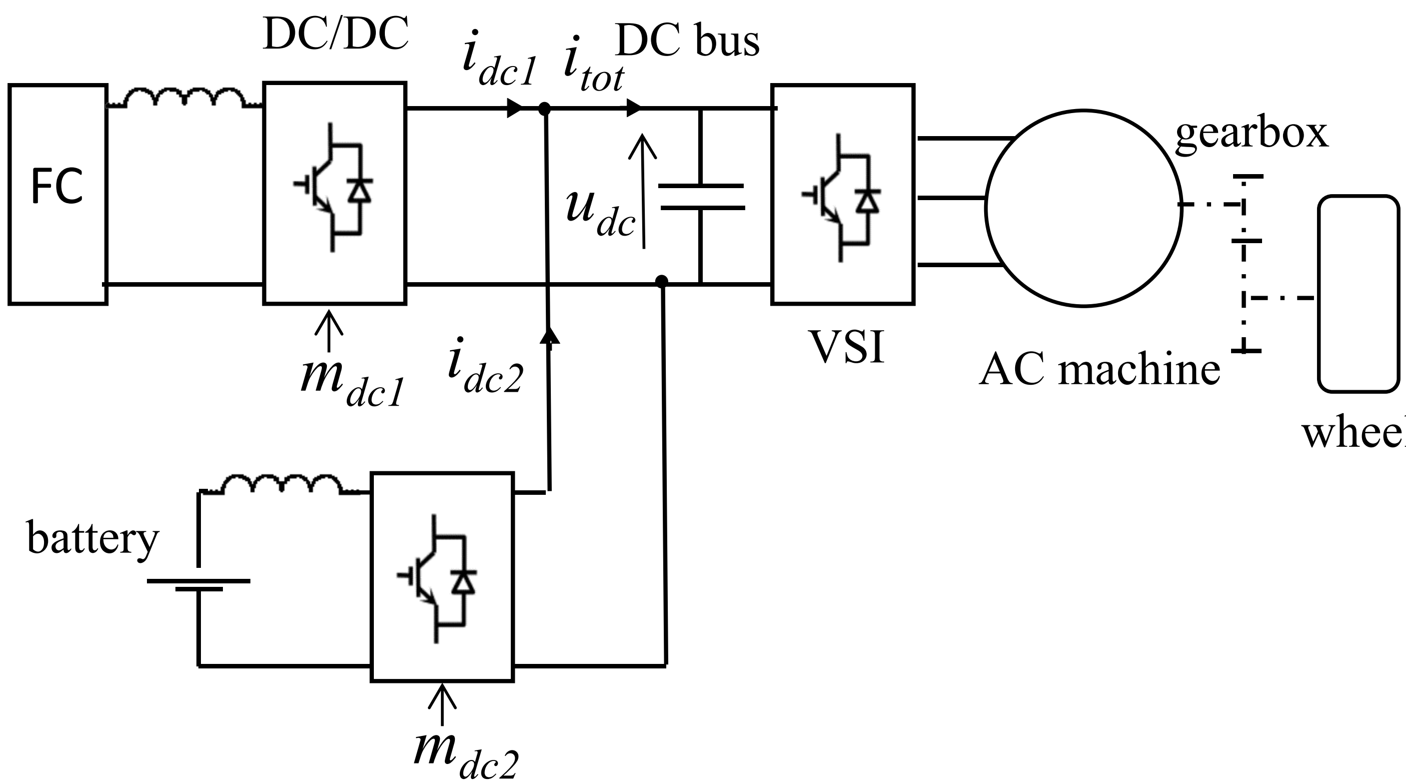
- Outline -

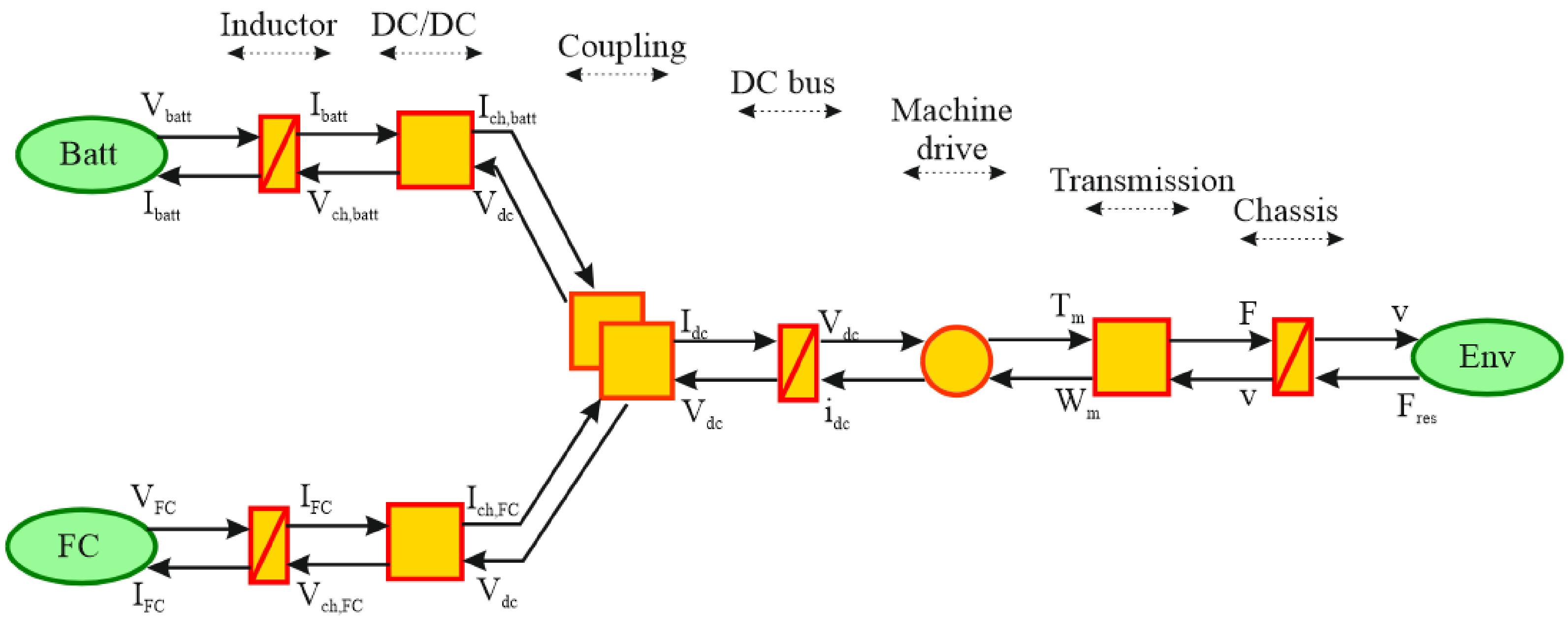
« Introduction »

- Fuel cell hybrid vehicles: high energy and power density
- Energy management strategy (EMS): efficiently manage power between sources
- Multi-objective optimization: prioritization depending on the driving cycle
- Energetic macroscopic representation (EMR): powertrain model, EMS development
- Local and global controllers: local controllers for bus voltage regulation, traction control, duty cycle control; global controller for energy management and optimized power split.
- Dynamic saturation and rate limitation: rate limitation to control the current growth rate in fuel cell, saturation to restrict operation of the battery within pre-defined bounds

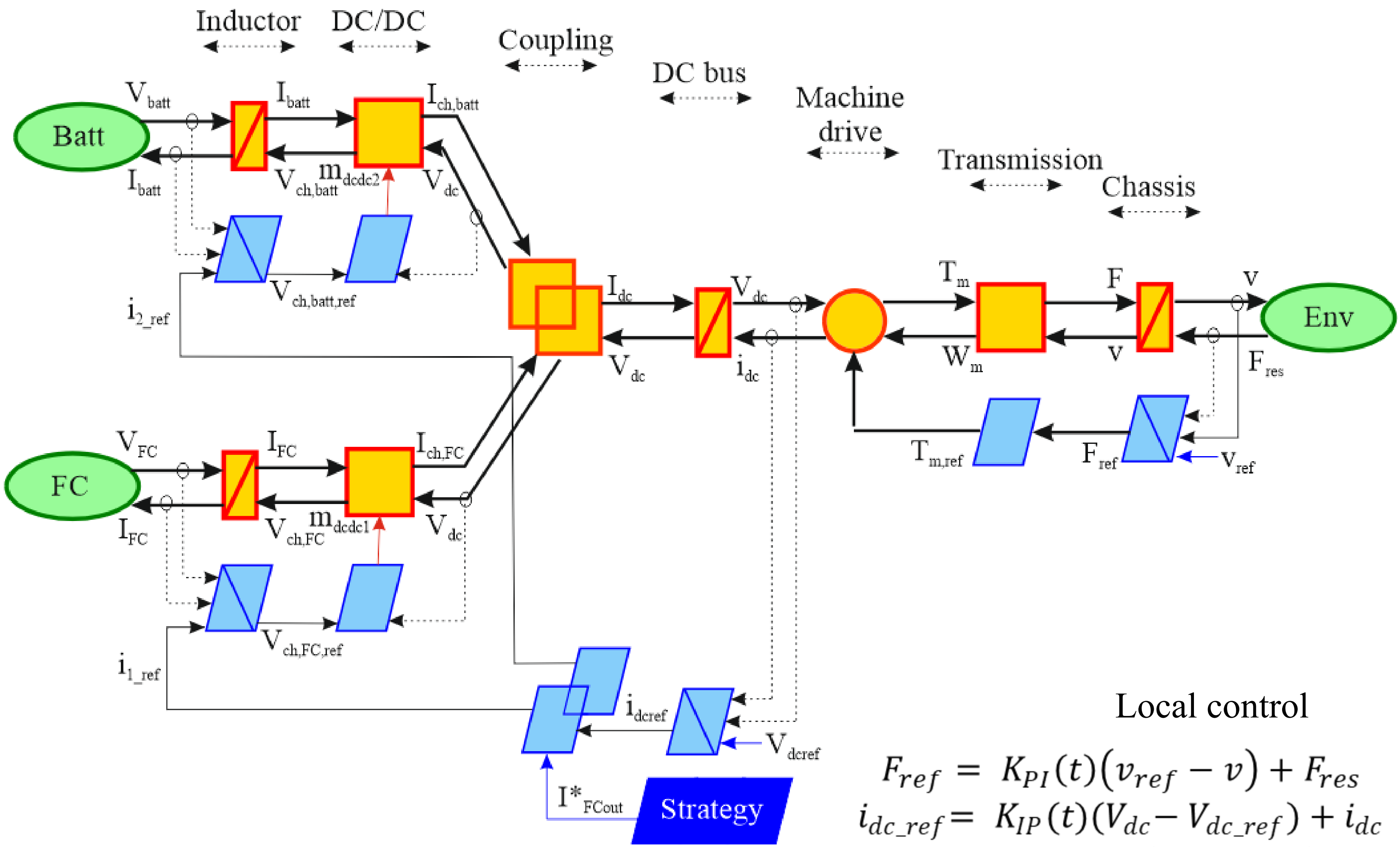
« EMR and control of the Studied FC vehicle »

- Hybrid topology with a battery as secondary source





Inductor
DC/DC
Coupling
DC bus
Machine drive
Transmission
Chassis
Batt
FC
Env
V batt
I batt
I ch,batt
V ch,batt
V dc
V FC
I FC
I ch,FC
V ch,FC
I dc
i dc
T m
W m
F
v
F res



Local control

$$F_{ref} = K_{PI}(t)\left(v_{ref} - v\right) + F_{res}$$

$$i_{dc\_ref} = K_{IP}(t)(V_{dc} - V_{dc\_ref}) + i_{dc}$$

$$V_{ch,FC,ref} = -K_{IP}(t)\left(i_{1_{ref}} - I_{FC}\right) + V_{FC}$$

$$V_{ch,batt,ref} = -K_{PI}(t)(i_{2\_dcref} - I_{batt}) + V_{batt}$$

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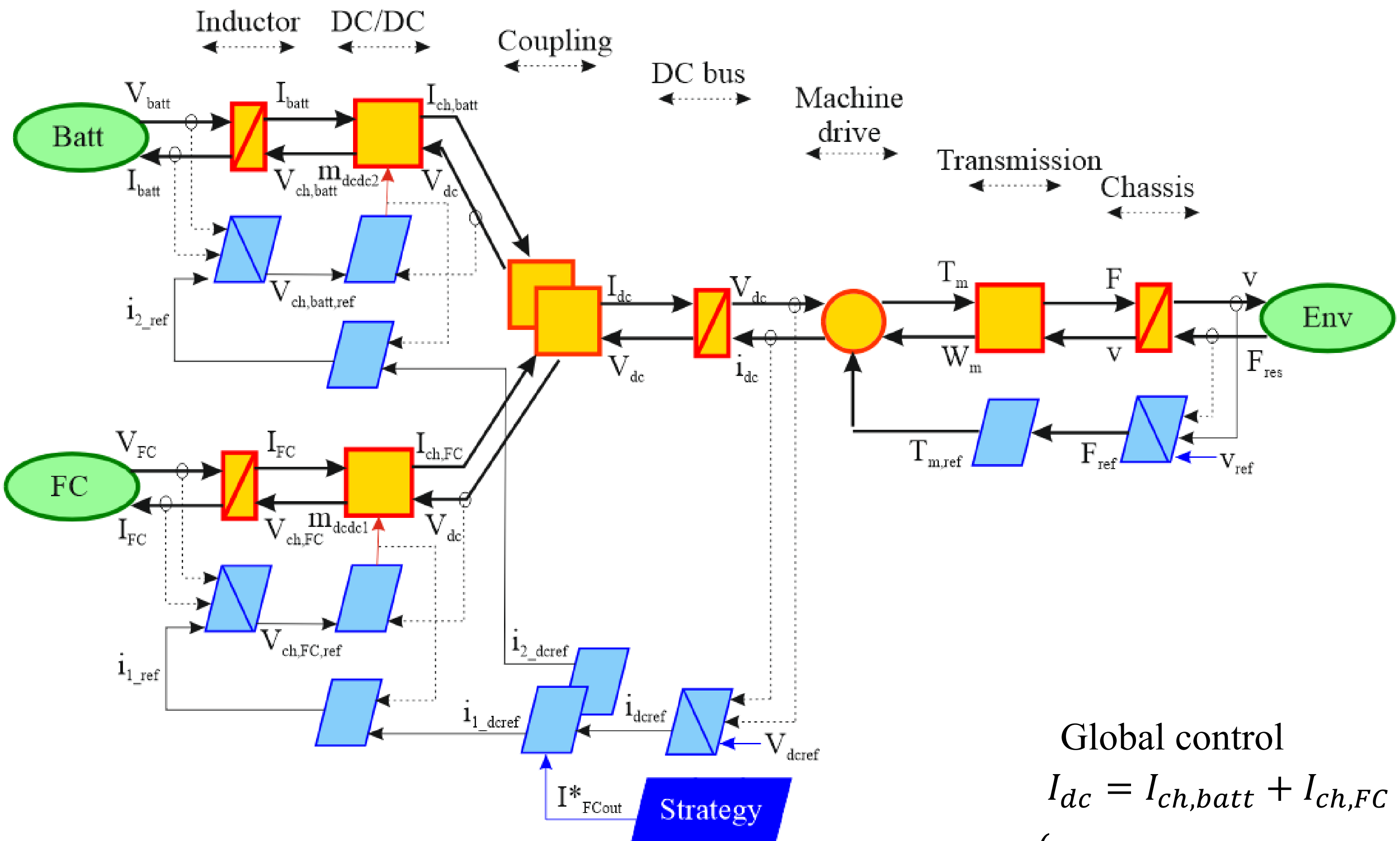
- EMR the FCHEV-



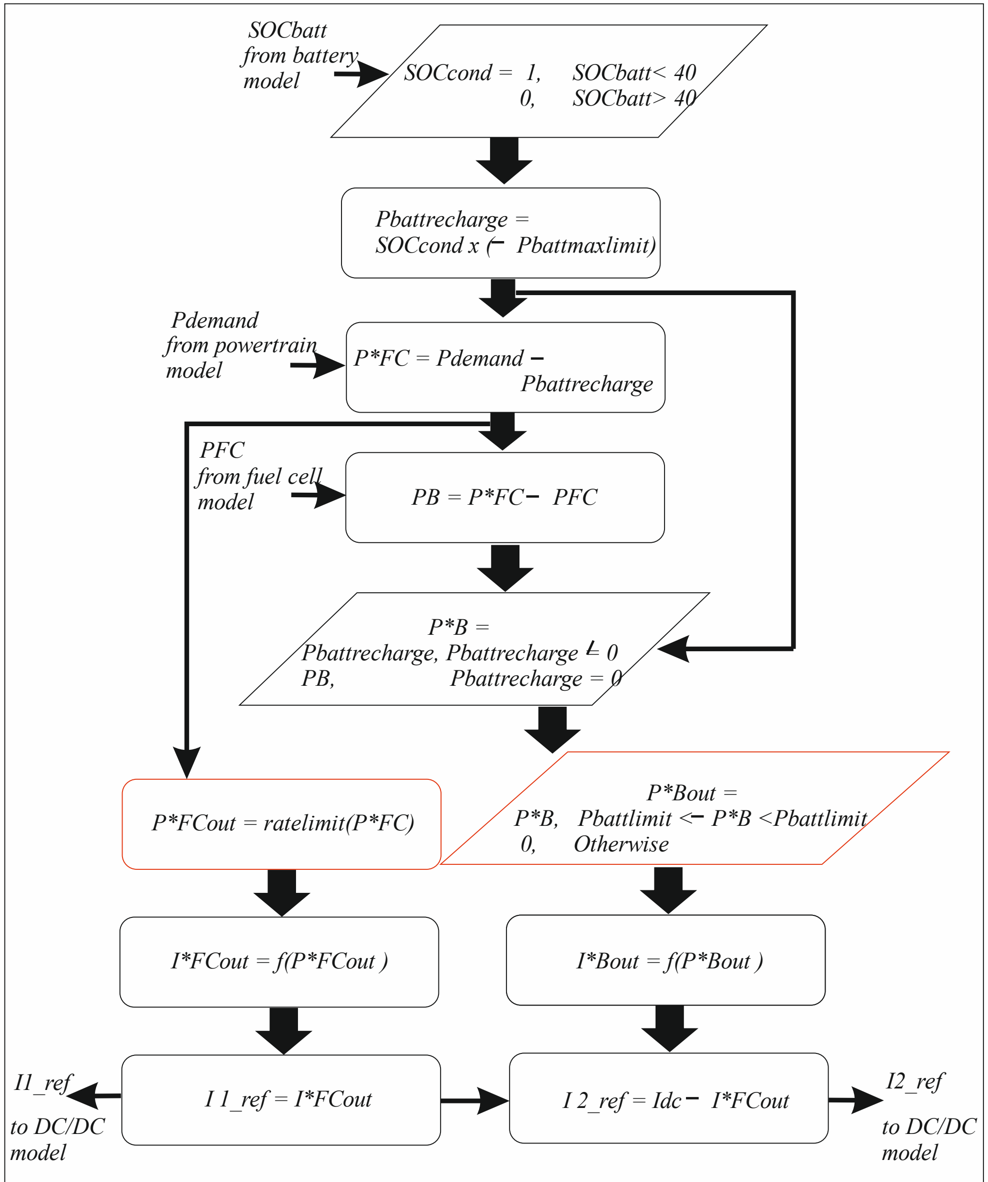
Global control

$$I_{dc} = I_{ch,batt} + I_{ch,FC}$$

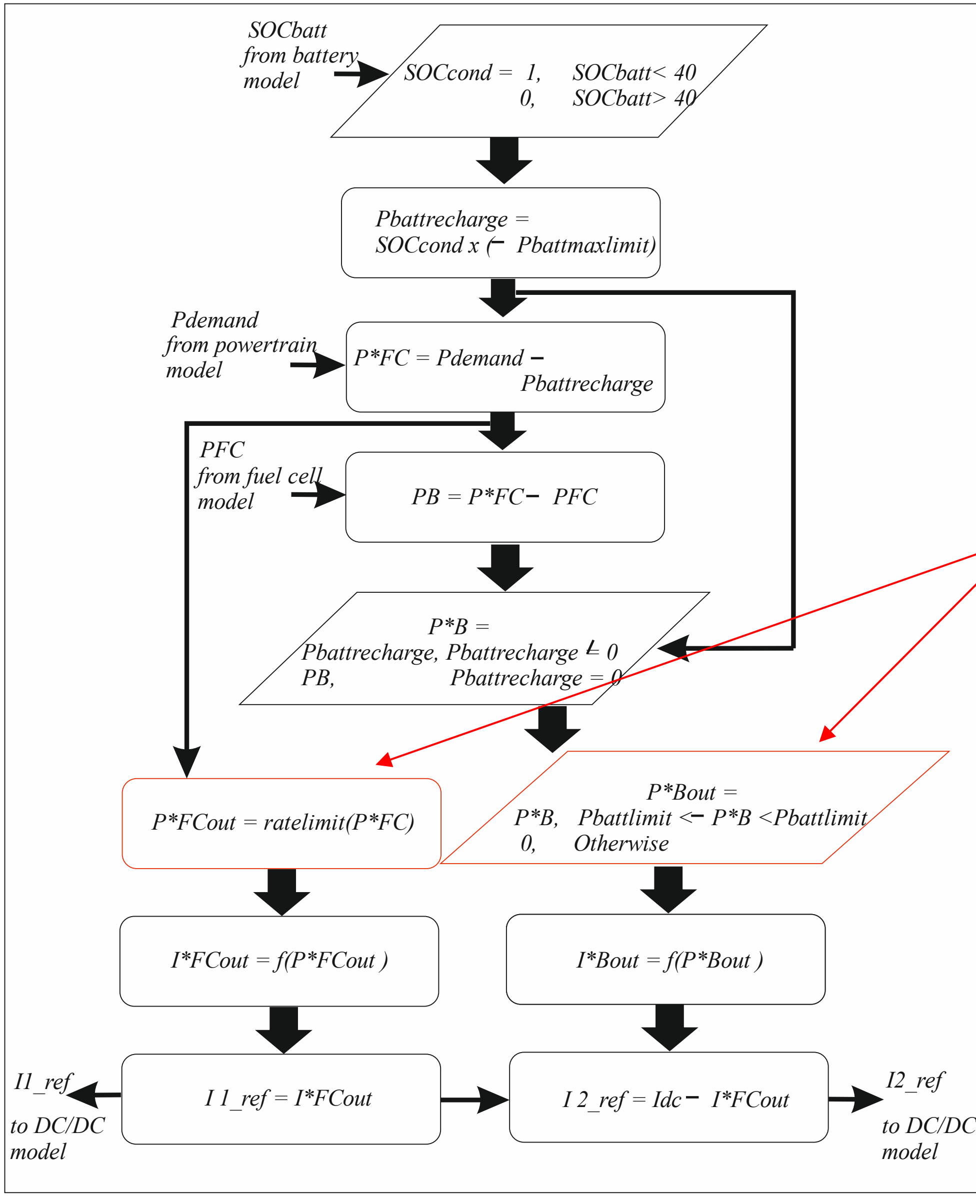
$$\begin{cases} i_{1\_ref} = I^*_{FCout} \\ i_{2\_ref} = i_{dc} - I^*_{FCout} \end{cases}$$

« Multi-objective Energy Management Strategy »

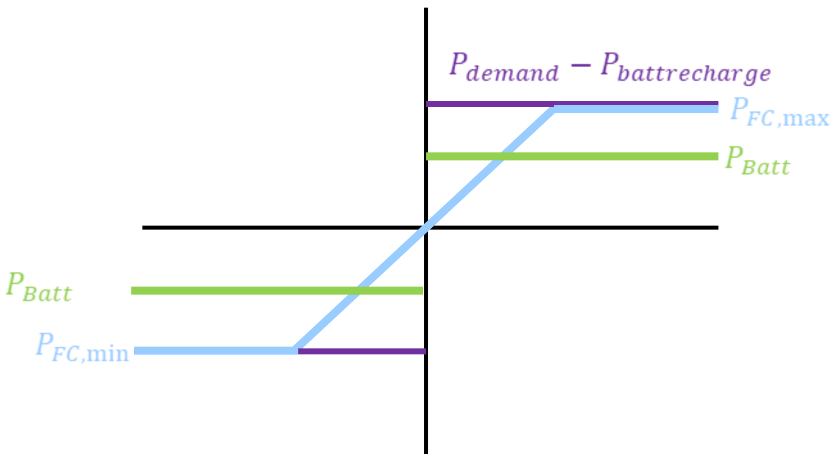
- Energy management-

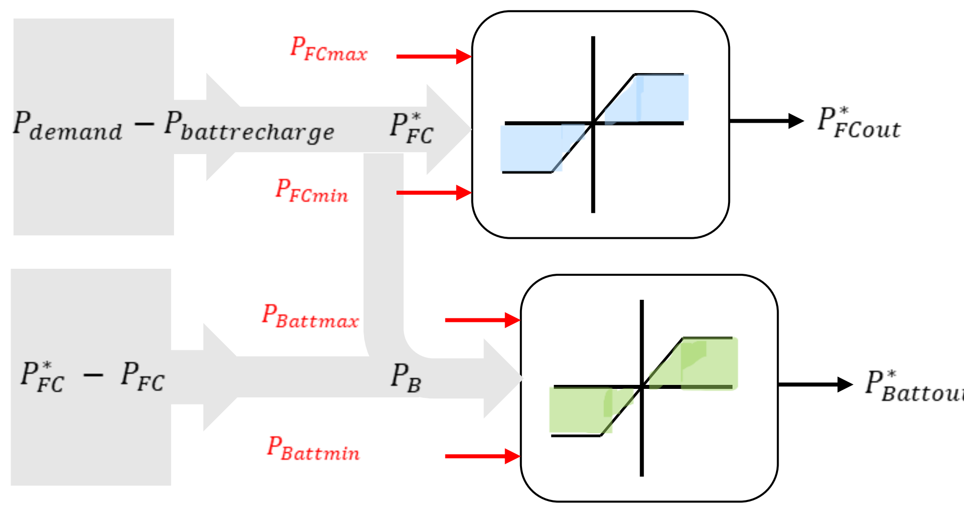


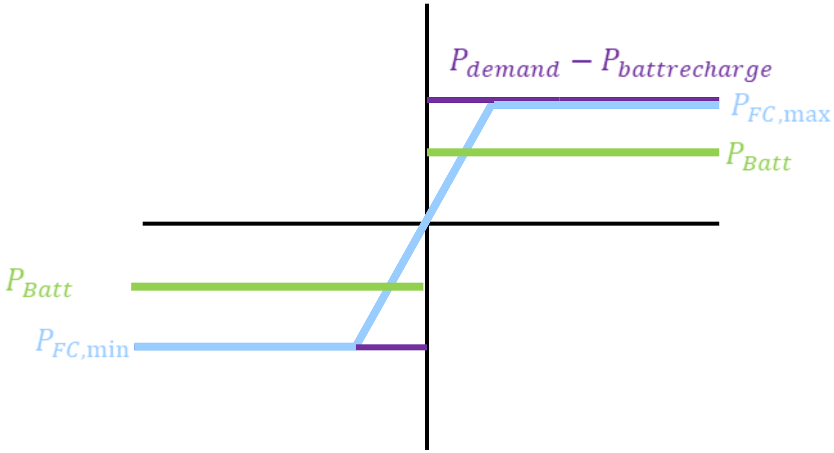
- Energy management-

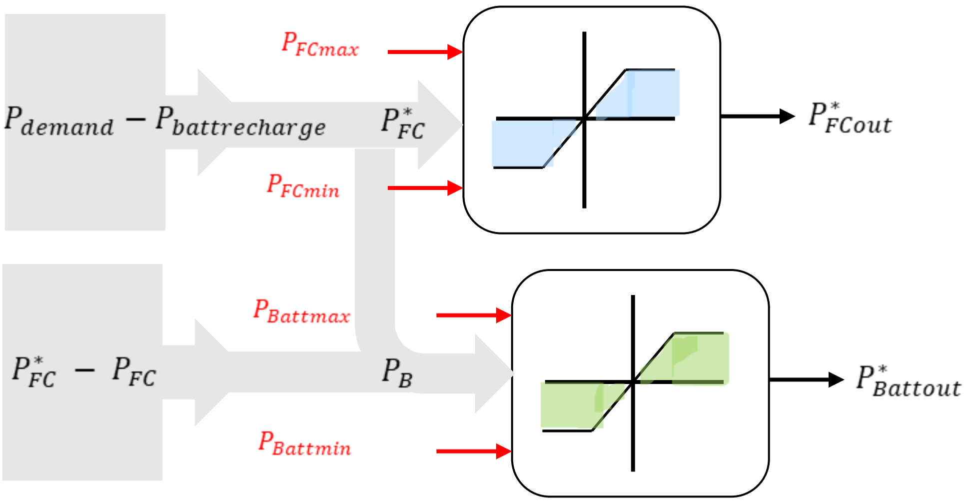


Dynamic saturation and rate limitation >>Optimization of boundaries

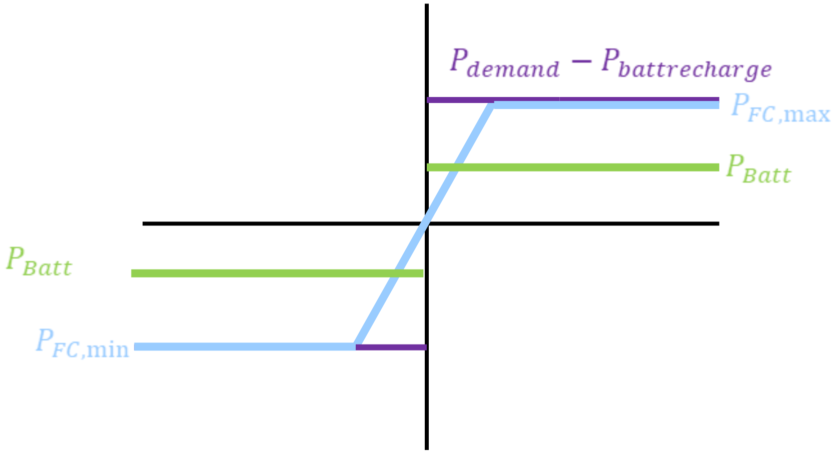

$P_{demand} - P_{battrecharge}$
$P_{FC,\max}$
P_{Batt}
P_{Batt}
$P_{FC,\min}$

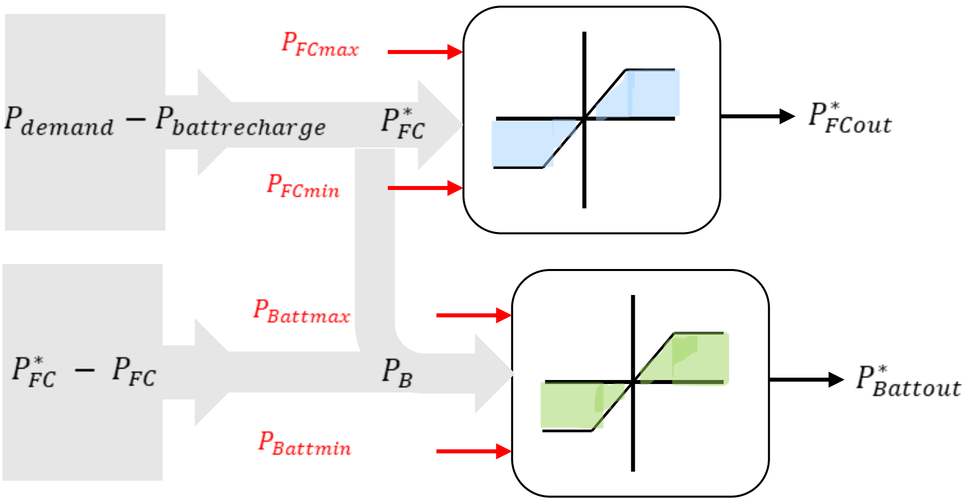

P_{FCmax}
$P_{demand} - P_{battrecharge}$
P^*_{FC}
P_{FCmin}
P^*_{FCout}
$P_{Battmax}$
$P^*_{FC} - P_{FC}$
P_B
$P_{Battmin}$
$P^*_{Battout}$


$P_{demand} - P_{battrecharge}$
$P_{FC,\max}$
P_{Batt}
P_{Batt}
$P_{FC,\min}$

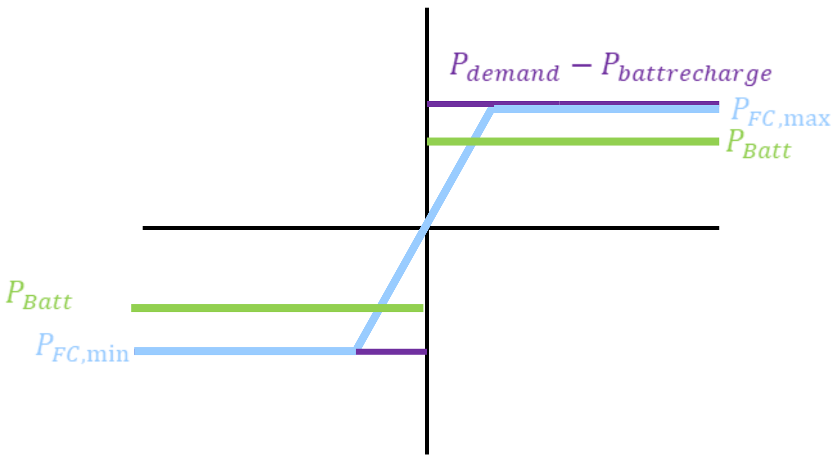

P_{FCmax}
$P_{demand} - P_{battrecharge}$
P_{FC}^{*}
P_{FCmin}
P_{FCout}^{*}
$P_{Battmax}$
$P_{FC}^{*} - P_{FC}$
P_B
$P_{Battmin}$
$P_{Battout}^{*}$

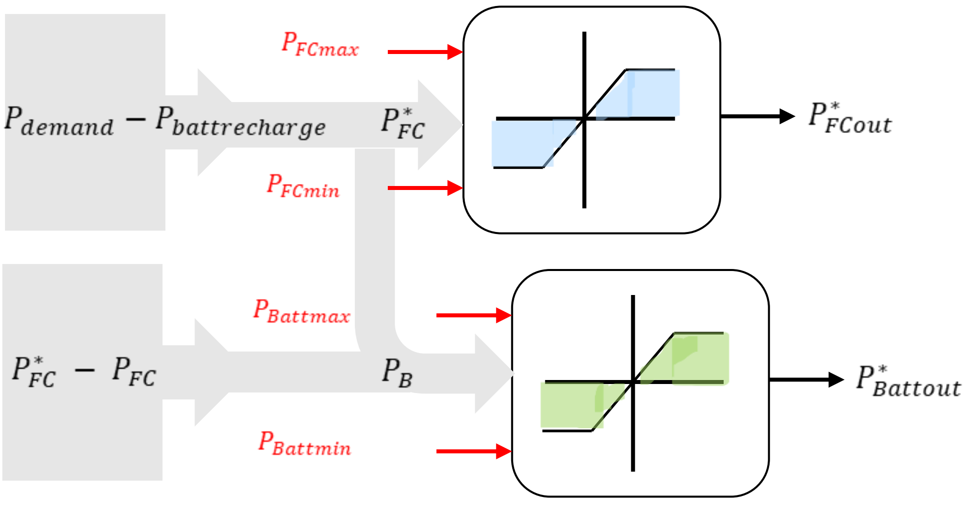
- Energy management-



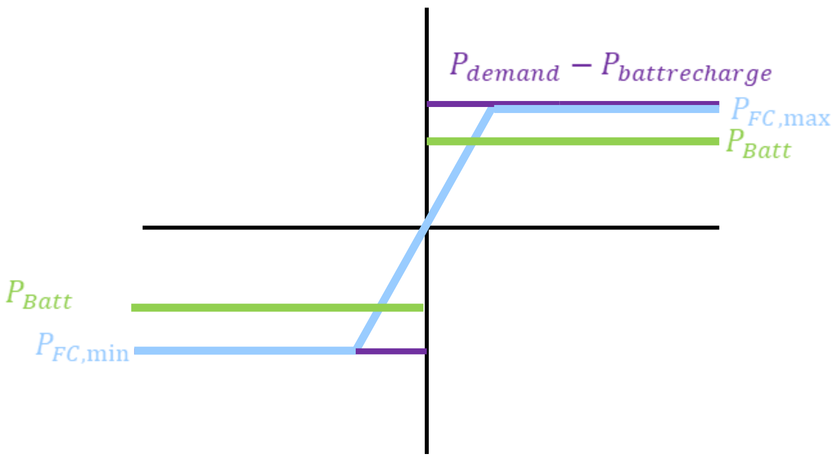


- Energy management-





- Multi-objective optimization-



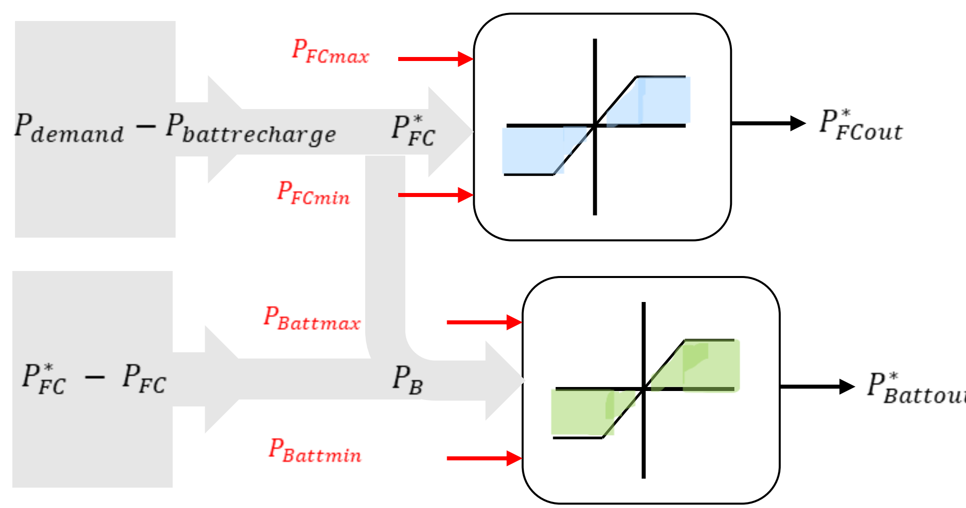
$$\min_{x} J = \int_{t_o}^{t_f} w_1 J_1(x) + w_2 J_2(x) + w_3 J_3(x)\, dx$$

$$x = \{P_{battmax}, \quad P_{battmin}, \quad P_{FCmax}, \quad P_{FCmin}\}$$

$$J_1 = \int_{t_o}^{t_f} \dot{m}\ dt$$

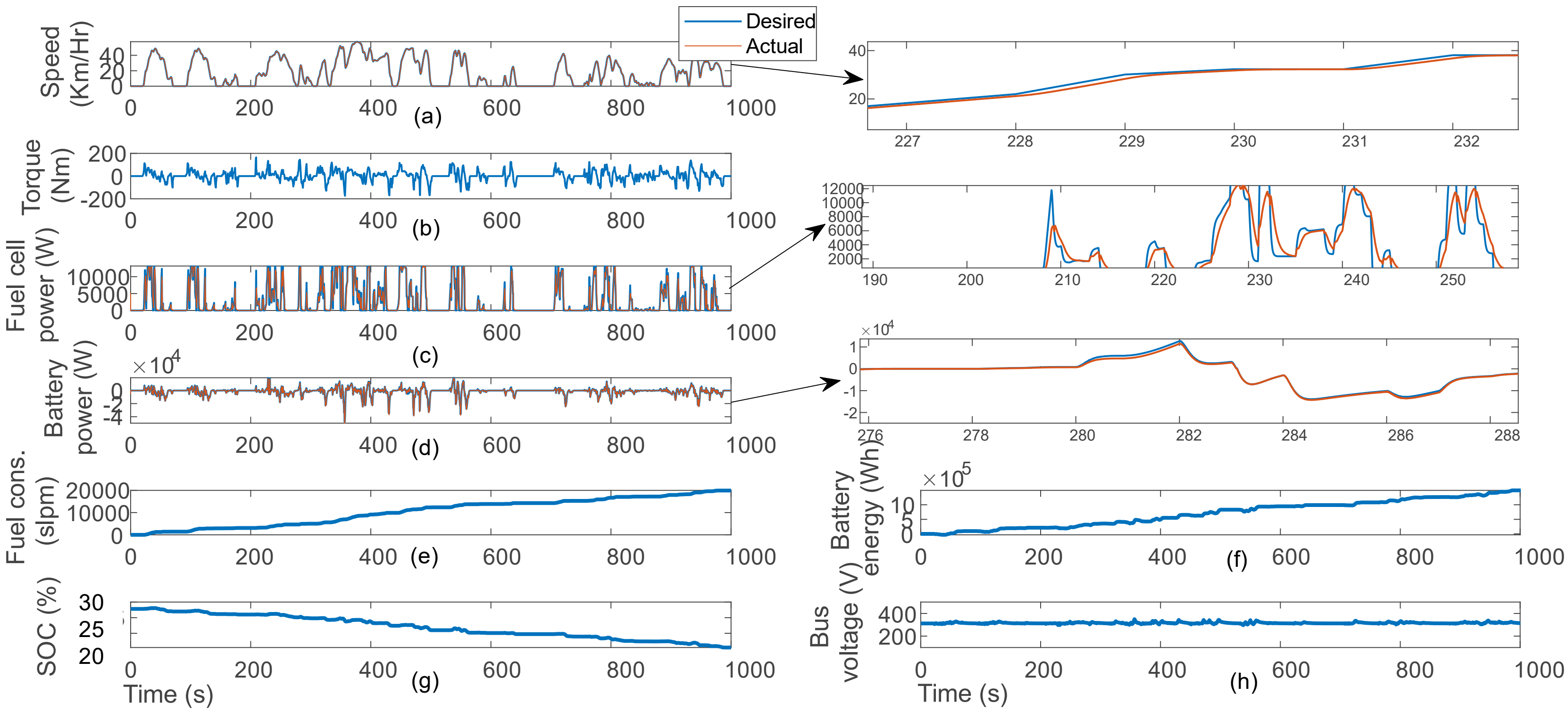
$$J_2 = \int_{t_o}^{t_f} E_{batt}\ dt$$

$$J_3 = \int_{t_o}^{t_f} P_{error}\ dt$$



« Simulation results »

- Local controller, AU driving cycle-



- Desired speed tracked
- DC bus voltage nearly constant
- Battery desired power tracked but fuel cell power tracking need improvement

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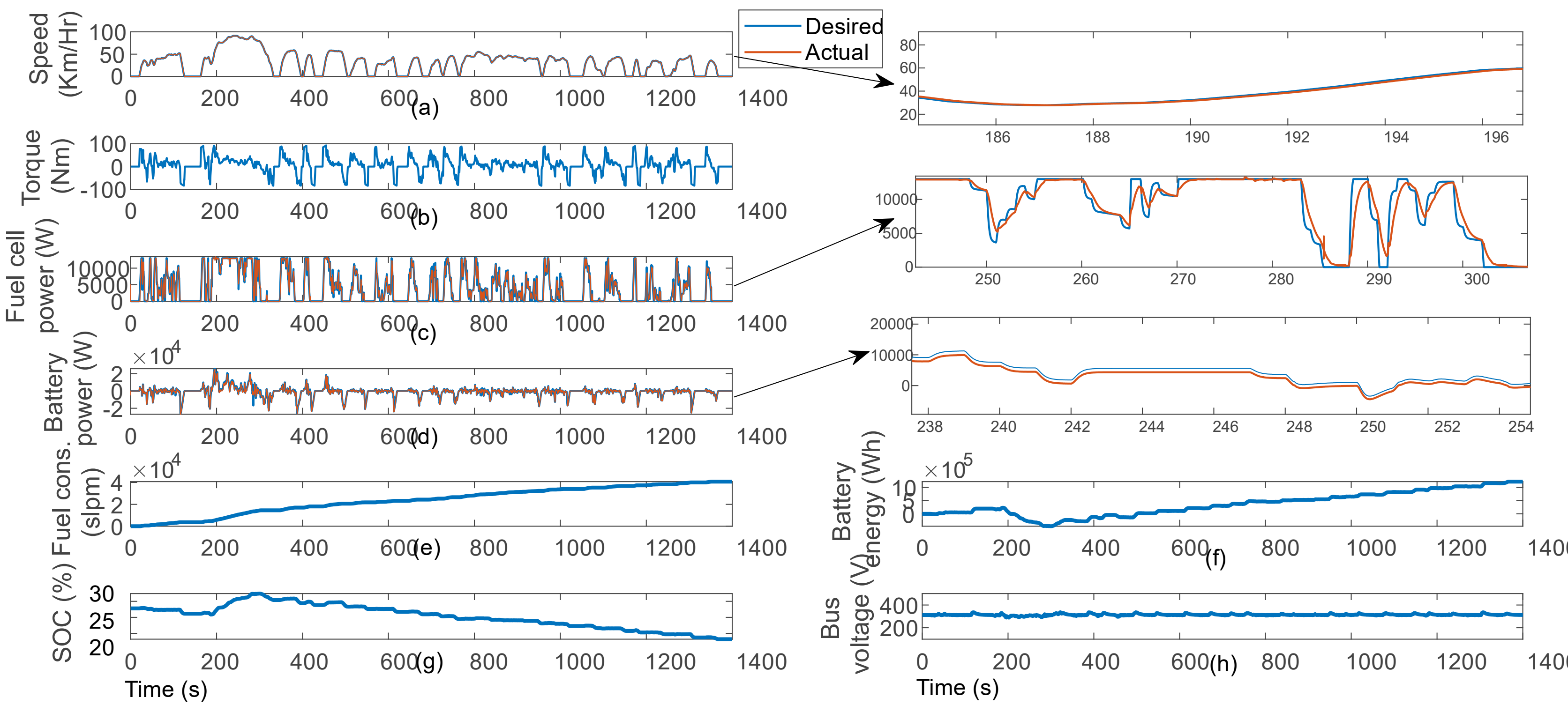
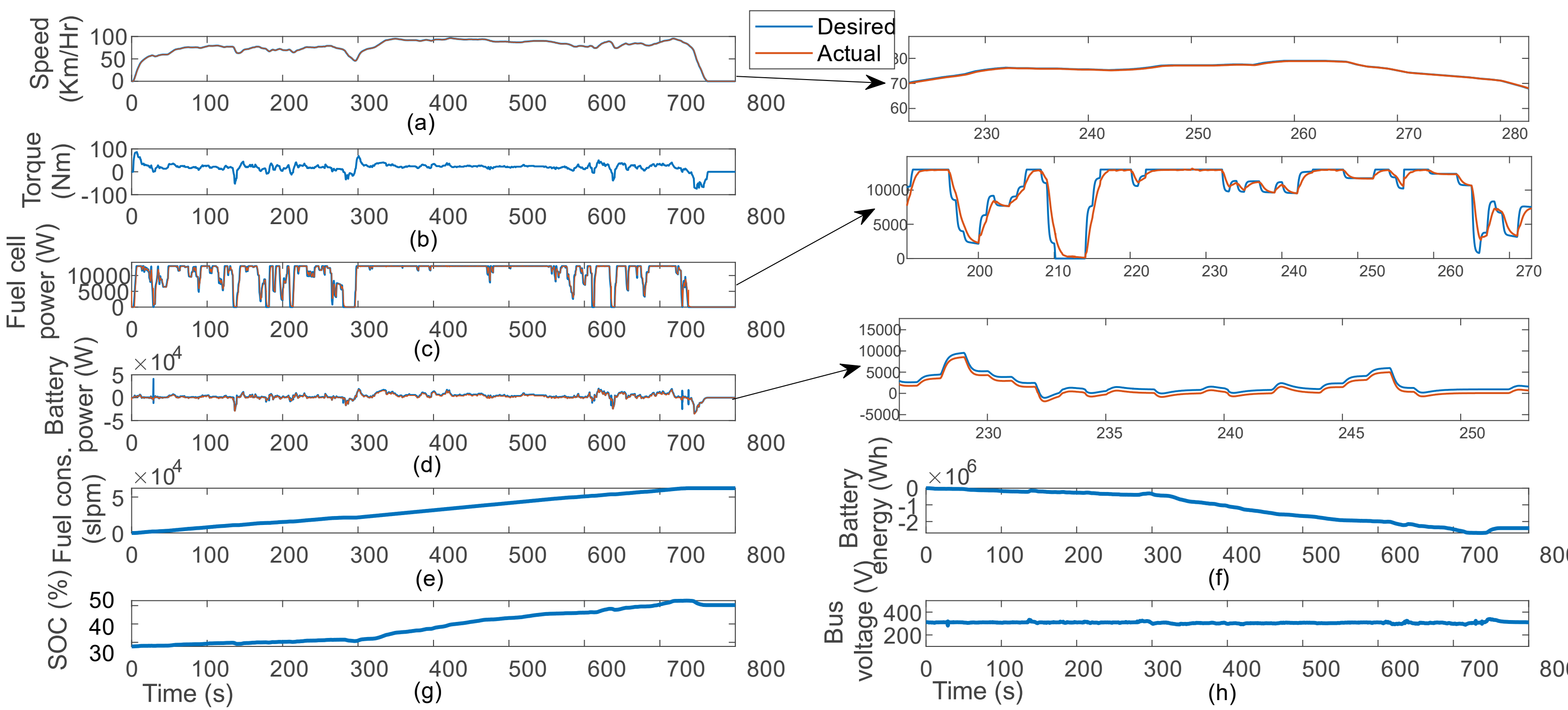
- Local controller, UDDS driving cycle-



- Desired speed tracked
- DC bus voltage nearly constant
- Fuel cell power tracking improved slightly

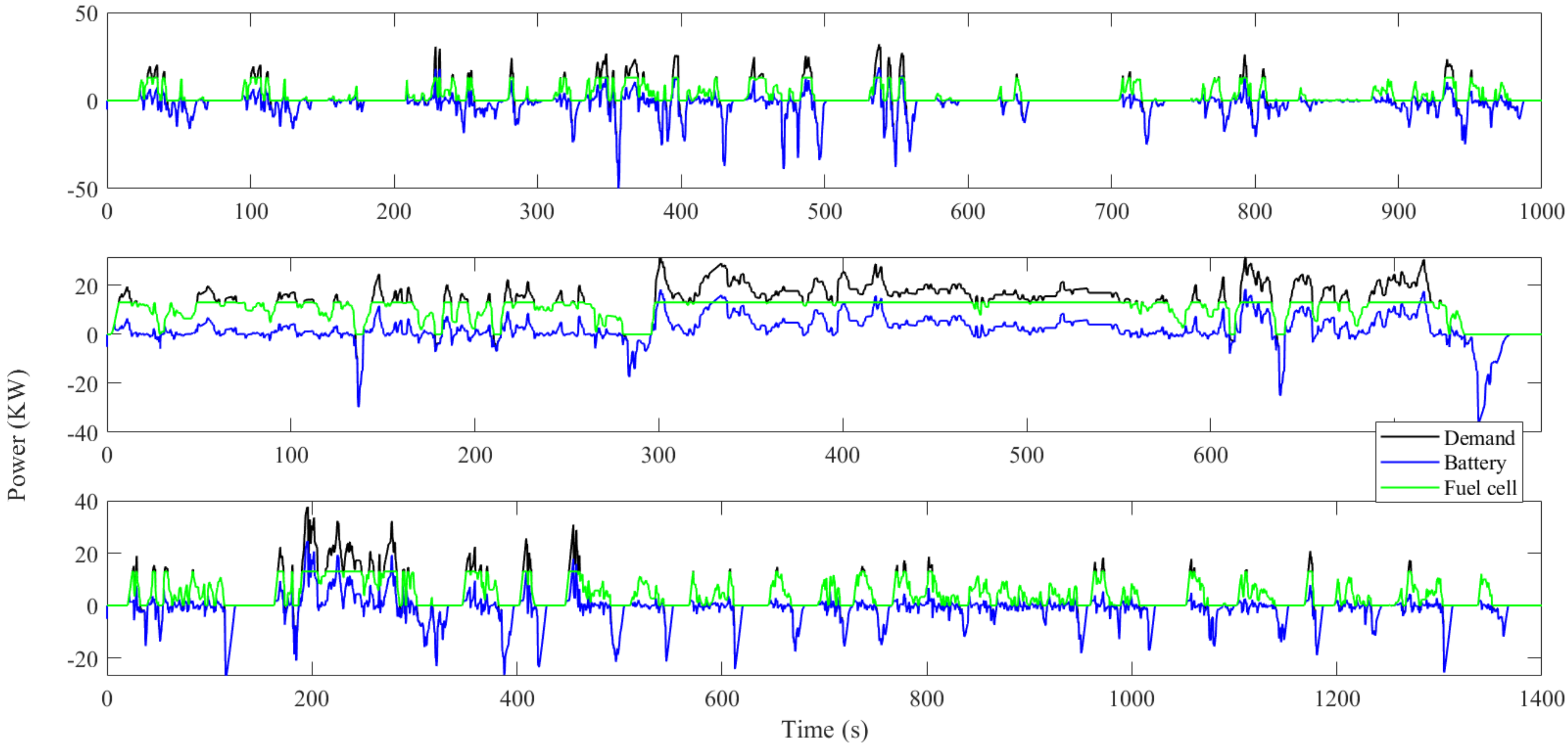
EMR-based energy management of a fuel cell hybrid vehicle

- Local controller, HWFET driving cycle-

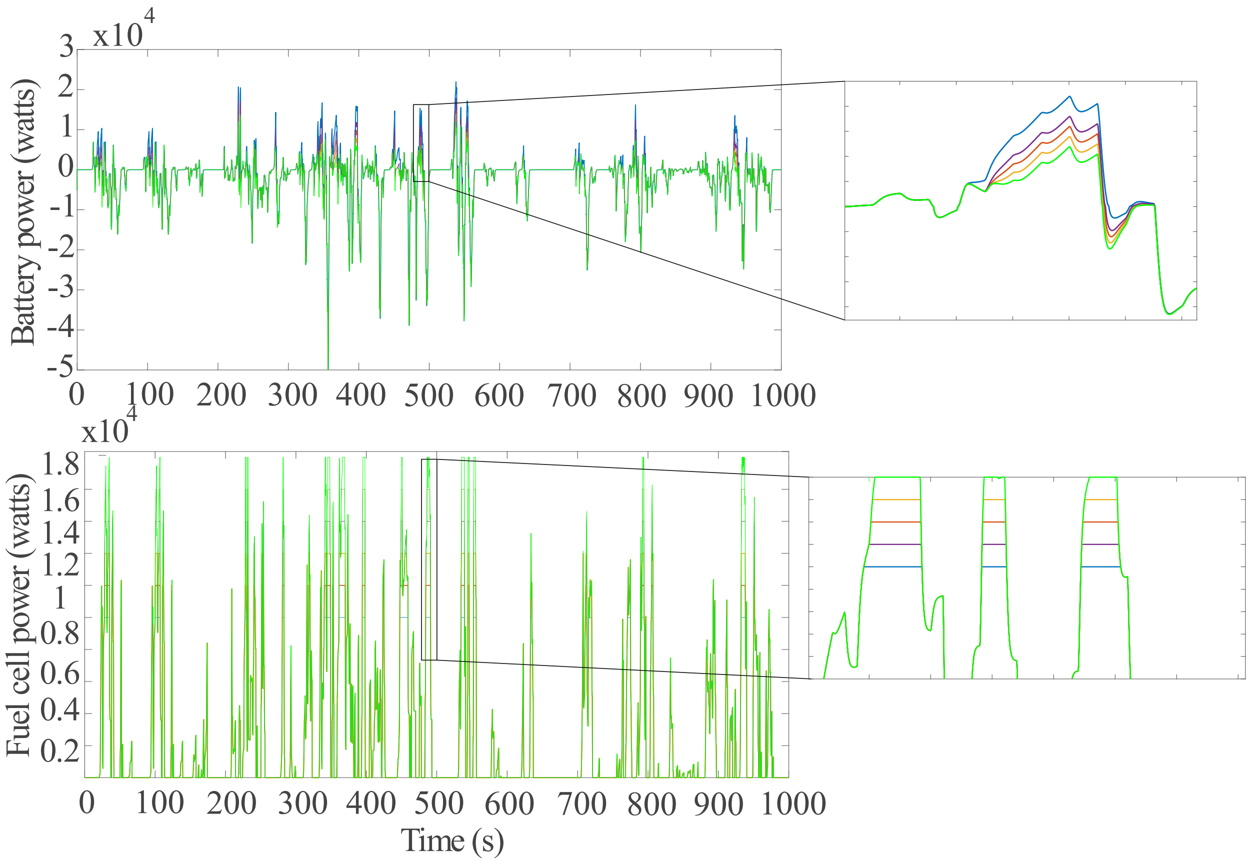


- Desired speed tracked
- DC bus voltage nearly constant
- Fuel cell power tracking significantly better

- Global controller for power split-



- Global controller's performance with AU, UDDS, HWFET driving cycles:
- Battery mostly taking over transients, fuel cell supplying average power



- Global controller's performance with AU driving cycle:
- As P_{FCmax} is varied, both fuel cell and battery power change
- When P_{FCmax} is decreased, fuel cell supplies least and battery compensates

« Conclusion »

- A fuel cell hybrid vehicle can combine the advantages of hybrid sources by employing an energy management strategy to optimally split the power between the sources

- An organized deduction of control structure involving both local and global control is feasible through EMR

- Optimization of maximum and minimum boundaries of fuel cell and battery operation can dynamically split the power between the sources and also respect the system constraints

- Multi-objective optimization can be used with prioritization between objectives

- First simulation results demonstrate the interest of the proposed EMS

« REFERENCES »

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