FIRST-PASS SYSTEM SUCCESS

APPLICATION WORKSHOPS FOR
HIGH-PERFORMANCE ELECTRONIC DESIGN

Fuel Cell Stack Control and Interface Converter

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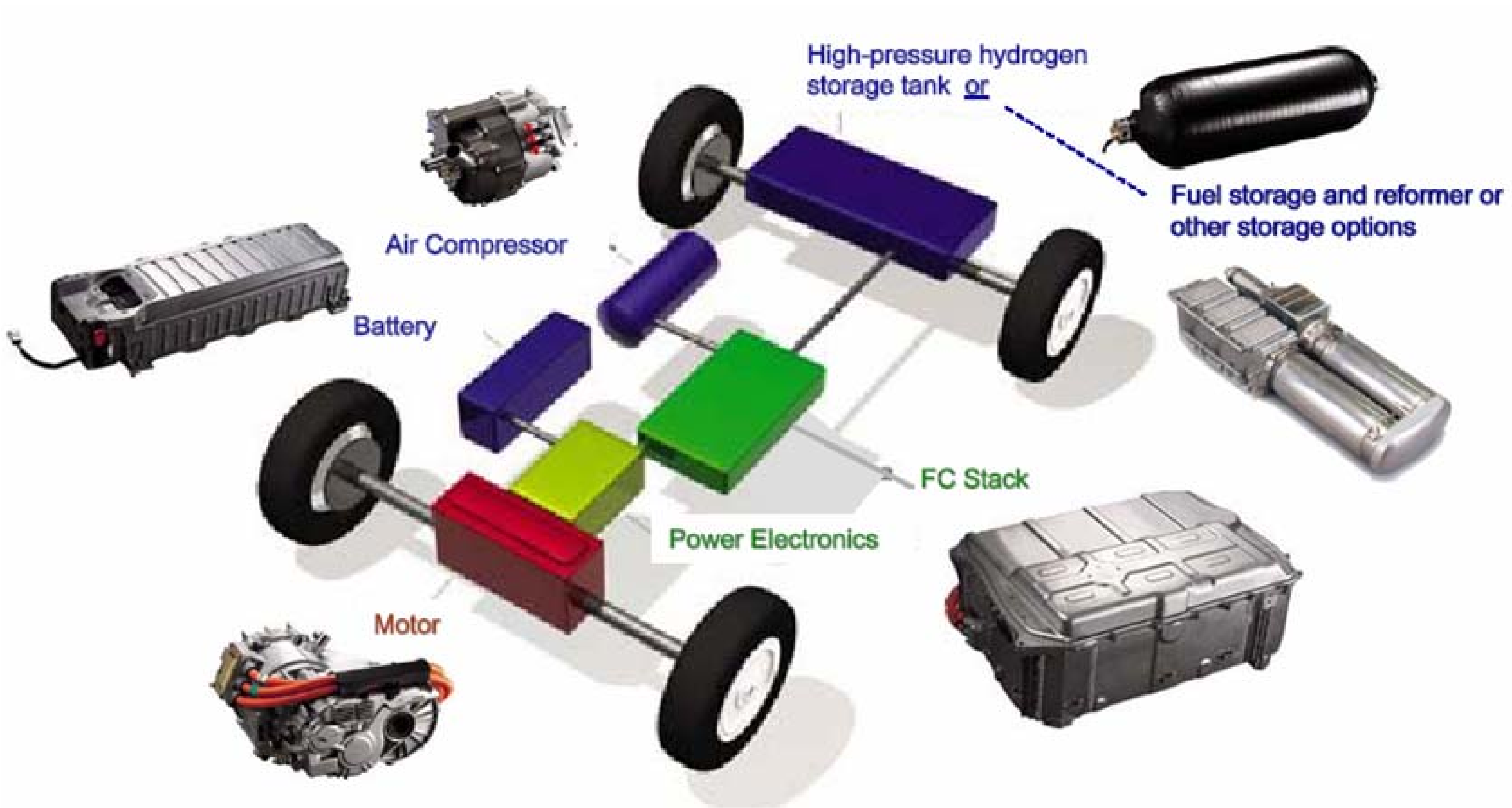
Fuel Cell Vehicle Component



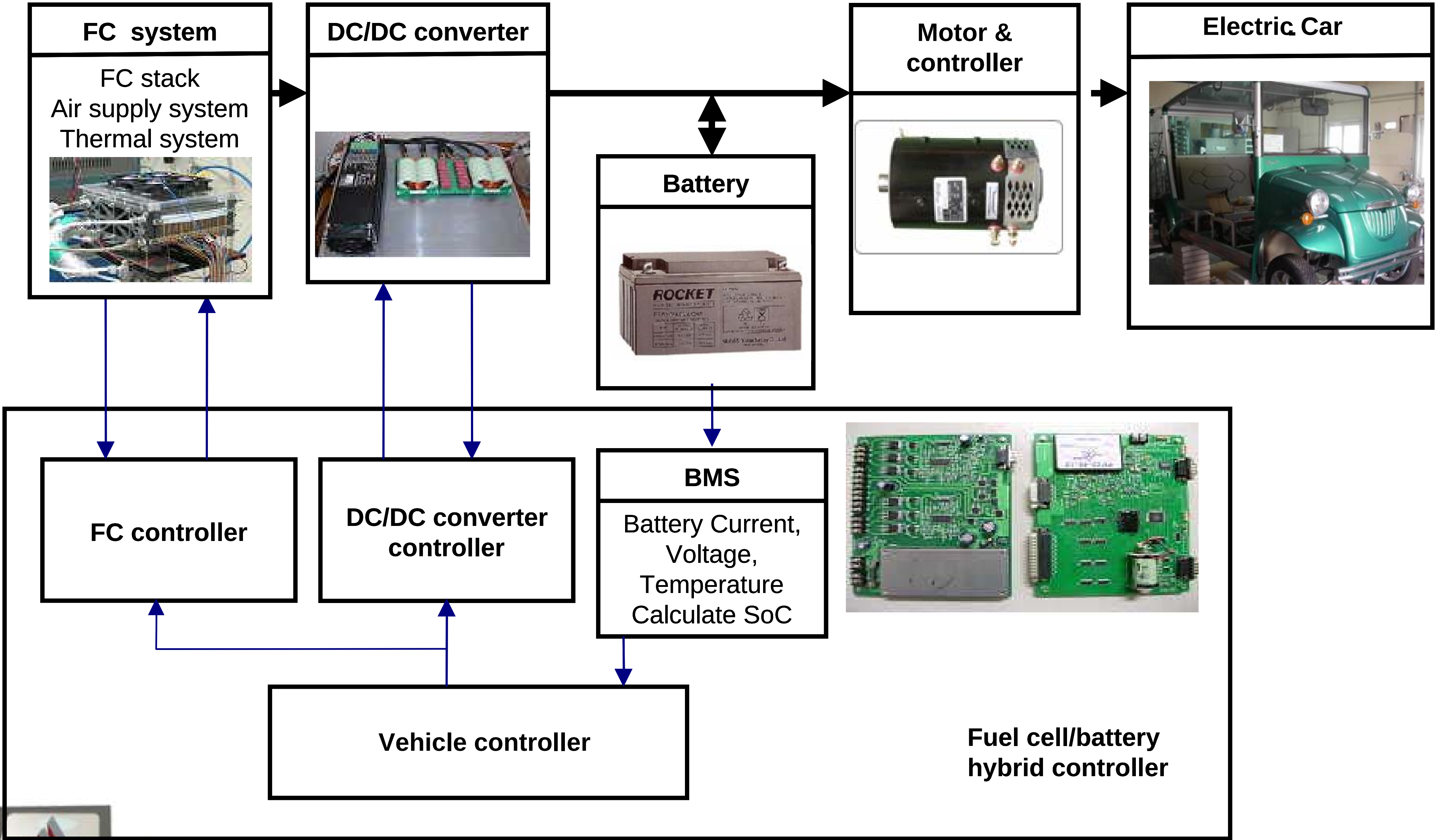
Energy Device of FC Vehicle

- **Energy Device**
  - Fuel Cell
  - Battery
  - Super-capacitor (Ultra-capacitor)

- **Comparison of Energy Storage**

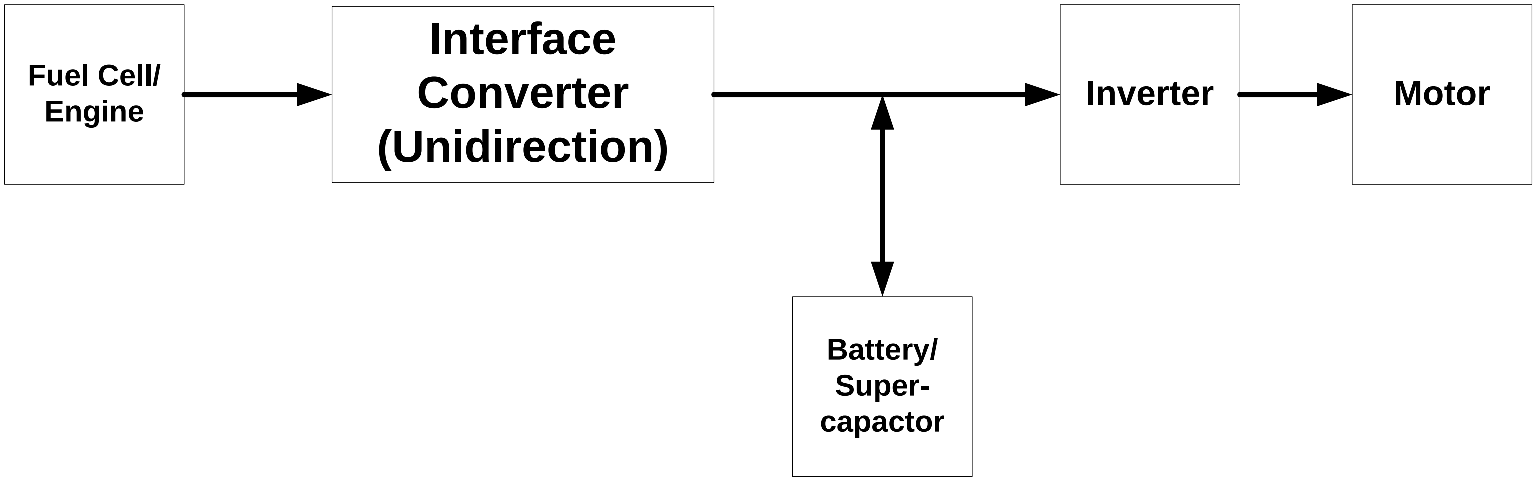
Power/kg	**SuperCap.> Battery**
Energy/kg	**Battery > SuperCap.**
Efficiency	**SuperCap. > Battery**
Cost	**Battery > SuperCap**
Life Cycle	**SuperCap. > Battery**

Fuel Cell Vehicle Structure

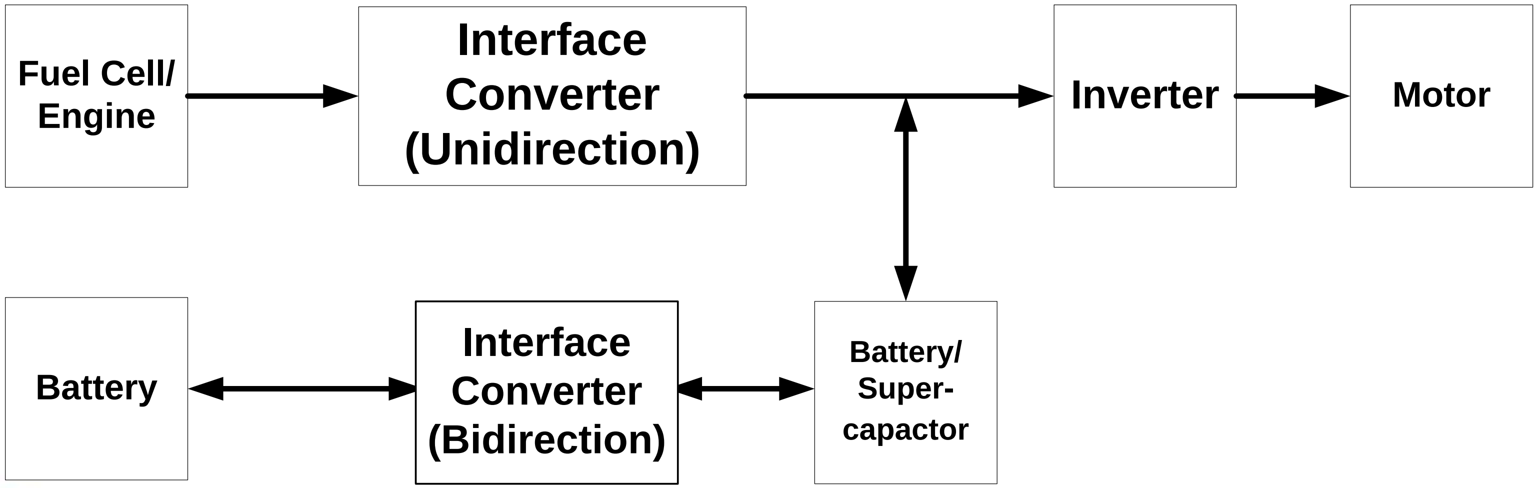


Interface Converter Usage

- 1 converter but more battery/SC

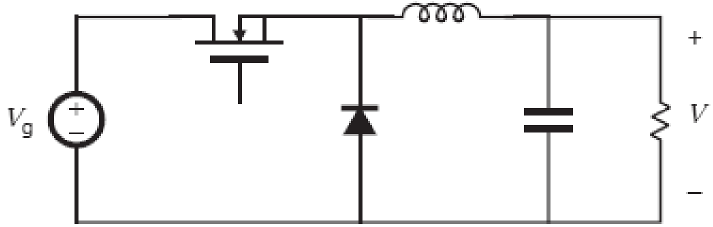


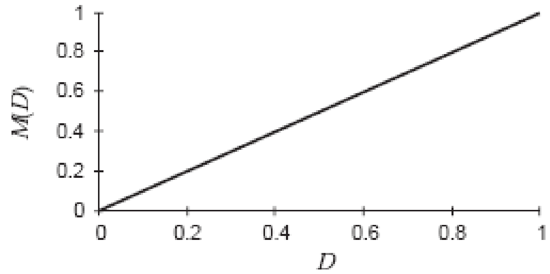
- 2 converter but less battery, high efficiency



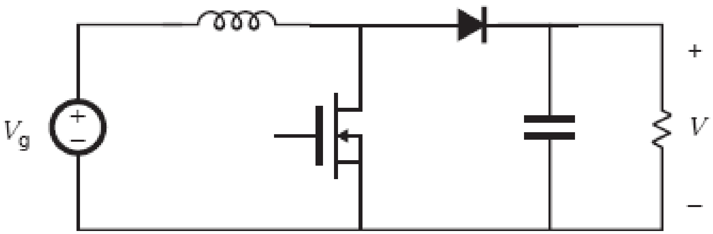
Non-isolation Type Interface

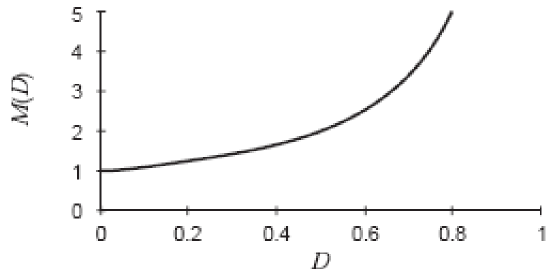
Buck Converter



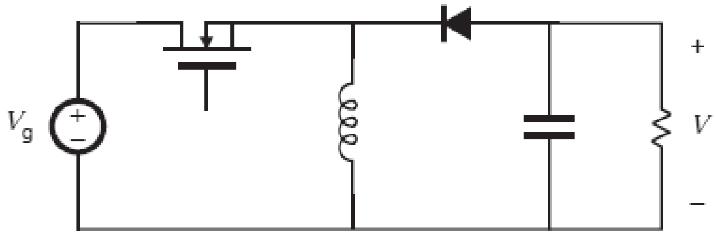


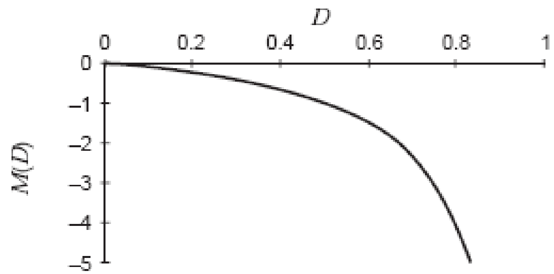
Boost Converter





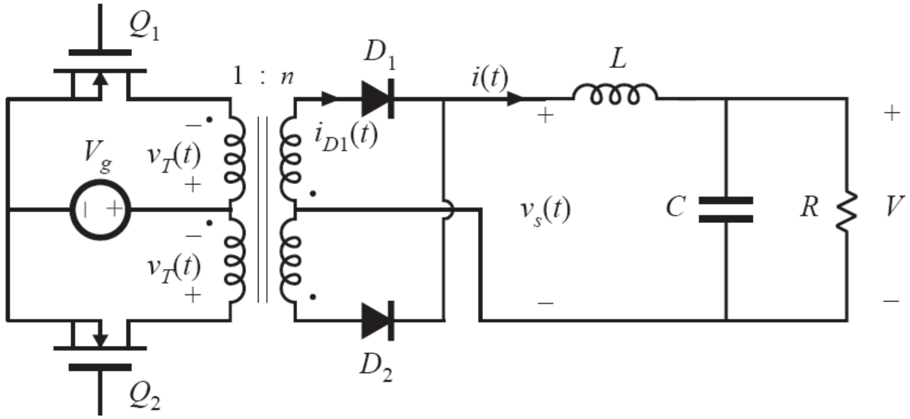
Buck-Boost Converter



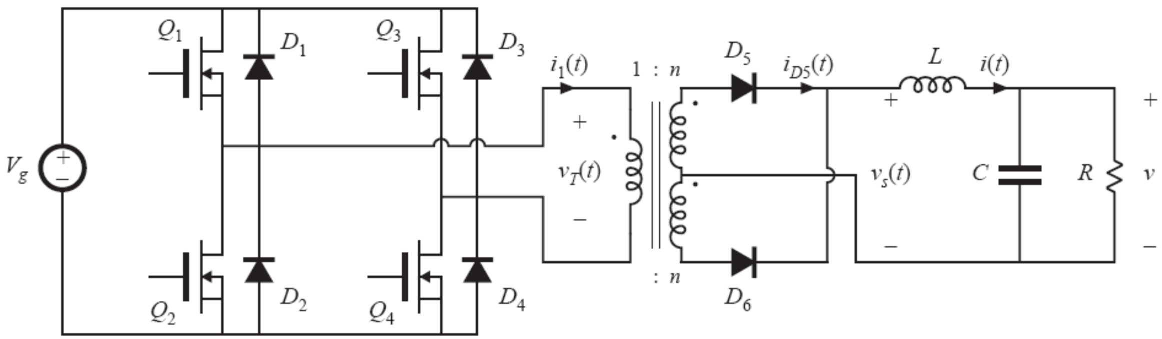


Isolation Type Interface

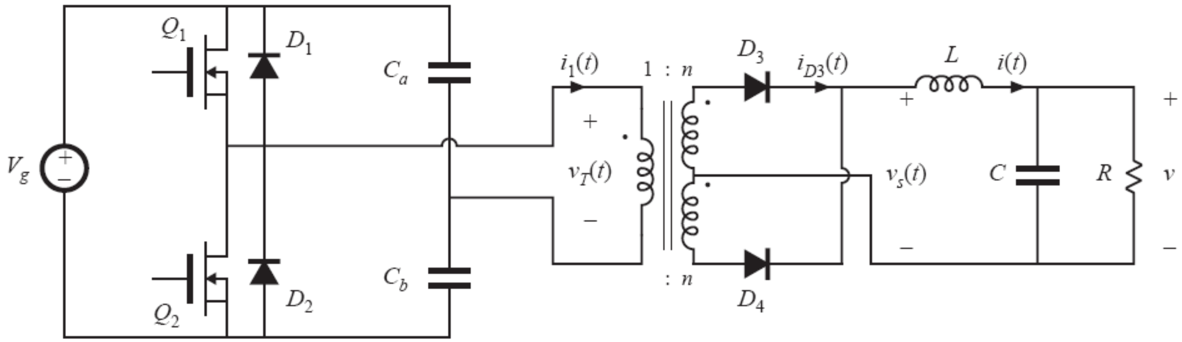
Push-pull Converter



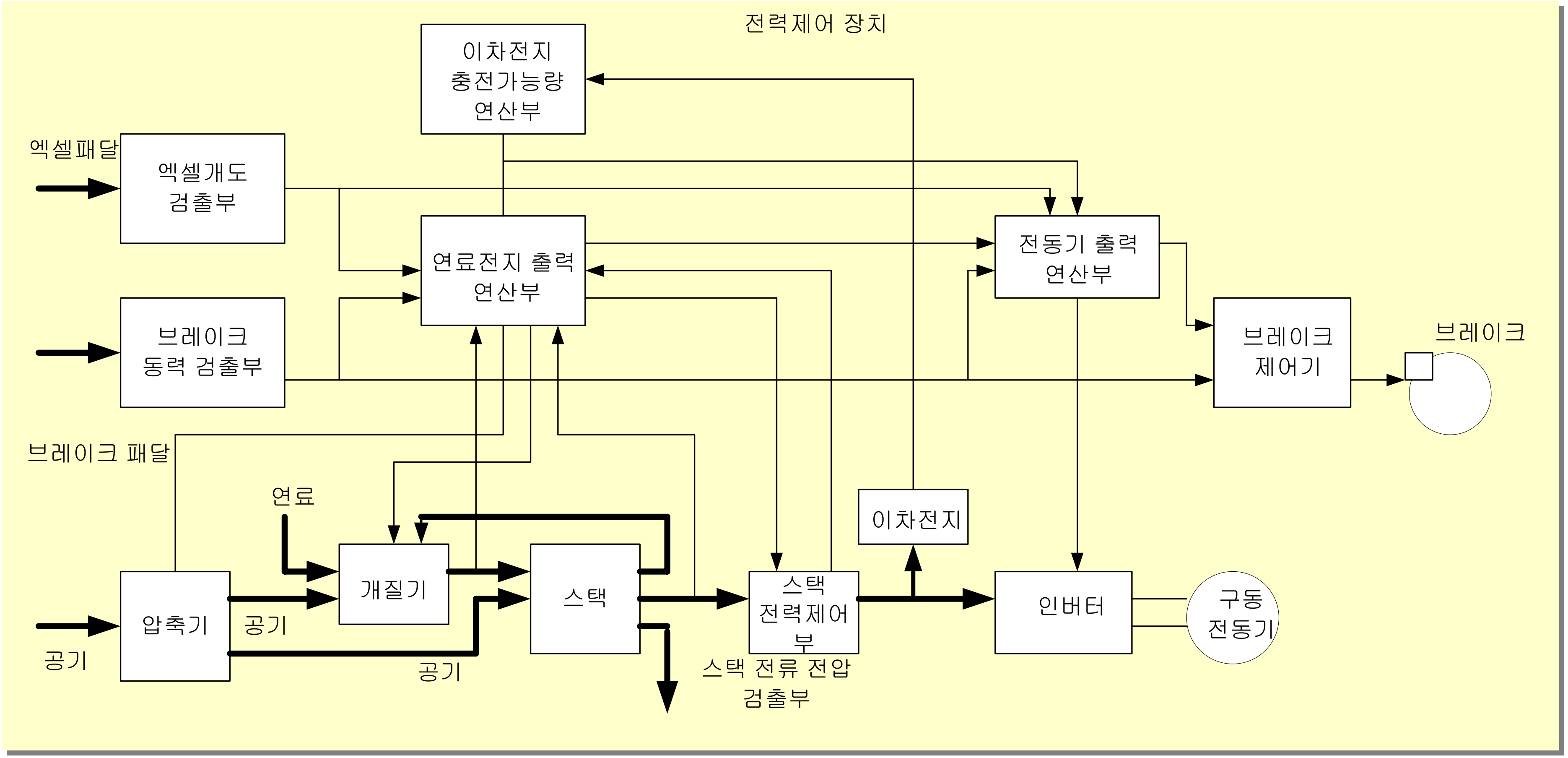
Full-bridge Converter



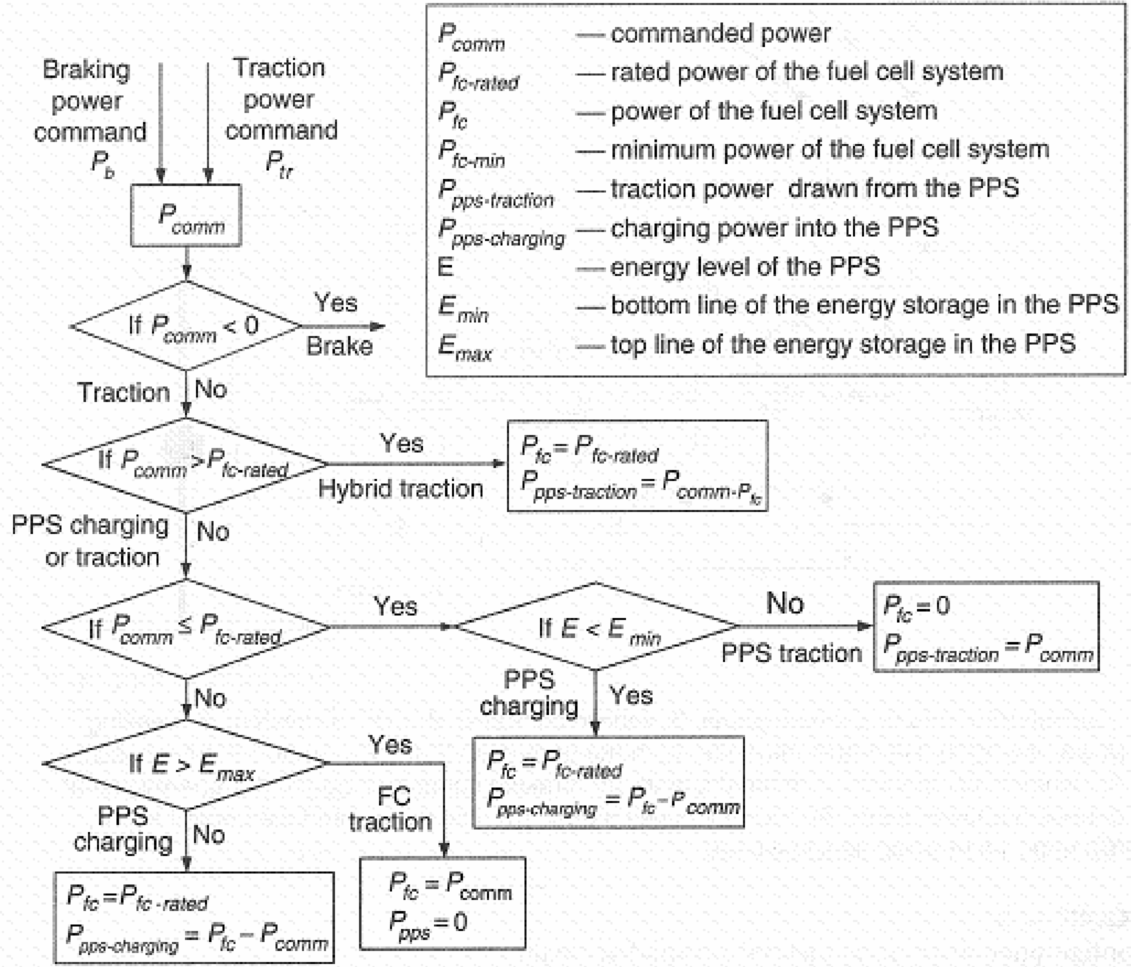
Half-bridge Converter



Control Cofiguration



Possible Control Strategy



Ref.: Modern electric, Hybrid Electric, and Fuel Cell Vehicles: chap. 13

-Fuel Cell (FC)

-Peaking Power System (PPS): Battery or SC

IF Pcomm>Pfc-rated
  Then Pfc=Pfc-rated
    Ppps =Pfc - Pcomm

ELSE (Pcomm<=Pfc-rated)
  If E<Emin
  Then Pfc=Pfc-rated
    Ppps=Pfc-Pcomm: Charge

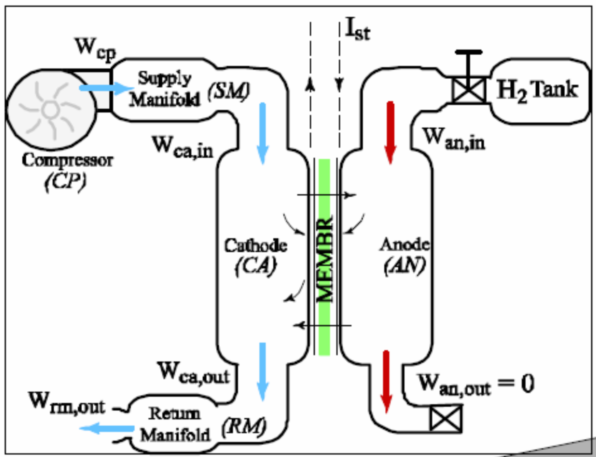
  Else if E>Emax
  Then Pfc=0
    Ppps=Pcomm: Battery only

  Else
    Pfc=Pcomm
    Ppps=0: Fuel Cell Alone
  End
END

Fuel Cell / Battery Modeling Methods

- Equational Models

  (Ex.: ***Huei Peng and Anna Stefanopoulou of Univ. of Michigan)***

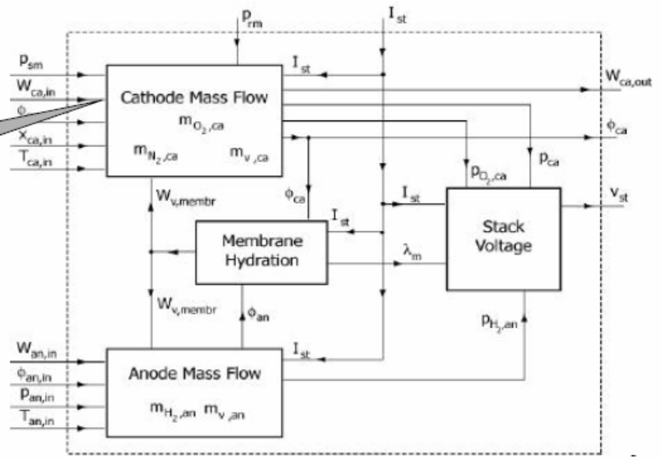


$$\frac{dm_{O_2}}{dt} = W_{O_2,in} - W_{O_2,out} - W_{O_2,react}$$

$$\frac{dm_{N_2}}{dt} = W_{N_2,in} - W_{N_2,out}$$

$$\frac{dm_{w,ca}}{dt} = W_{v,ca,in} - W_{v,ca,out} + W_{v,gen} + W_{v,membr}$$

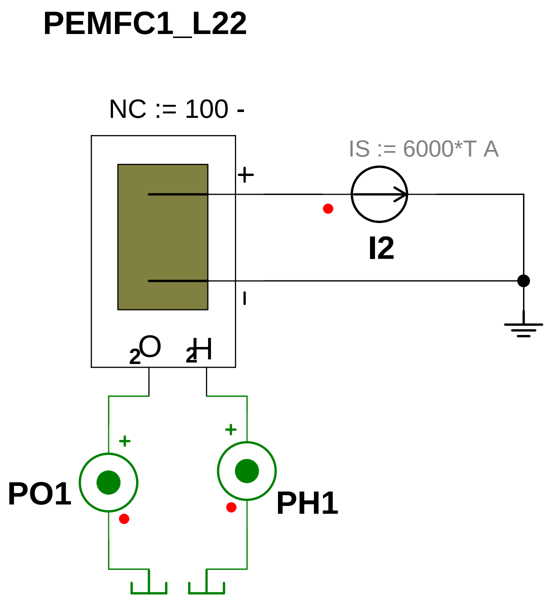
- **Cathode Mass Flow Model**
- **Anode Mass Flow Model**
- **Membrane Hydration Model**
- **Stack Voltage Model**

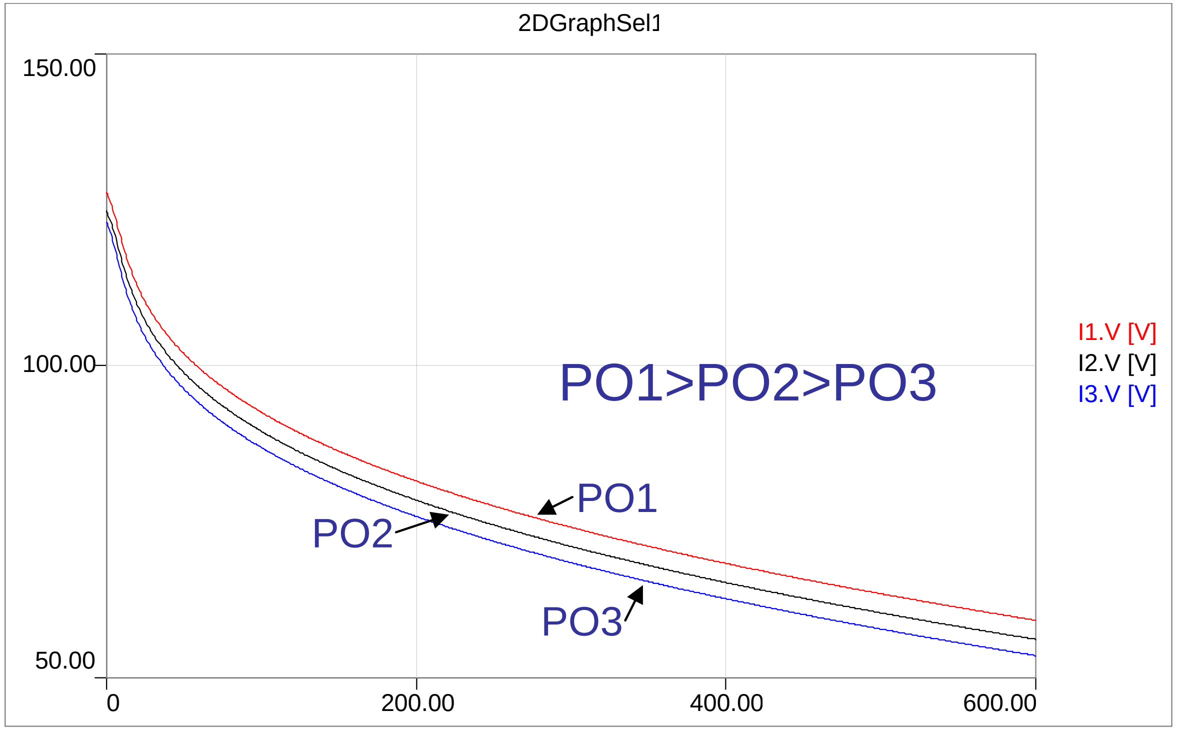


- Equivalent Circuit Model
- Look Up Table

Simplorer Supplied Model

- Equation based model :
  - many parameters should be defined.

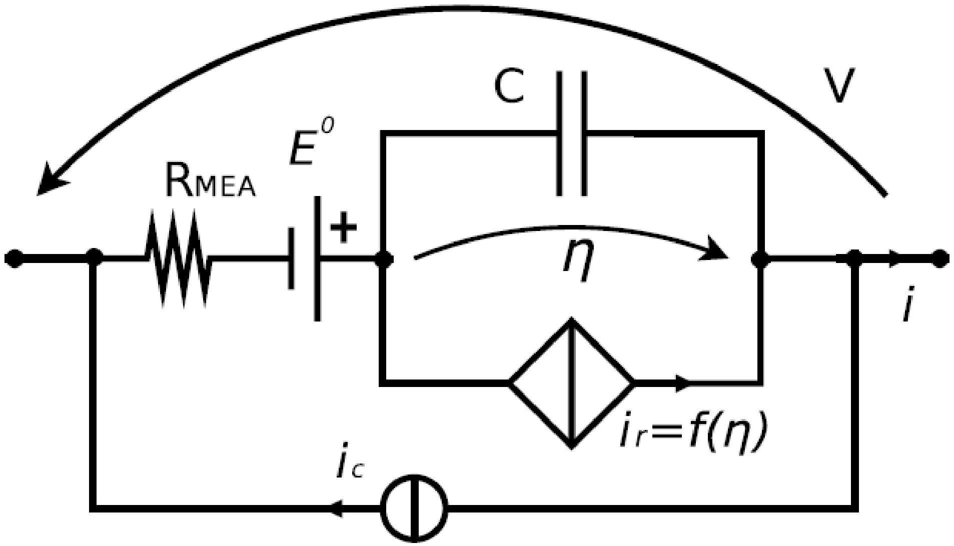




I-V curve of fuel cell stack(n=100)

FC Equivalent Circuit Model

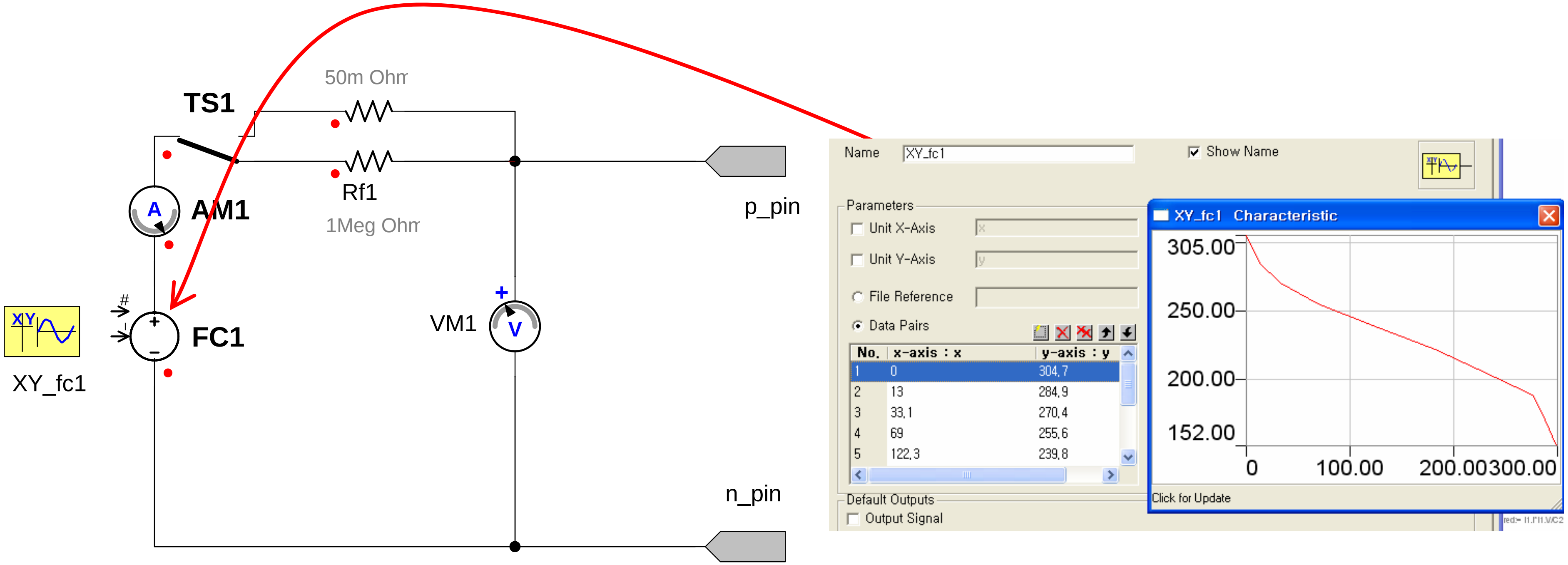
- Parameters are dependent
  - T, I and other conditions



Cell voltage	$V = E^0 - \eta - R_{\mathrm{MEA}}(i + i_c)$
Overvoltage differential equation	$\frac{\mathrm{d}\eta}{\mathrm{d}t} = \frac{i + i_c - i_r}{C}$
Butler–Volmer equation	$i_r = i_r(\eta, \ldots)$
External load's characteristic	$f(i, V, t) = 0$

FC LUT Based Model

- Current controlled voltage source
- Sufficient for steady state



Battery Energy Related Parameter

- SOC (State of Charge)

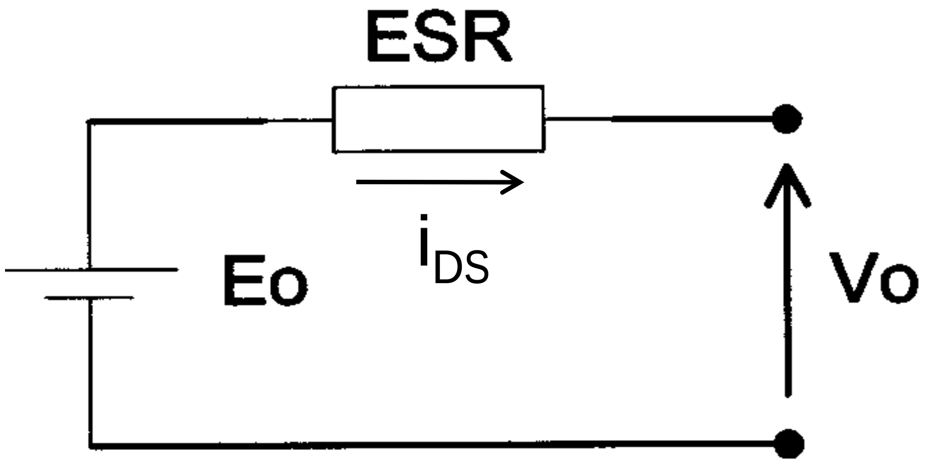
$$\frac{\text{Ah Capacity remained}}{\text{rated Ah capacity}}$$

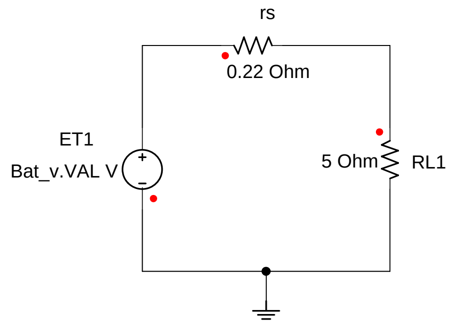
- DOD (Depth of Discharge) = 1-SOC

$$\frac{\text{Ah Capacity drained}}{\text{rated Ah capacity}}$$

- Specific energy(Wh/kg), Specific power(W/kg), Energy density(Wh/L)

Battery Model Implementation (1)





$$SOC = SOC_0 - \int \frac{i_{DS}}{Q_n(C)} dt = 1 - \int \frac{i_{DS}}{Q_n(C)} dt \quad \text{if Qo} = \text{Qn}$$

$$E_o = V_{off} + (V_n - V_{off}) \times SOC$$

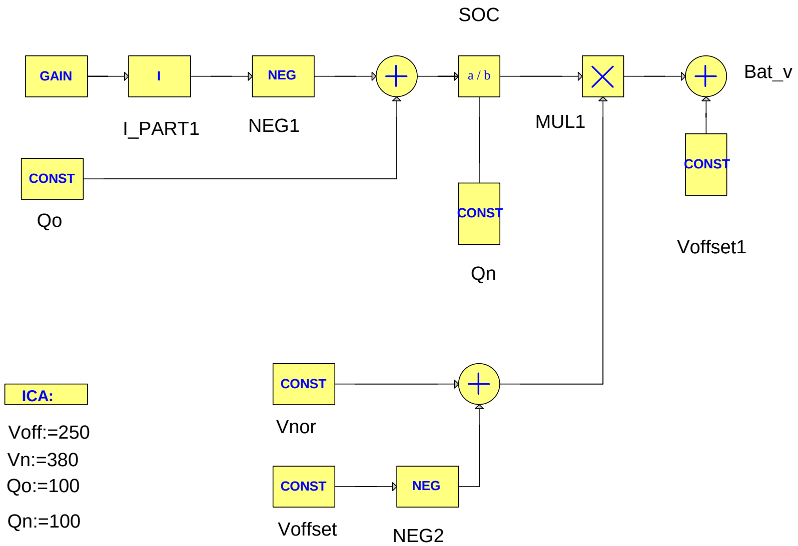
$$V_o = E_o - ESR \times i_{DS}$$

Q_o: initial Ah capacity

Q_n: rating Ah capacity(C10)

V_{off}: offset voltage at 0% SOC

V_n: nominal voltage at 100% SOC



Popular but much error

(C is dependent on I and T)

Battery Model Implementation (2)

$$C_p = I^k T$$

$$CR_{n+1} = CR_n + \frac{\delta t \times I^k}{3600}[Ah]$$

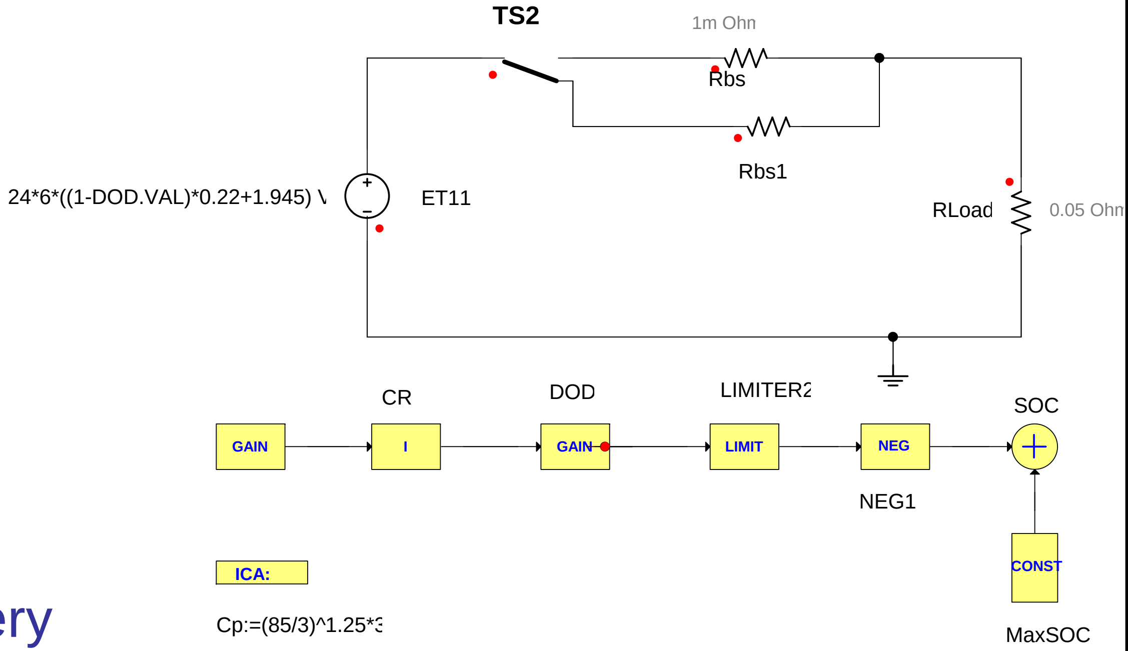
$$DOD_n = \frac{CR_n}{C_p}$$

$$SOC = 1 - DOD$$

k : Peukert Coefficient

CR: Energy removed from battery

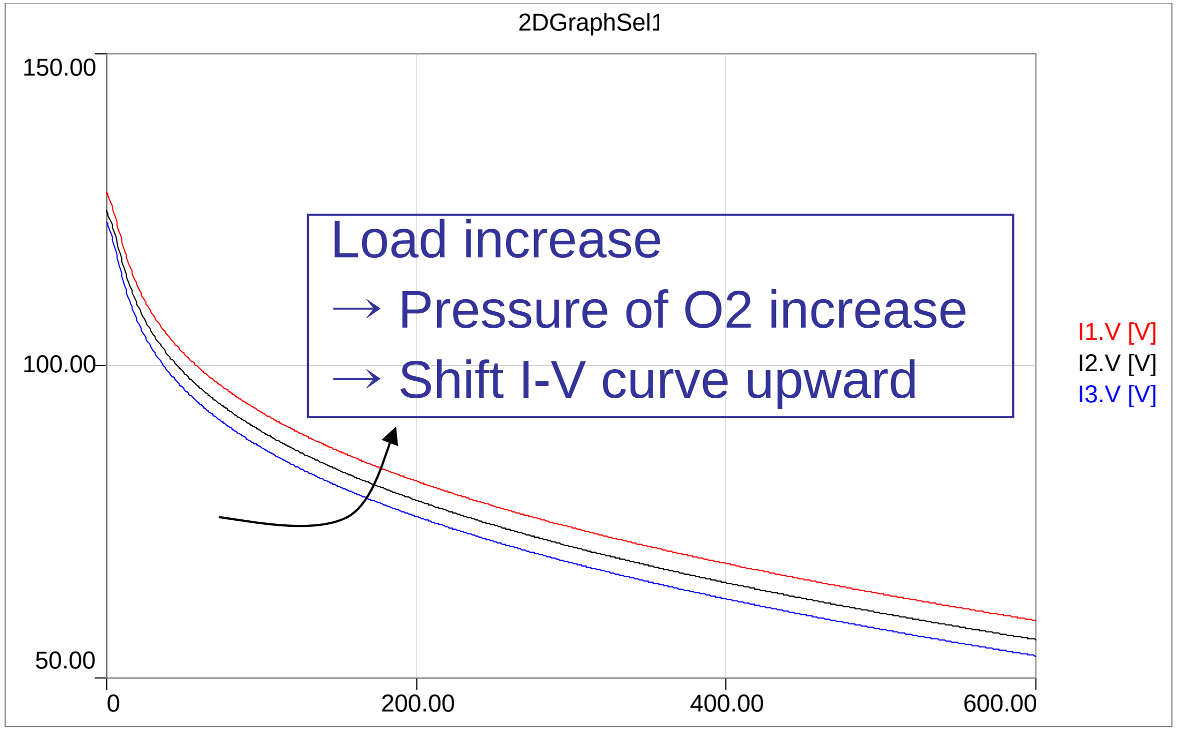
DOD: Depth of Discharge



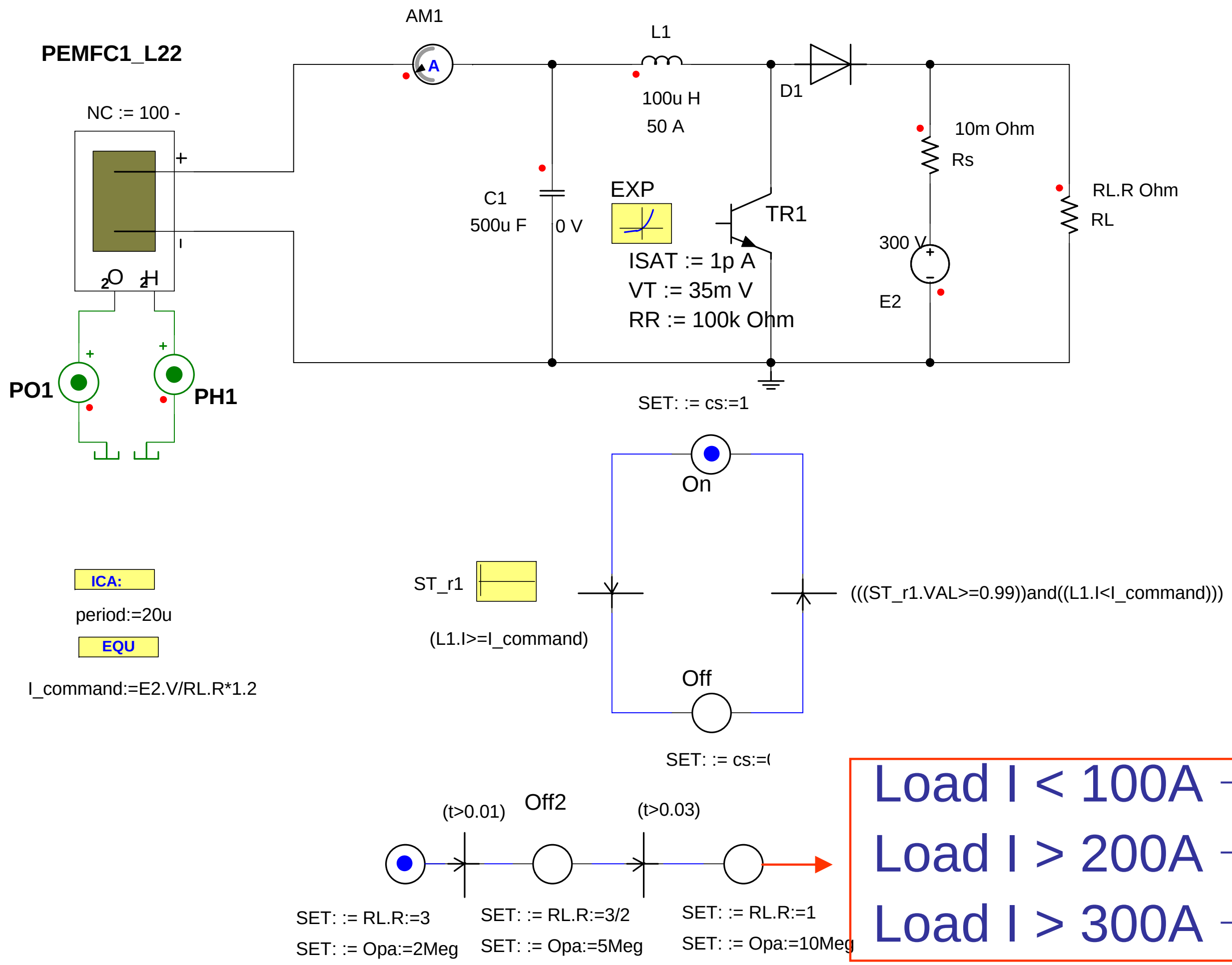
Better accuracy but
more parameters
(OCV must be defined)

Stack Control Concept

- A lot of stack control method
  - Optimization for whole system is complex.
- A concept for stack control
  - Control the air flow/pressure relating to the load

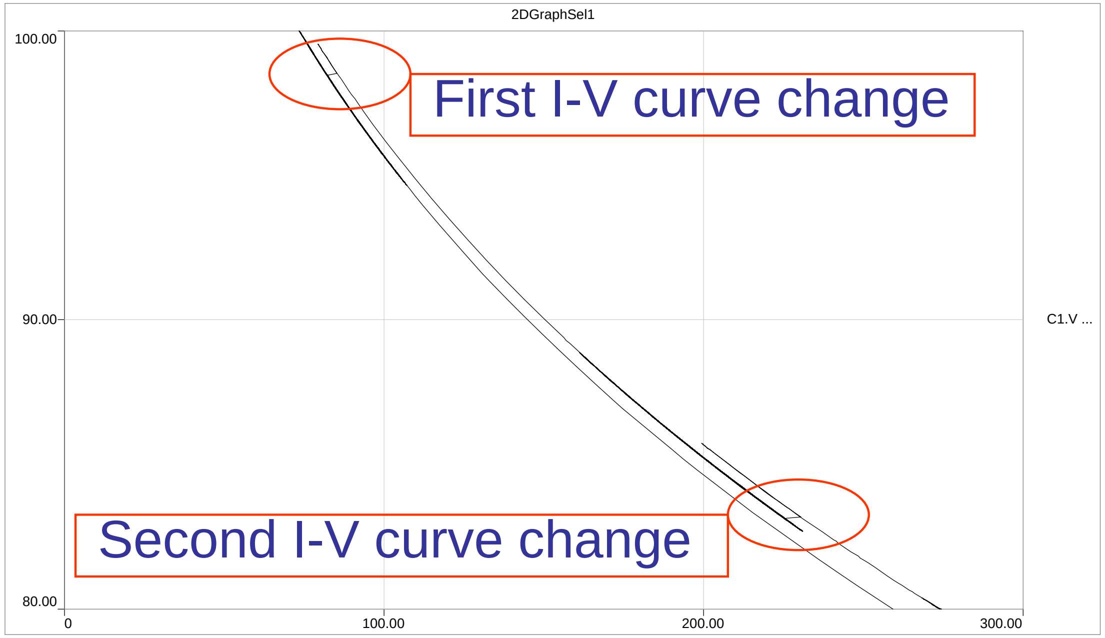


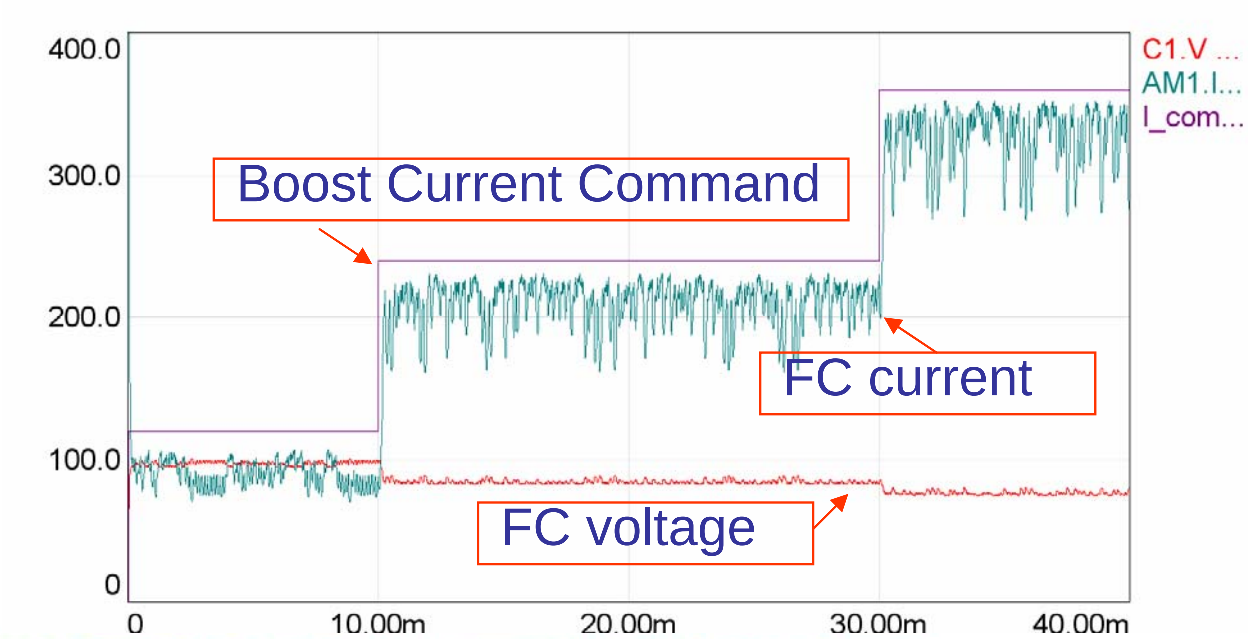
Stack Control Example



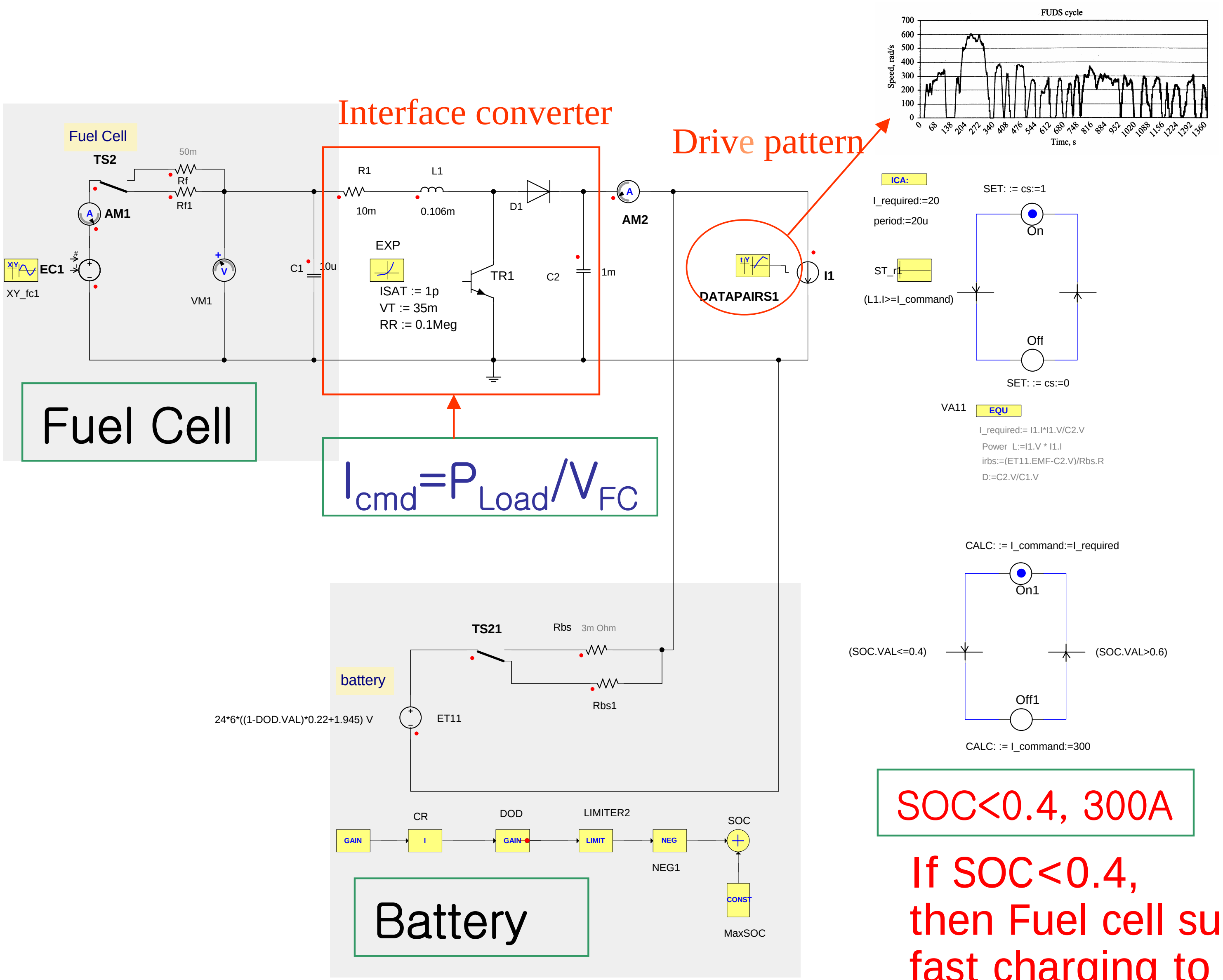
Load I < 100A → PO_2 = 2M Pa
Load I > 200A → PO_2 = 5M Pa
Load I > 300A → PO_2 = 10M Pa

Stack Control Example



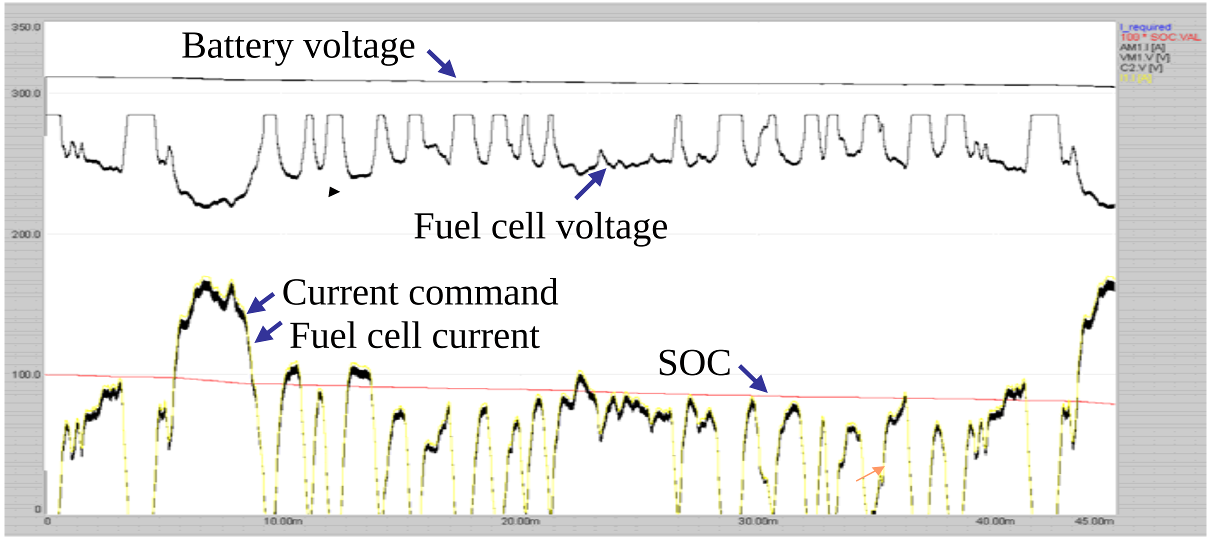


Energy Flow Control During Driving Cycle

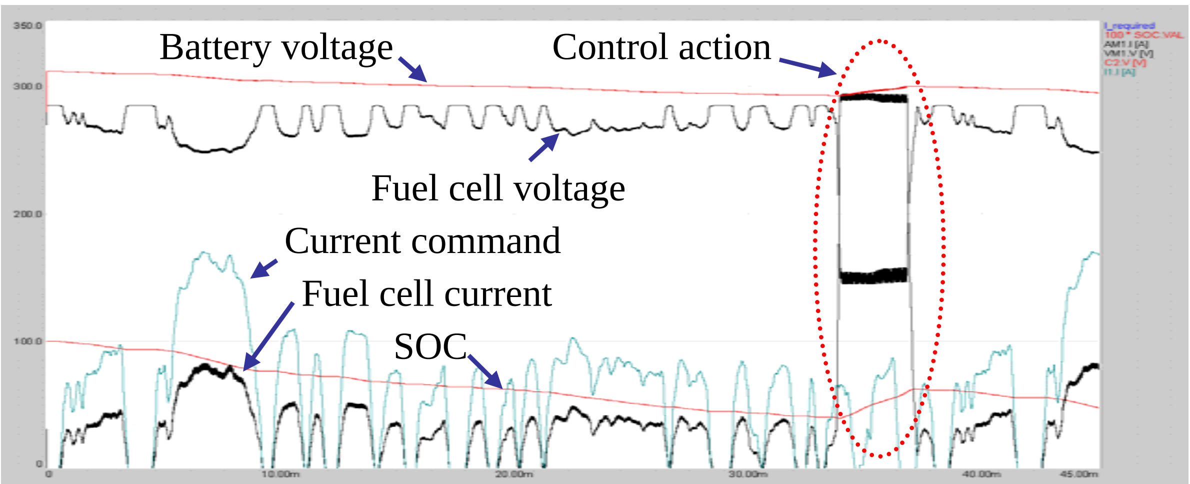


If SOC<0.4,
then Fuel cell supplies
fast charging to battery

Drive Cycle Simulation Result

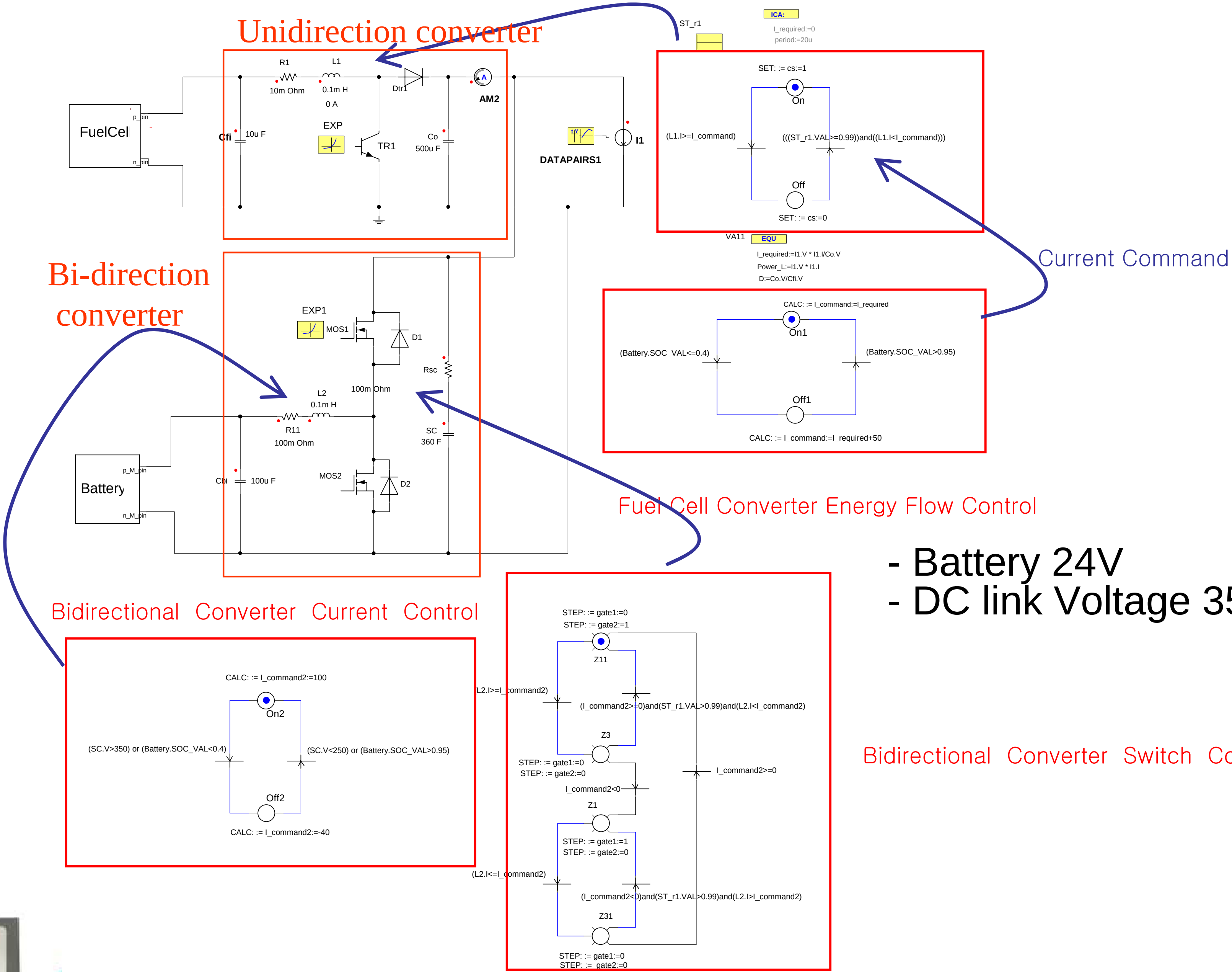


Sufficient rating battery or FC dominant operation
→ SOC stable
but battery over-capacity



Small rating battery or small FC capacity
→ Wide SOC variation, control requirement

Compex Hybrid System



- Battery 24V
- DC link Voltage 350V

Energy Flow Control Strategy

IF SOC < 0.4
 Then Pfc=Pload+Pcharge until SOC>0.95
 Battery charge mode

IF SOC>0.95
 Then Pfc=Pload until SOC<0.4

IF Vsc>350V
 Then Battery charge mode

IF Vsc<250V
 Then Battery discharge mode

Simulation Result