EMR'23, Lille (France)

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

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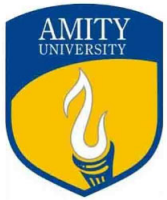


- Outline -

1 **Introduction**

2 **EMR and control of the FC vehicle**

3 **Multi-objective Energy management**

4 **Simulation results**

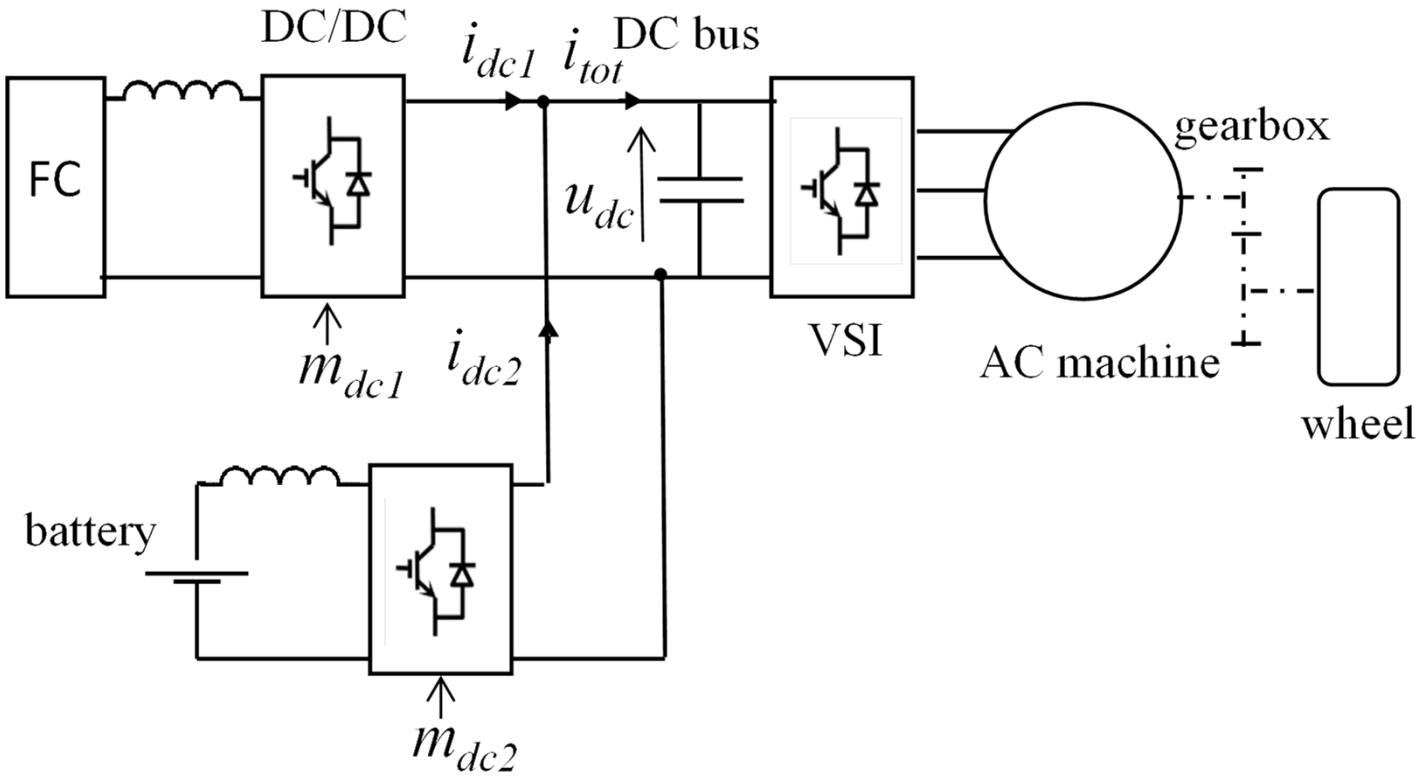
« Introduction »

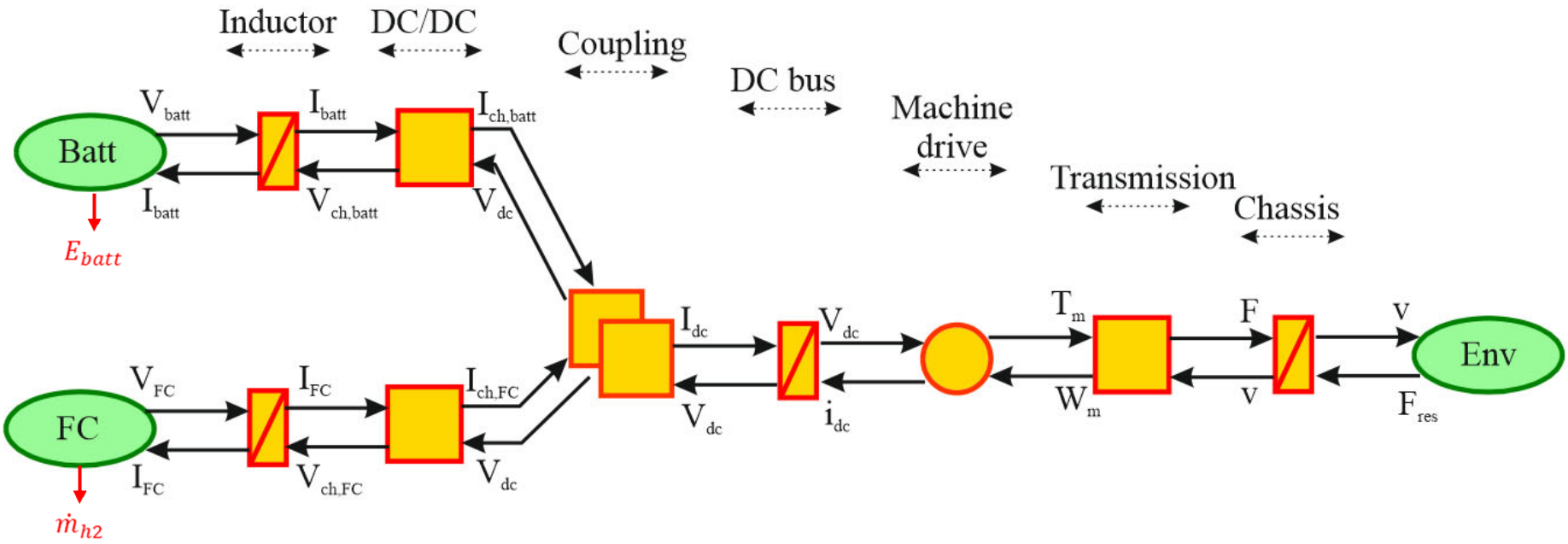
- Fuel cell hybrid vehicles combining advantages of high energy density of fuel cells and higher power density of batteries
- Energy management control strategy to efficiently manage power sharing between sources
- Multi-objective optimization with analysis of parameter variation on different objective functions.
- Prioritization of one or more objectives over others depending on the driving cycle

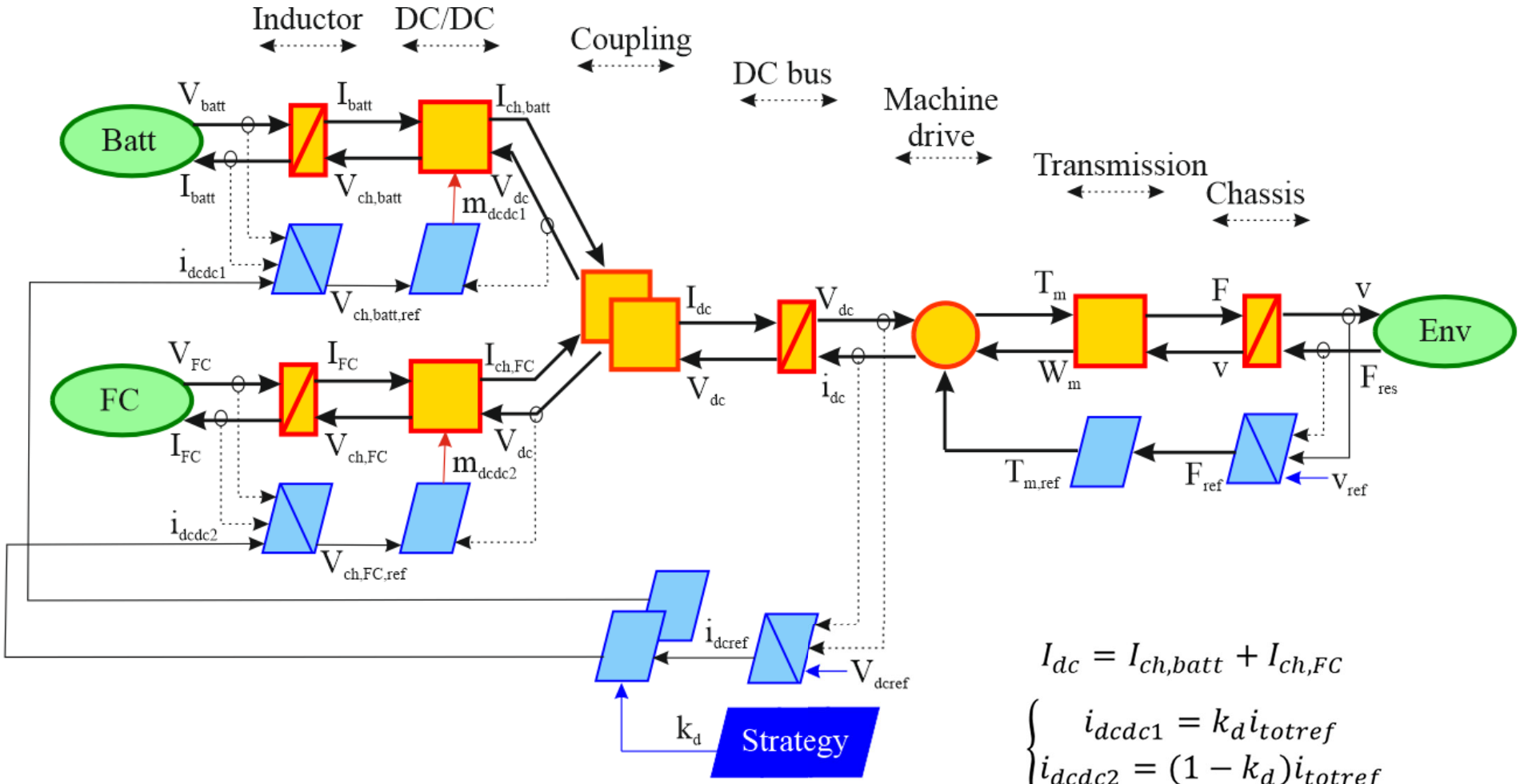
- An energy management strategy (EMS) along with a multi-objective optimization (MOO) for a fuel cell battery hybrid with three objectives: fuel consumption, battery energy, and drivability
- Energetic macroscopic representation (EMR) for powertrain representation and development of EMS.
- EMS comprises of battery and power management sub-modules, control by adjusting power split, and operating limits of dynamic rate limitation and dynamic saturation.

« EMR and control of the Studied FC vehicle »

- Hybrid topology with a battery as secondary source



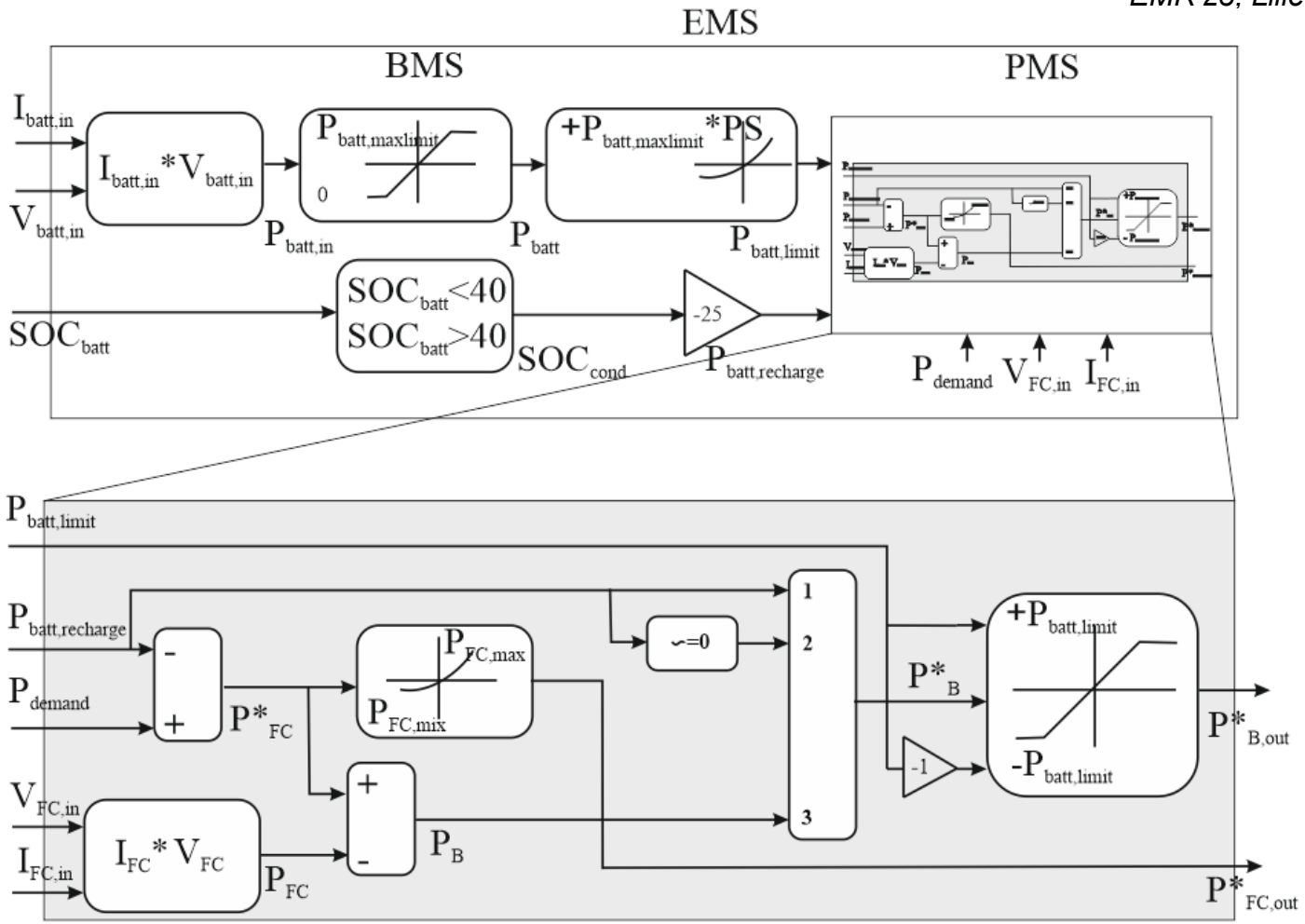

Inductor
DC/DC
Coupling
DC bus
Machine drive
Transmission
Chassis
Batt
FC
Env
V_{batt}
I_{batt}
$I_{ch,batt}$
$V_{ch,batt}$
V_{dc}
E_{batt}
V_{FC}
I_{FC}
$I_{ch,FC}$
$V_{ch,FC}$
$\dot{m}_{h2}$
I_{dc}
i_{dc}
T_m
W_m
F
v
F_{res}



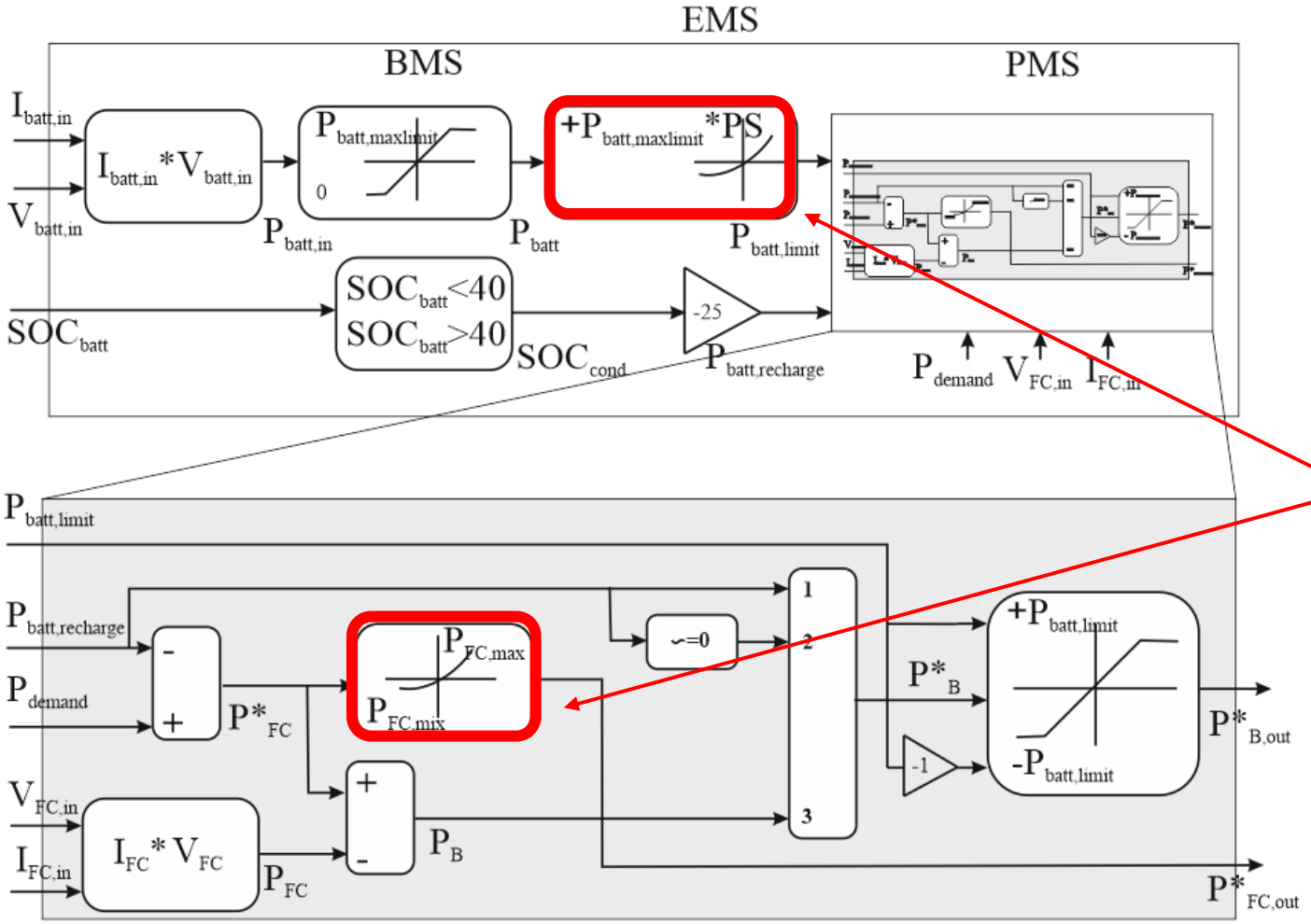
$$I_{dc} = I_{ch,batt} + I_{ch,FC}$$

$$\begin{cases} i_{dcdc1} = k_d i_{totref} \\ i_{dcdc2} = (1 - k_d) i_{totref} \end{cases}$$

« Multi-objective Energy Management Strategy »



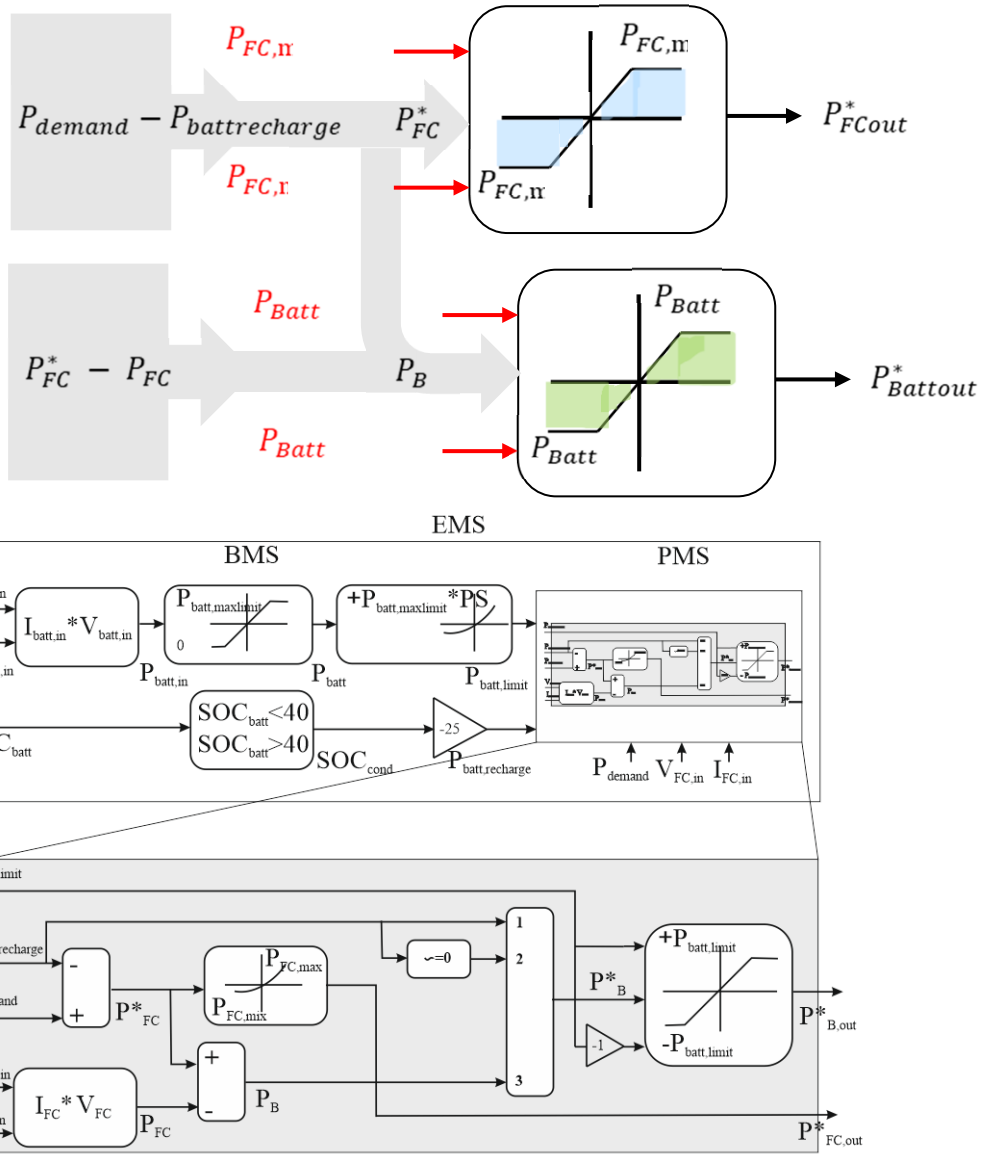
- Optimization of fuel cell and battery operation limits
- Dynamic saturation and rate limitation

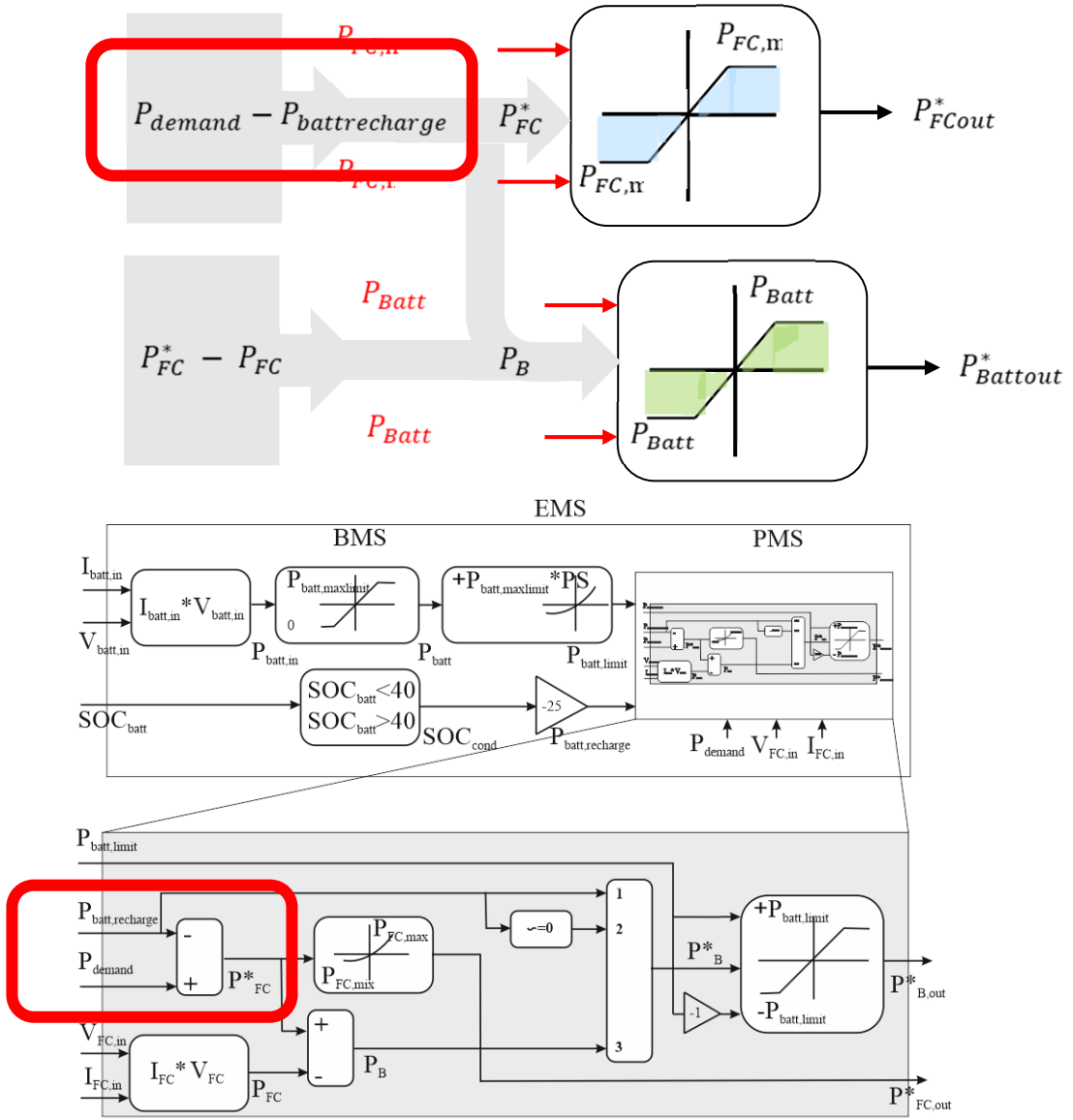


Dynamic saturation and rate limitation>> Optimization of boundaries

- Optimization of $\pm P_{battmax}$ *and* $\pm P_{FCmax}$

- Energy Management-




$P_{demand} - P_{battrecharge}$
P^*_{FC}
$P_{FC,max}$
$P_{FC,min}$
P^*_{FCout}
$P^*_{FC} - P_{FC}$
P_B
P_{Batt}
$P^*_{Battout}$
EMS
BMS
PMS
$I_{batt,in}$
$V_{batt,in}$
$I_{batt,in} * V_{batt,in}$
$P_{batt,maxlimit}$
$+P_{batt,maxlimit} * PS$
$P_{batt,in}$
P_{batt}
$P_{batt,limit}$
SOC_{batt}
$SOC_{batt}<40$
$SOC_{batt}>40$
SOC_{cond}
-25
$P_{batt,recharge}$
P_{demand} $V_{FC,in}$ $I_{FC,in}$
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P^*_{FC}
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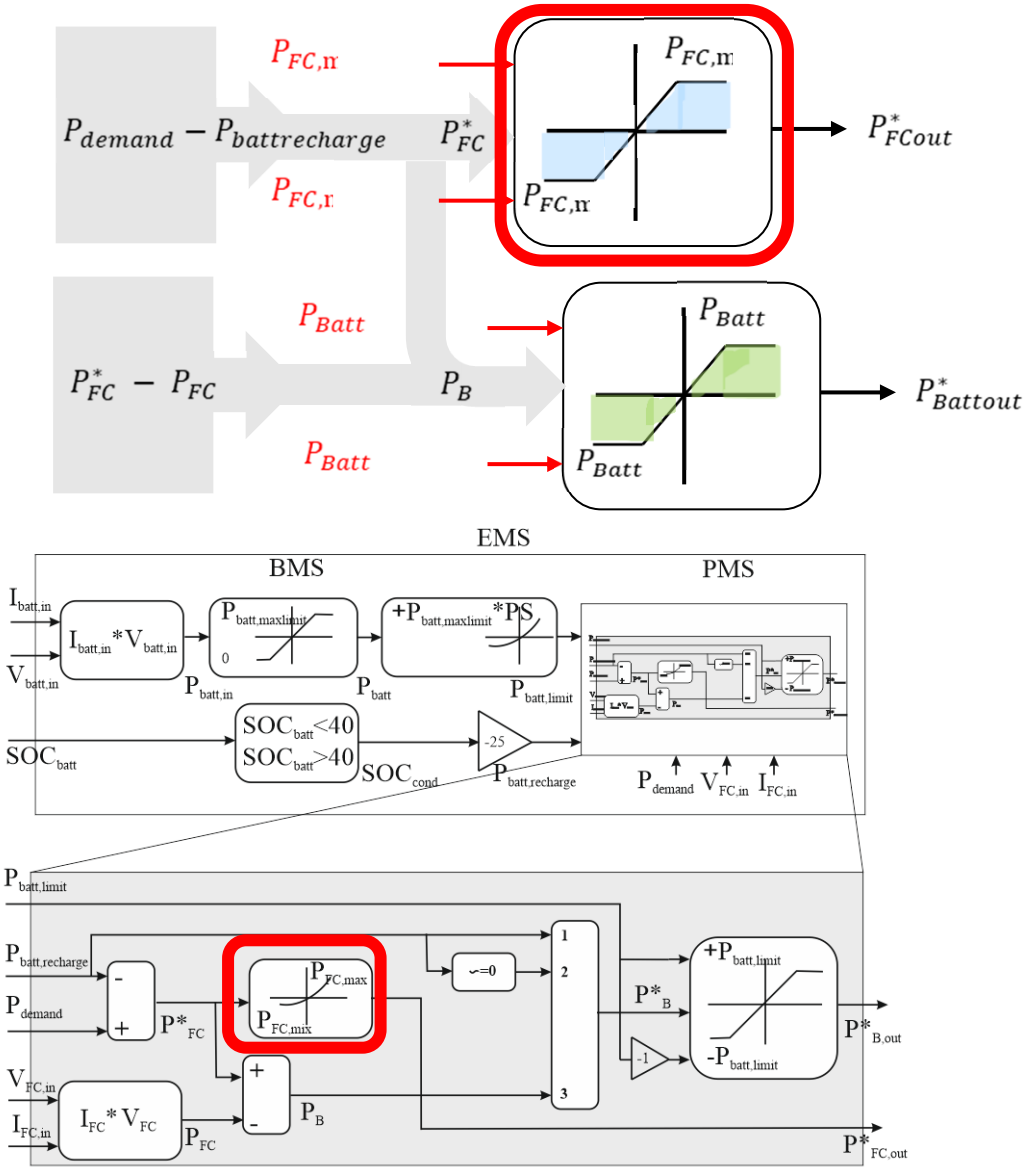
$P_{FC,mix}$
P^*_B
$+P_{batt,limit}$
$-P_{batt,limit}$
$P^*_{B,out}$
$V_{FC,in}$
$I_{FC,in}$
$I_{FC} * V_{FC}$
P_{FC}
P_B
$P^*_{FC,out}$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$P_{FC,min}$
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$+P_{batt,maxlimit} * PS$
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$P_{FC,mix}$
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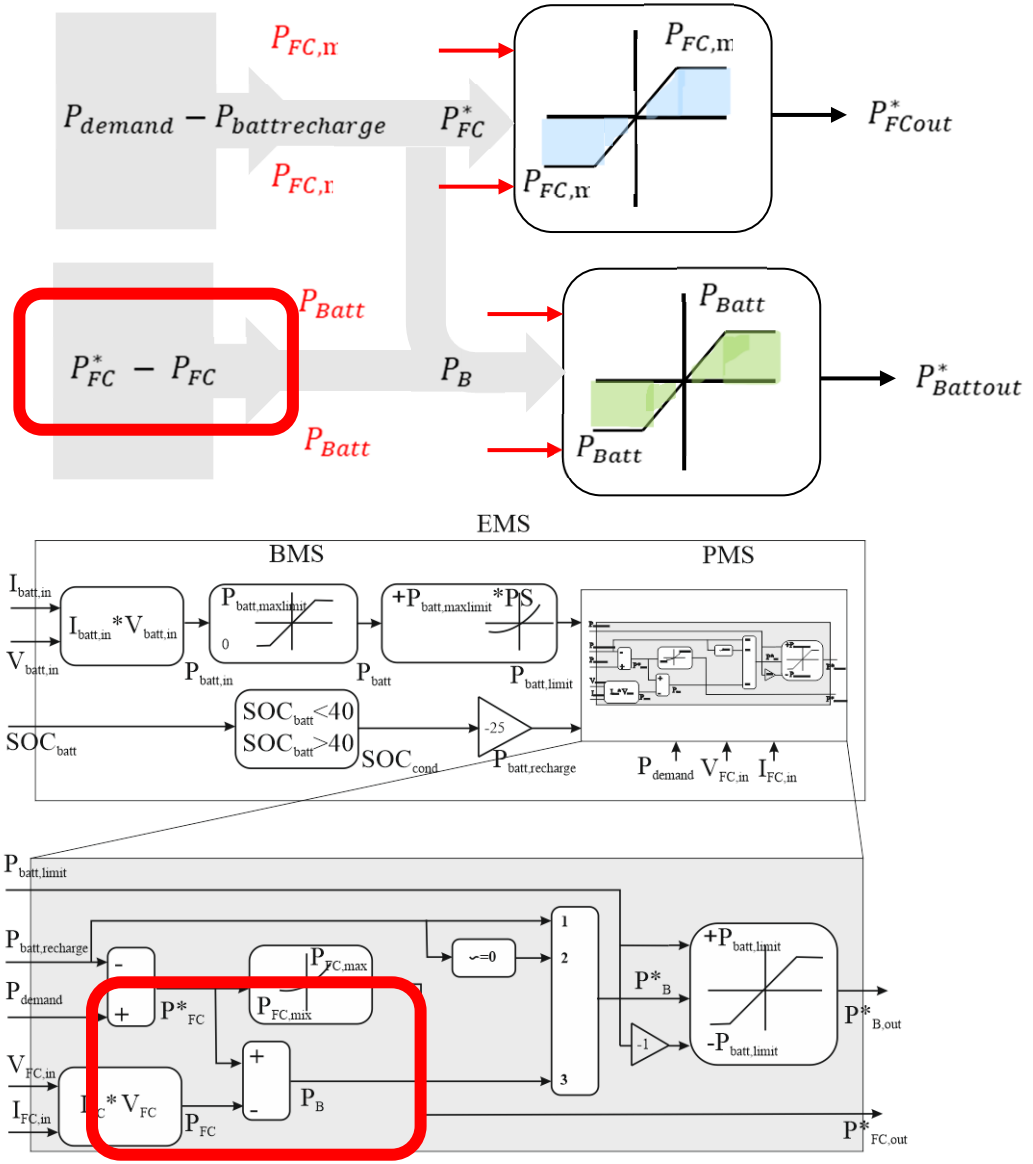
P^*_B
$+P_{batt,limit}$
$-P_{batt,limit}$
$P^*_{B,out}$
$P^*_{FC,out}$
$I_{FC} * V_{FC}$
P_{FC}
P_B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$I_{FC,in} * V_{FC}$
P_{FC}
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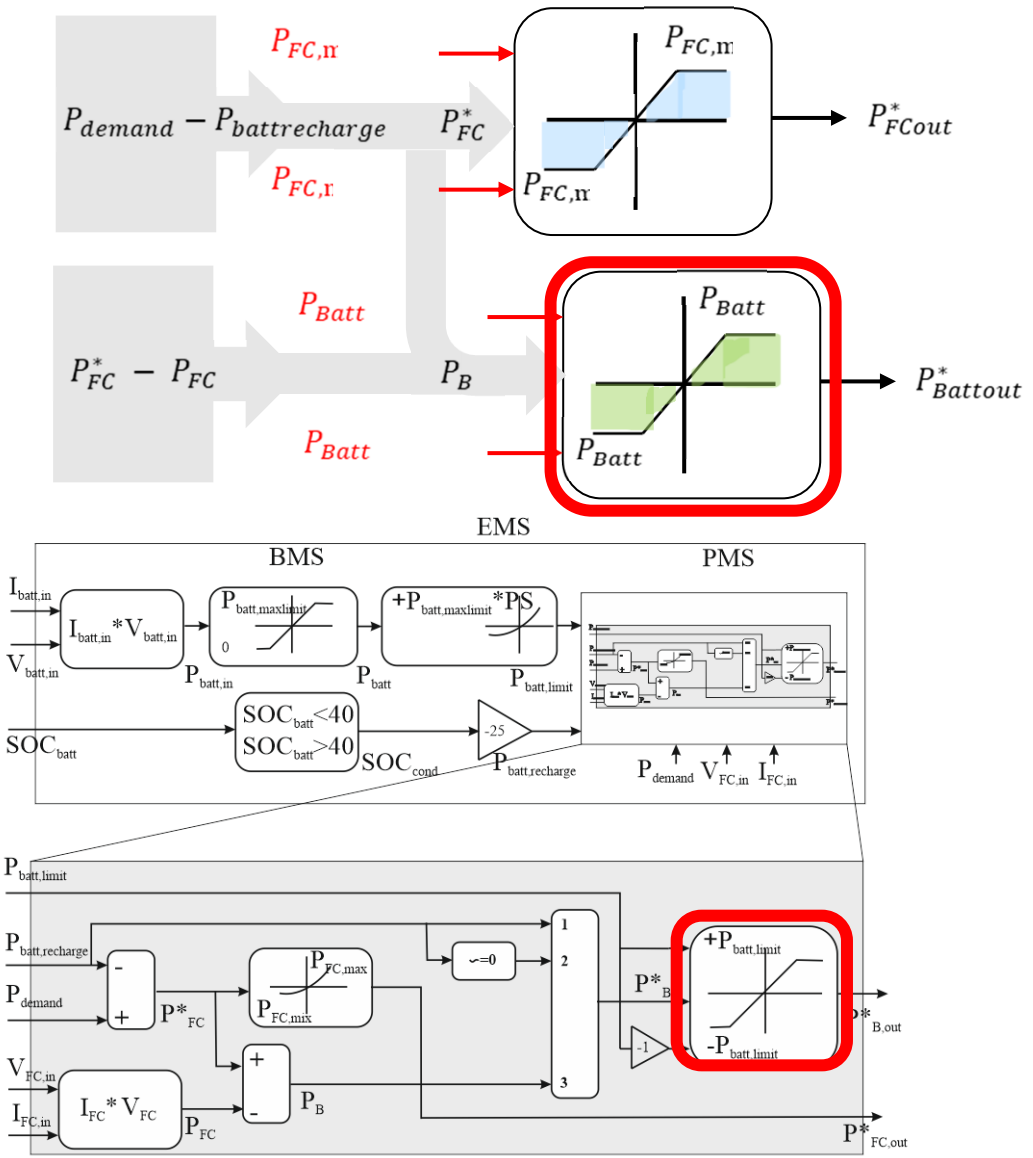
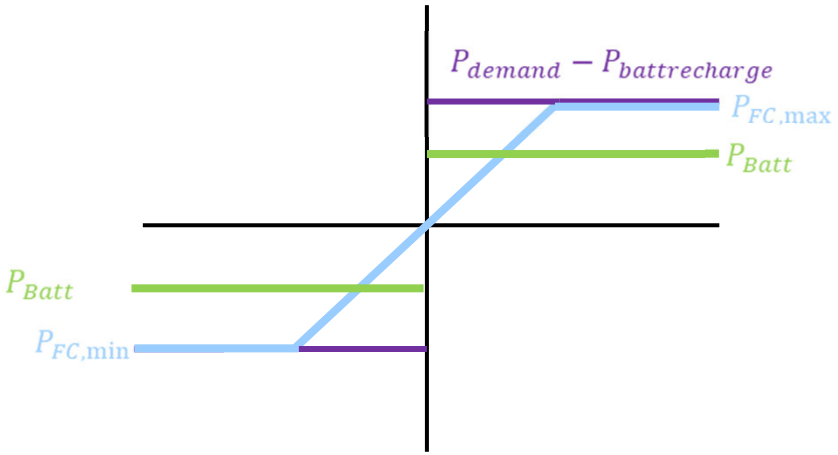
- Energy Management-

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$P_{FC,max}$
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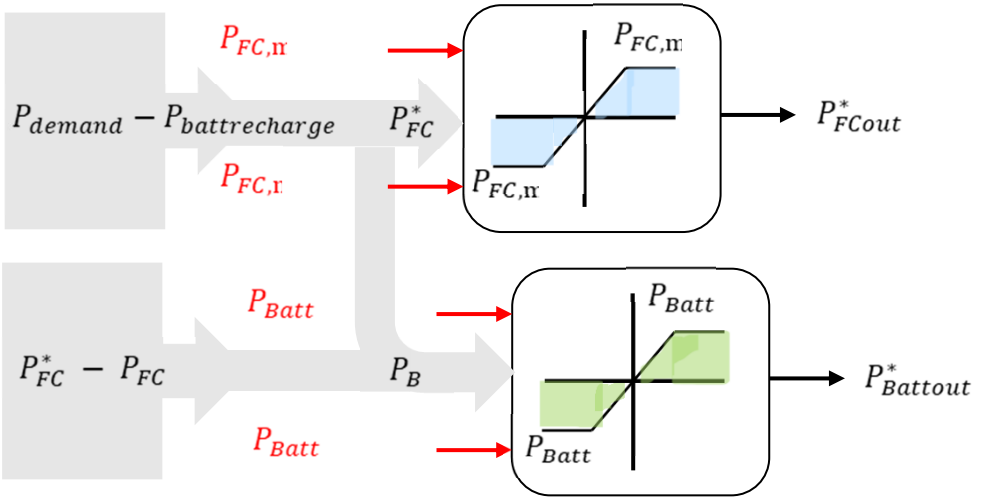
$P_{FC,min}$


$P_{FC,m}$
$P_{demand} - P_{battrecharge}$
P^*_{FC}
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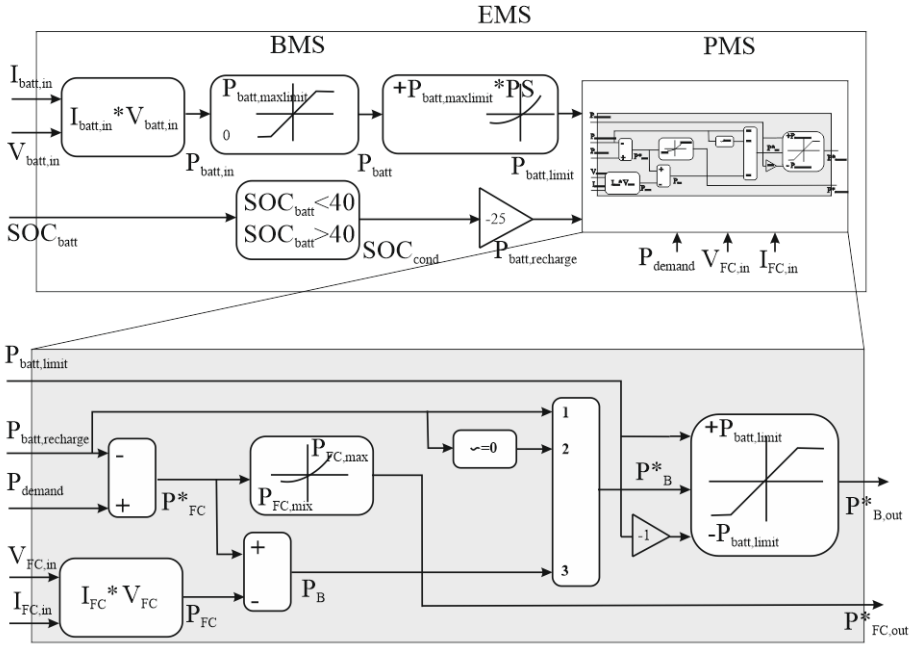
$P_{FC,m}$
P^*_{FCout}
P_{Batt}
$P^*_{FC} - P_{FC}$
P_B
P_{Batt}
P_{Batt}
P_{Batt}
$P^*_{Battout}$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P_{demand}
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P^*_B
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$-P_{batt,limit}$
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P_{FC}
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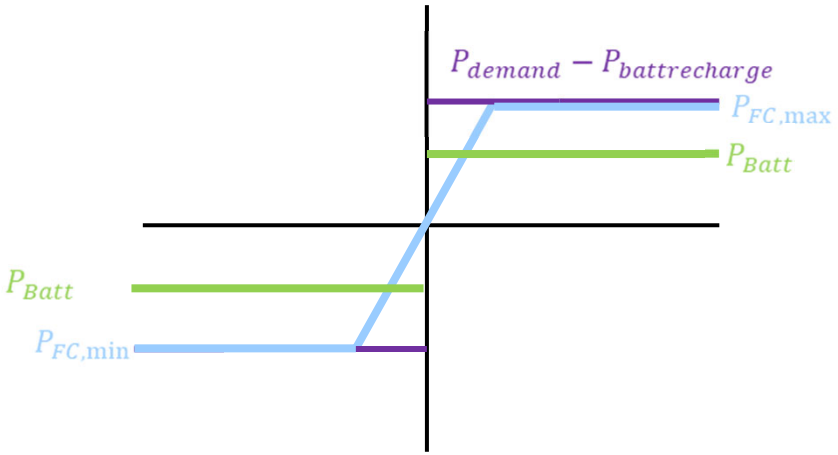
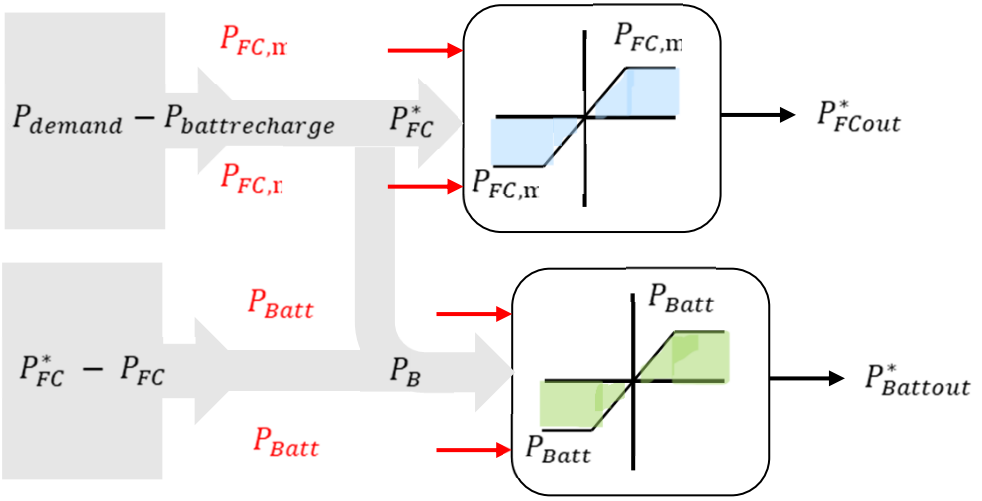
$P^*_{FC,out}$


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


$P_{FC,m}$
$P_{demand} - P_{battrecharge}$
P^*_{FC}
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$P_{FC,m}$
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P^*_{FCout}
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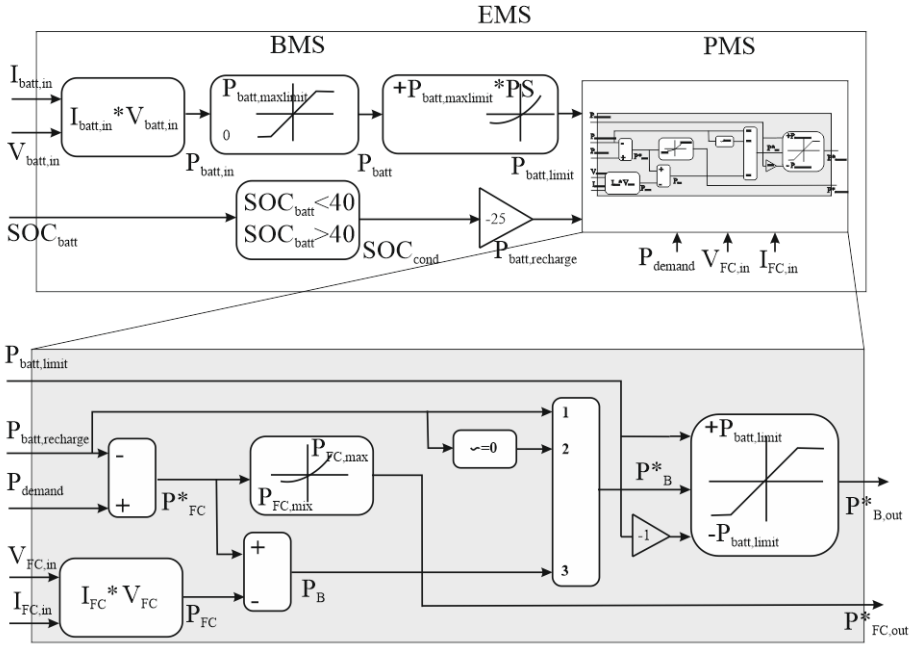
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P^*_B
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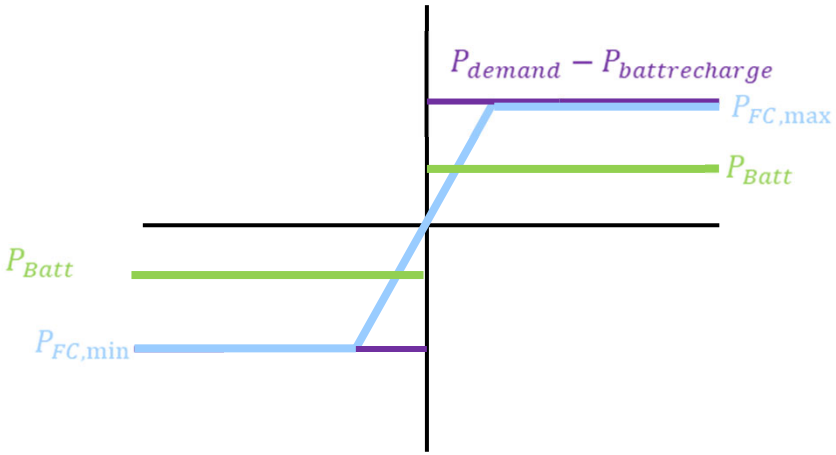
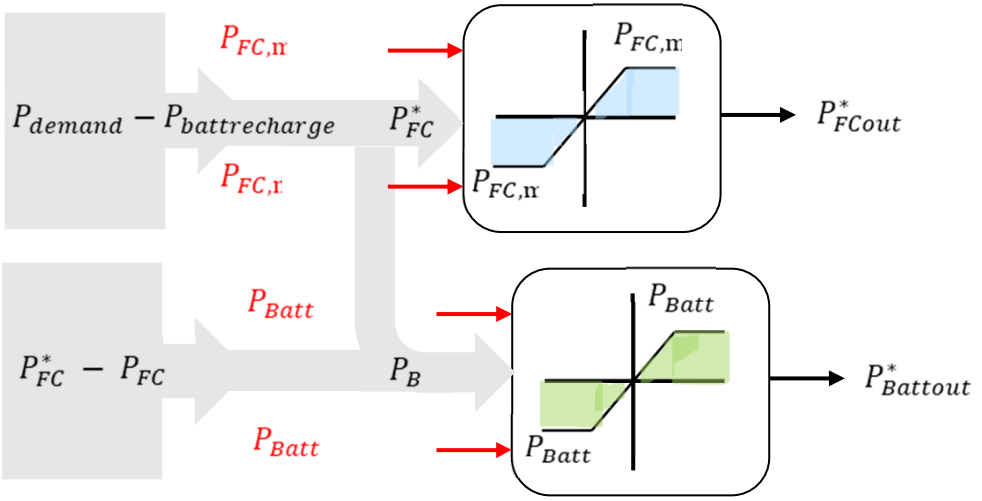
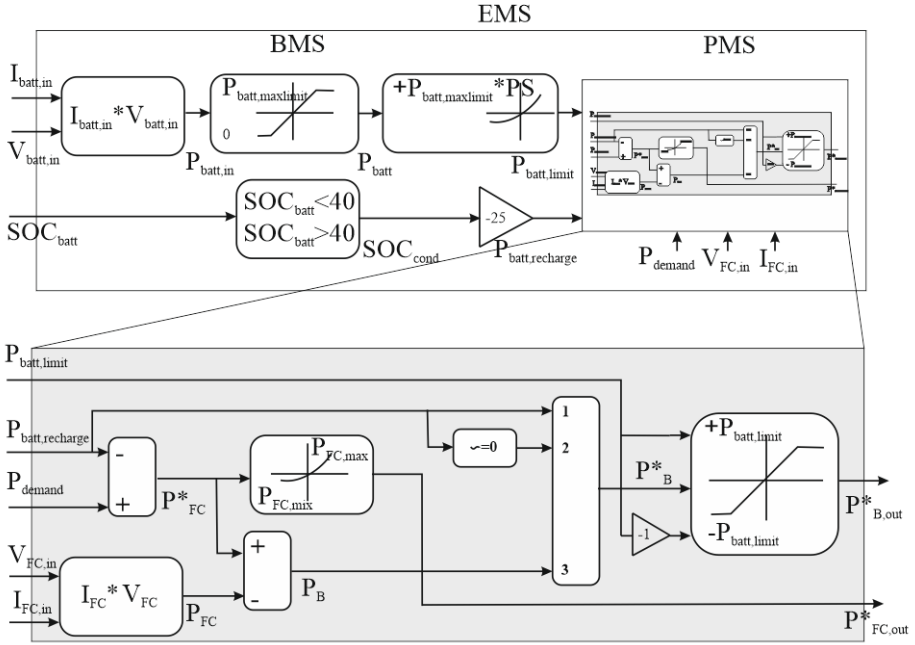
$-P_{batt,limit}$
$P^*_{B,out}$
$V_{FC,in}$
$I_{FC,in}$
$I_{FC} * V_{FC}$
P_{FC}
P_B
$P^*_{FC,out}$

EMR-based energy management of a fuel cell hybrid vehicle

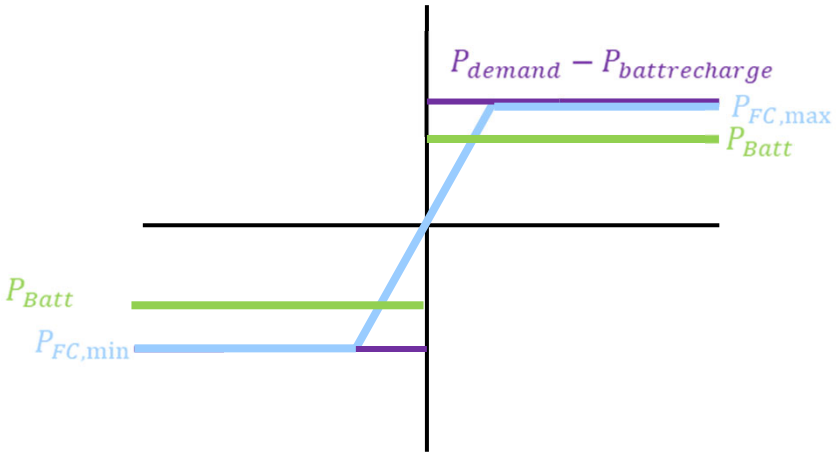
- Energy Management-

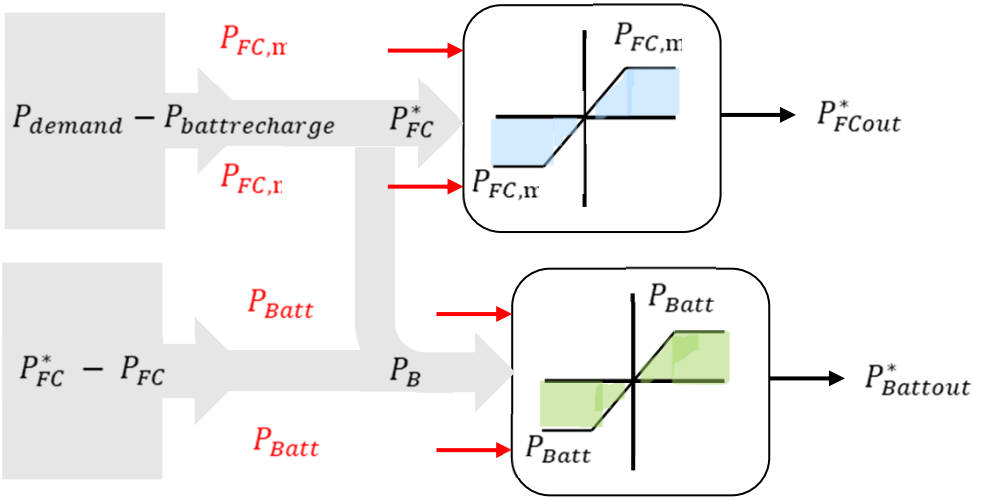


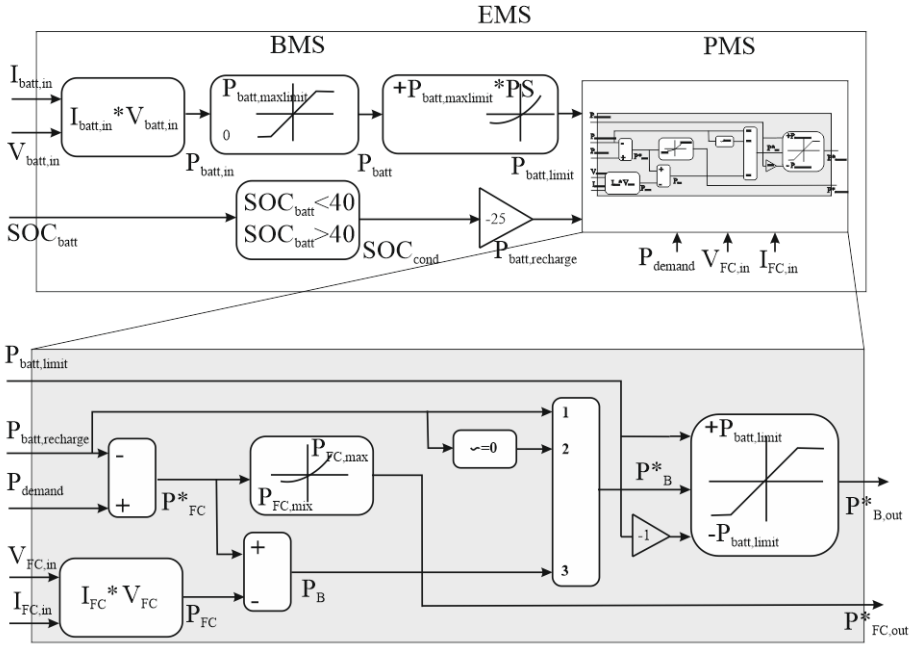


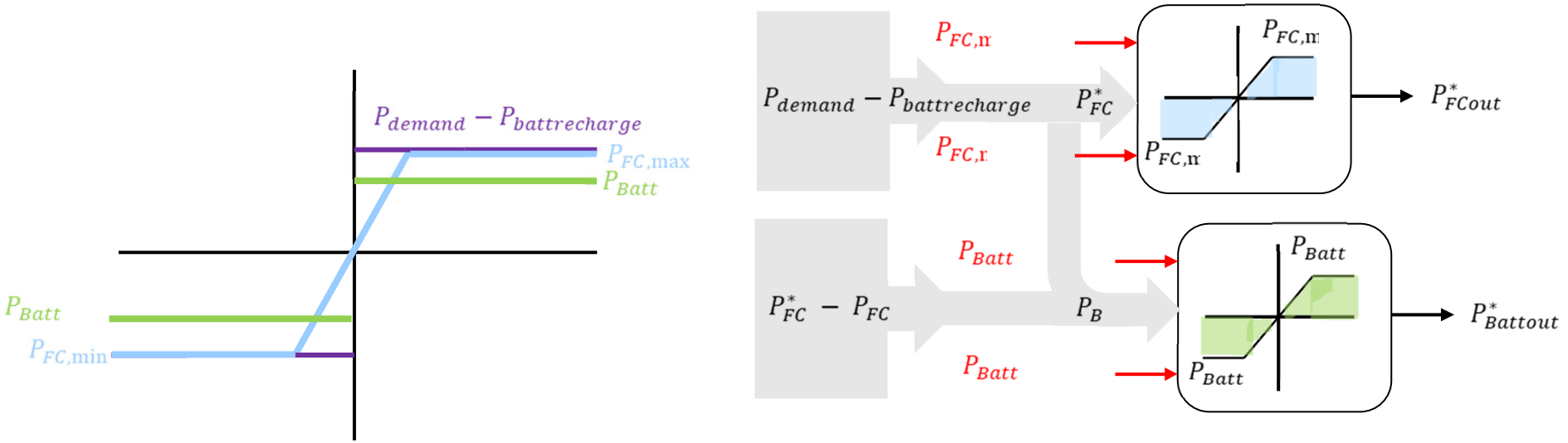


- Energy Management Stategy -









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

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

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

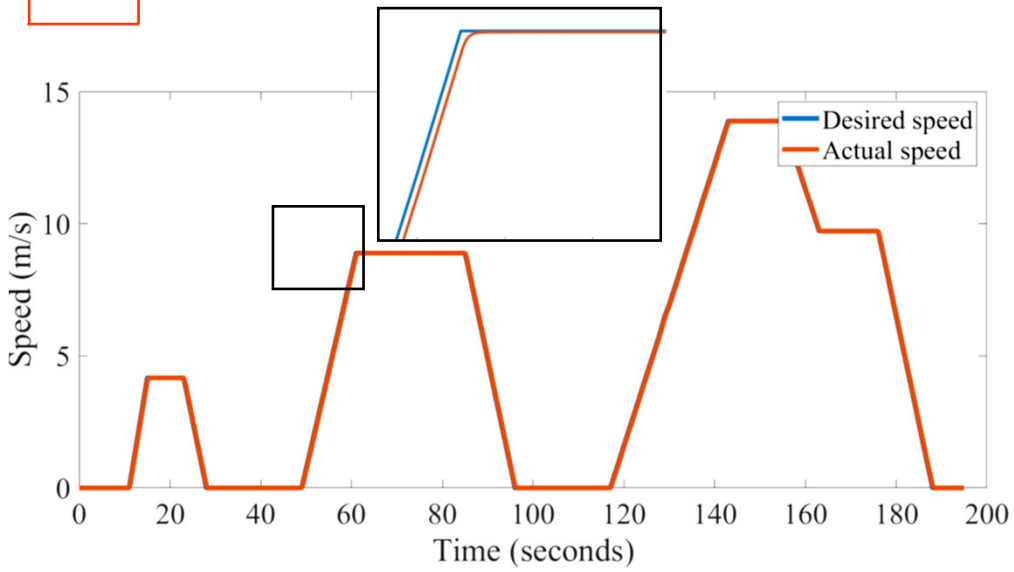
$$J_2 = \int_{t_o}^{t_f} E_{batt}\ dt$$

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

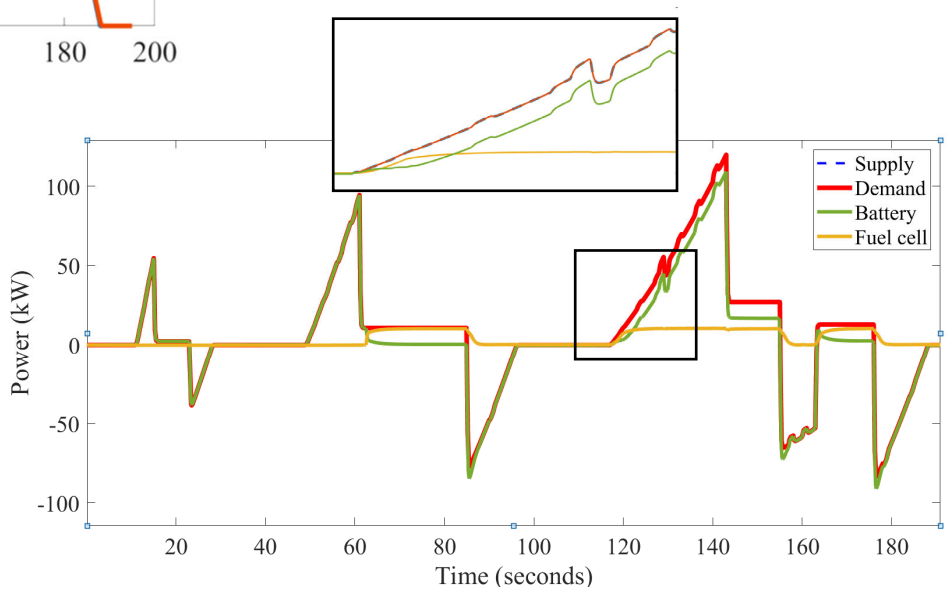
« Simulation results »

EMR-based energy management of a fuel cell hybrid vehicle

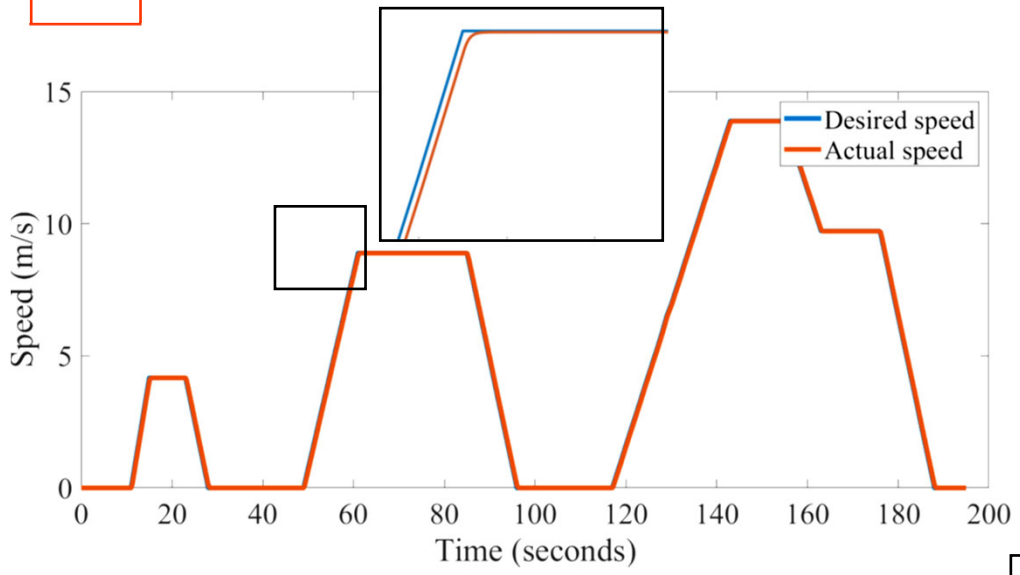
- Powertrain dynamics-



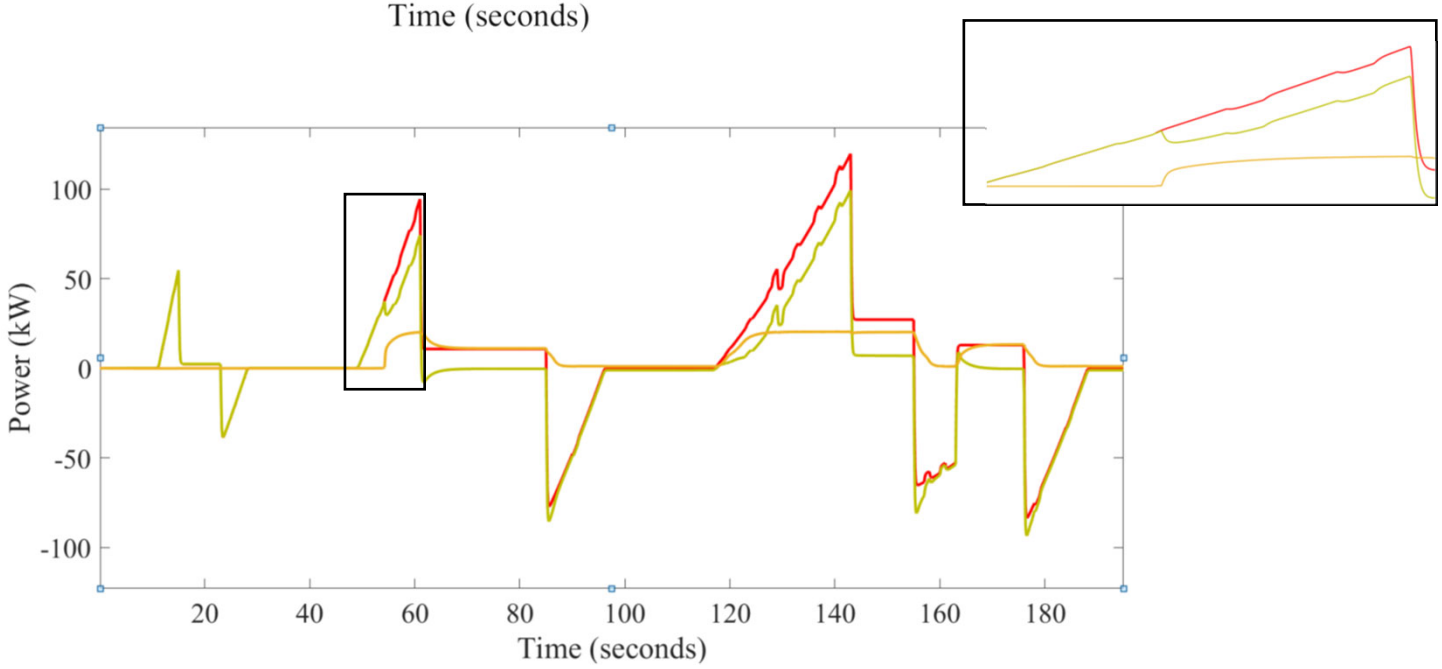
$P_{battmin}$	-100KW
$P_{battmax}$	100KW
P_{FCmax}	15KW
P_{FCmin}	2KW



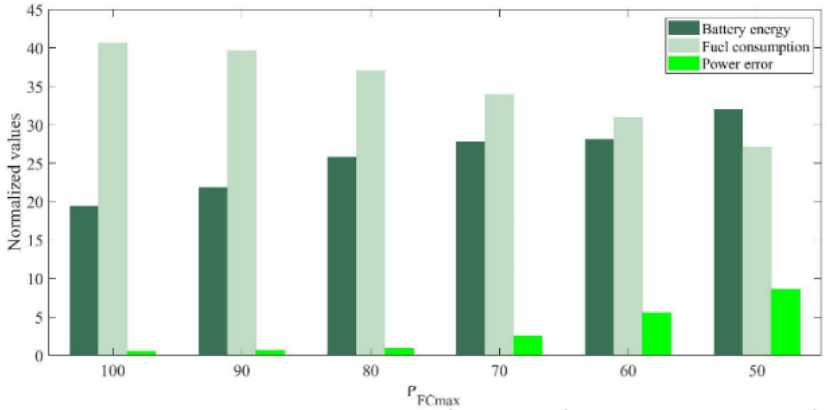
- Powertrain dynamics-



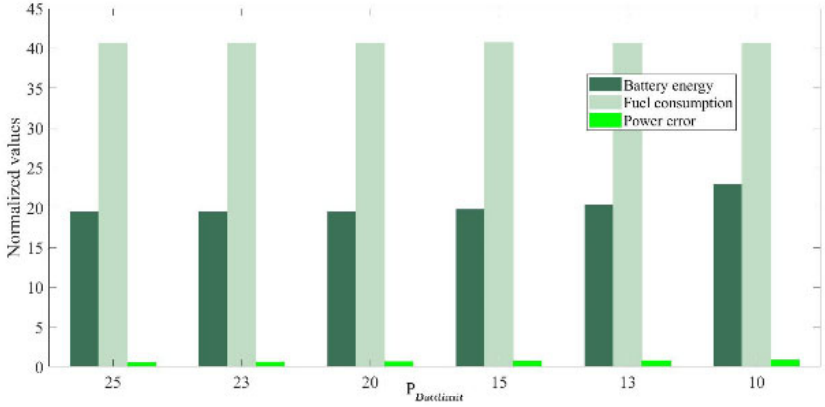
$P_{battmin}$	-97KW
$P_{battmax}$	97KW
P_{FCmax}	20KW
P_{FCmin}	2KW



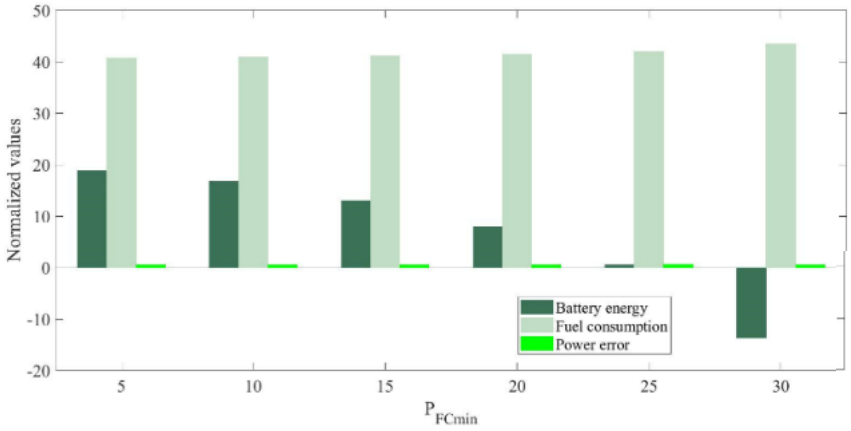
- Battery energy, fuel consumption and power error -



P_{FCmin} as constant and equal to 1KW and $P_{battlimit}$ is 25 KW

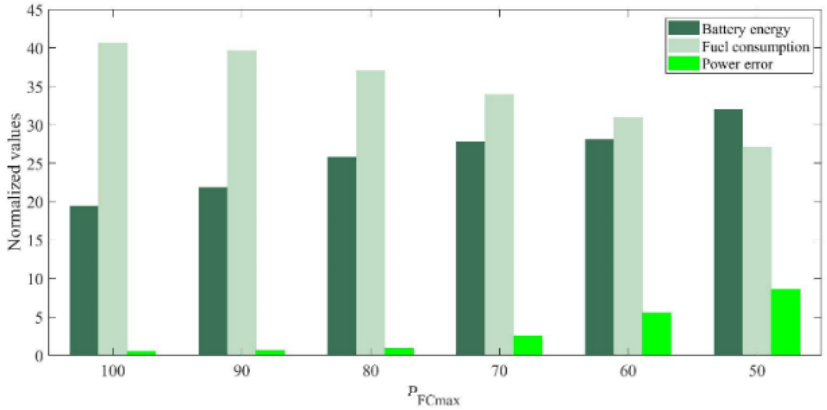


P_{FCmax} as constant and equal to 100KW and $P_{battlimit}$ is 25 KW

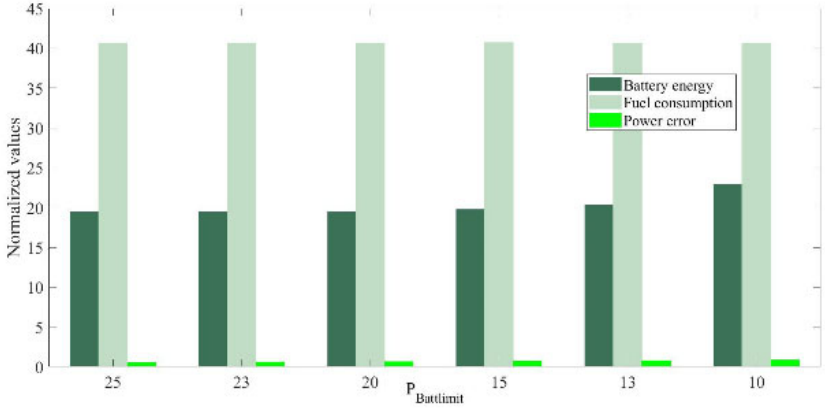


P_{FCmax} as constant and equal to 100KW, P_{FCmin}(KW) is constant and equal to 1KW

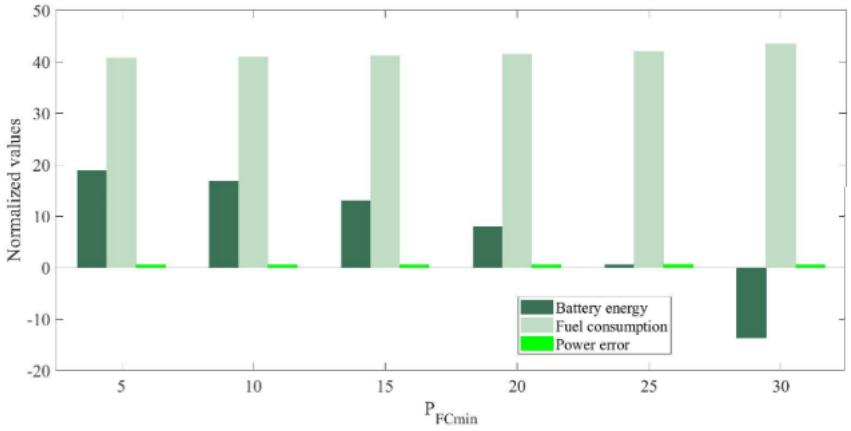
- Battery energy, fuel consumption and power error -



Battery energy increasing by 39.34% , fuel consumption decreasing by 31.85% and error increasing by 94% as P_{FCmax} decreased



Battery energy improving by 97% , fuel consumption increasing by 6.2% and error increasing by 0.7%



Battery energy improving by 18% , fuel consumption increasing by 0.05% and error increasing by 37% as $\pm P_{battmax}$ is decreased.

« Conclusion »

- 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

« BIOGRAPHIES AND REFERENCES »

EMR-based energy management of a fuel cell hybrid vehicle

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Coordinator of the CUMIN interdisciplinary programme
Chair of the steering committee of IEEE-VPP Ccnference
PhD in Electrical Engineering at University of Toulouse (1995)
Research topics: EMR formalism, HIL testing, control & EV-HEVs

Alain.Bouscayrol@univ-lille.fr

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