Decentralized Dynamic Load Power Allocation Strategy for Fuel Cell/Supercapacitor-Based APU of Large More Electric Vehicles

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- ☐ Decentralized Dynamic Load Power Allocation
- ☐ Experimental Verification
- ☐ Conclusions

Fuel Cell (FC) Vehicle is Developing Rapidly

Car Industry

Energy Crisis

Air Pollution

Electric Vehicle

Hybrid Electric Vehicle (ICE)

- ☺ Energy saving
- ☺ Low emission
- ☹ It's hard to achieve zero emissions

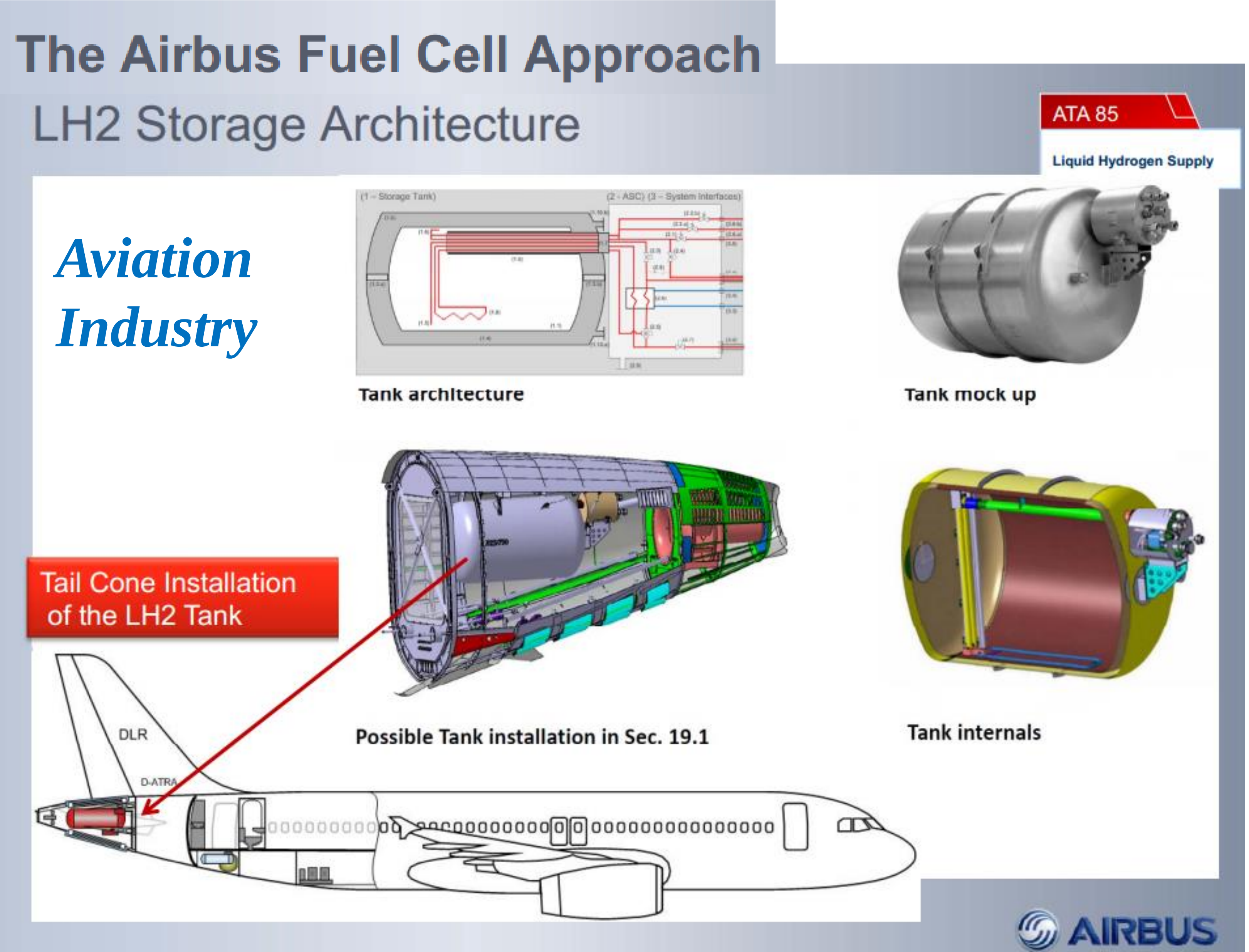
Electric Vehicle (Battery)

- ☺ Zero emission
- ☺ Low noise
- ☺ High efficiency
- ☹ Short running mileage
- ☹ Long charging time

Fuel Cell Vehicle

- ☺ Zero emission
- ☺ Long driving range
- ☺ High efficiency
- ☺ Fast filling time
- ☹ Hard to produce H_2

Fuel-Cell APU of Future MEA



The Airbus Fuel Cell Approach

LH2 Storage Architecture

ATA 85

Liquid Hydrogen Supply

Aviation Industry

Tank architecture

Tank mock up

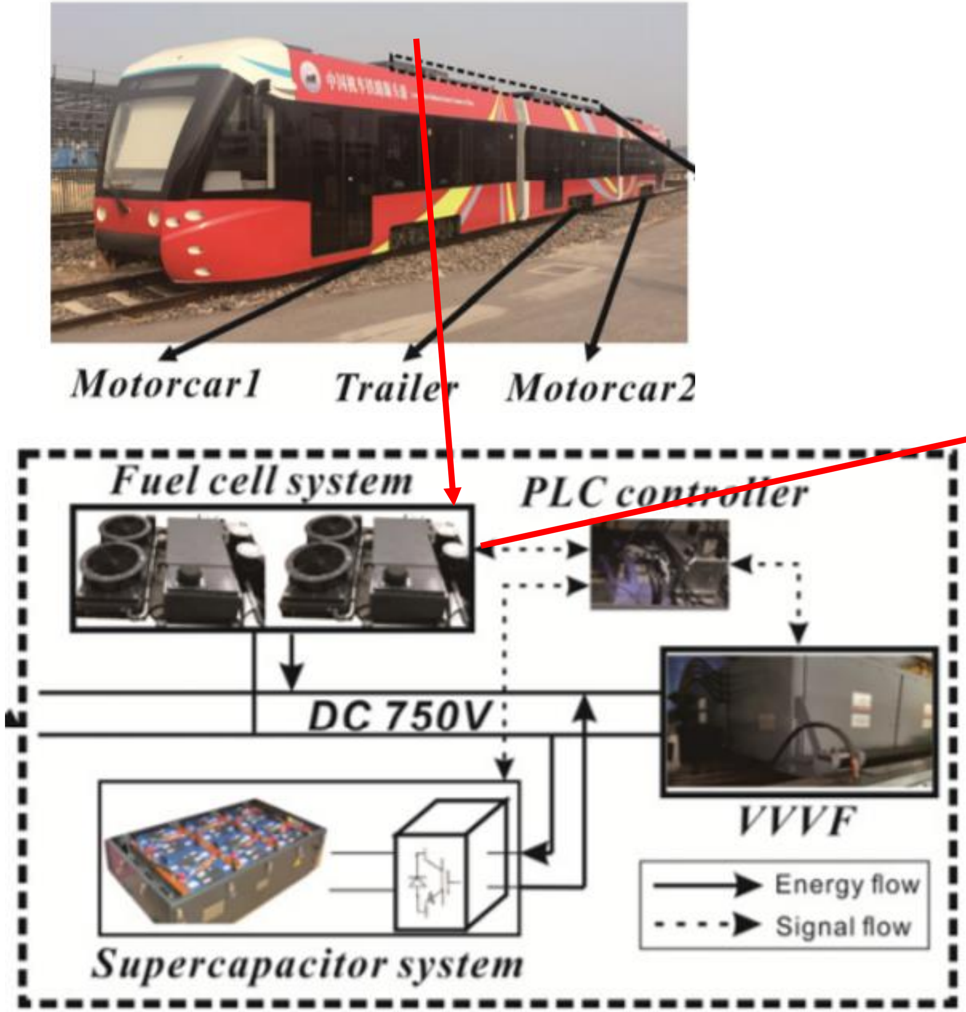
Possible Tank installation in Sec. 19.1

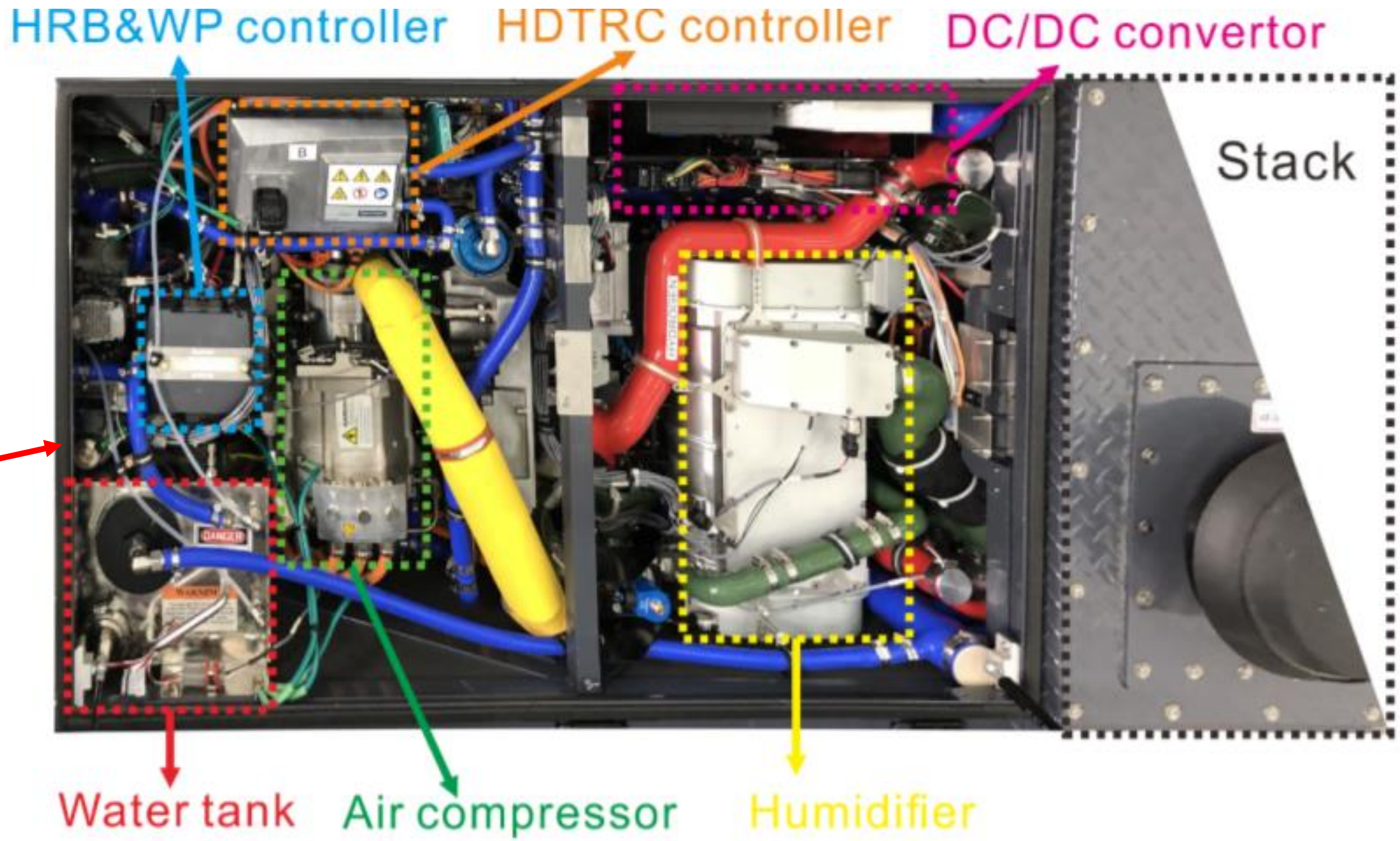
Tank internals

Tail Cone Installation of the LH2 Tank

Fuel-Cell Power System of Electric Trams

Rail Traffic Industry



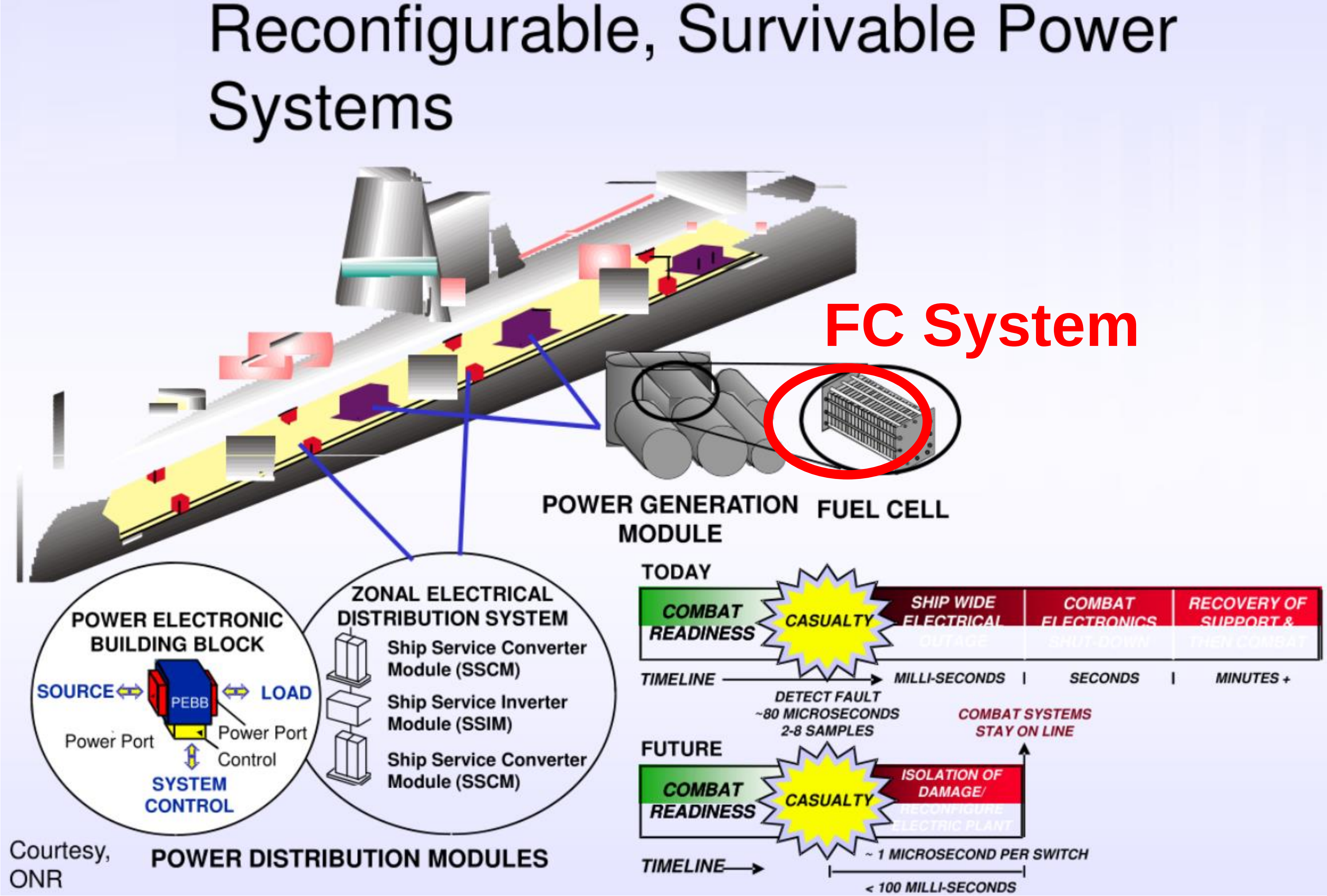


Multiple Fuel Cells Hybrid Power System for Electric Trams

Source from: Y. Yan, Q. Li, W. Chen, Southwest Jiaotong Uni.

Fuel-Cell Power System of Electric Ships

Ship and Submarine



Source from: US Navy All-Electric Ship Program

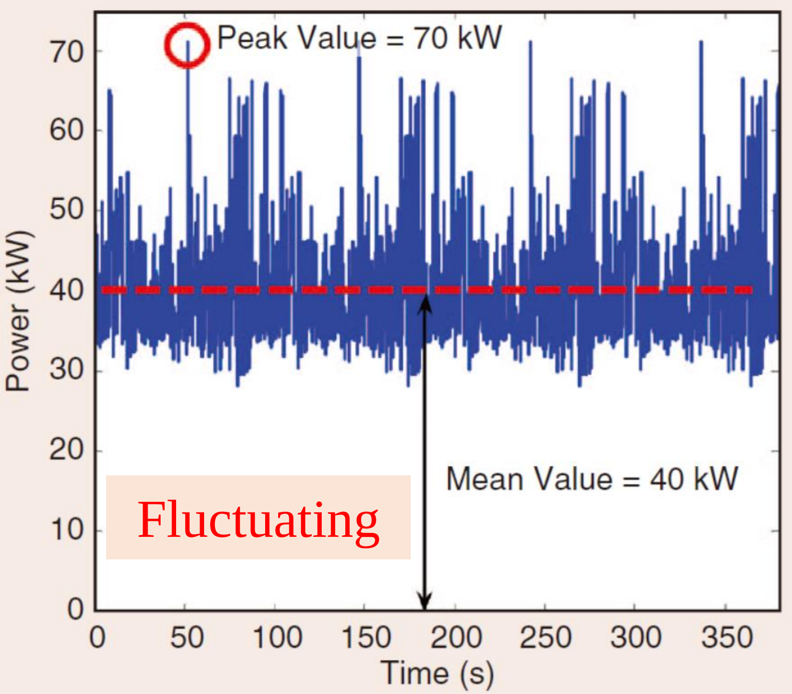
FC Power system of an All Electric Ship

Problem Formulation

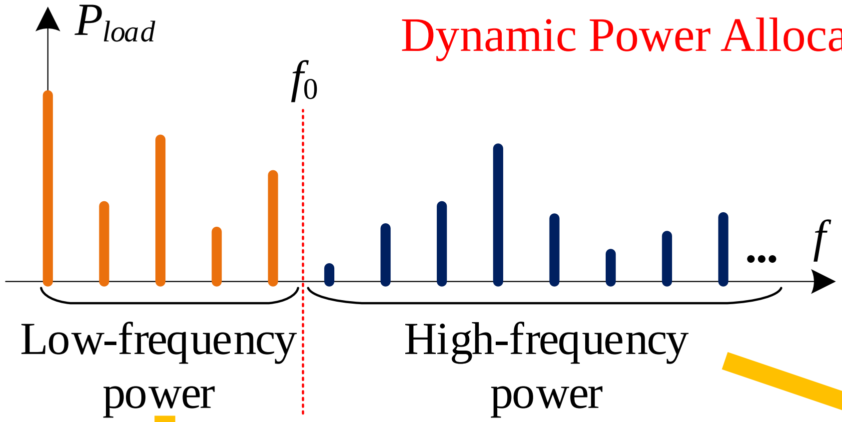
Problem: Fast Fluctuating Load Power v.s. Slow Dynamic Response of FC → Solution: Hybridization

e.g. Pulsating Load Profile for an MEA*:

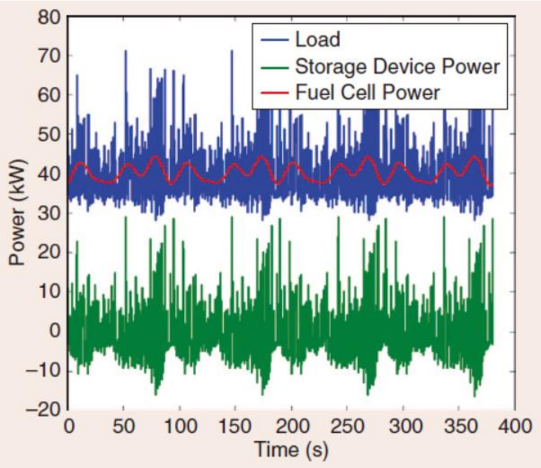
- peak power possibly lasting for 20–200 ms;
- peak-to-average power ratio being more than 5-to-1 across a time scale of 50–500 ms



Load profile capture in some flight phase



Dynamic Power Allocation



Expected power allocation

Fuel Cell (FC)

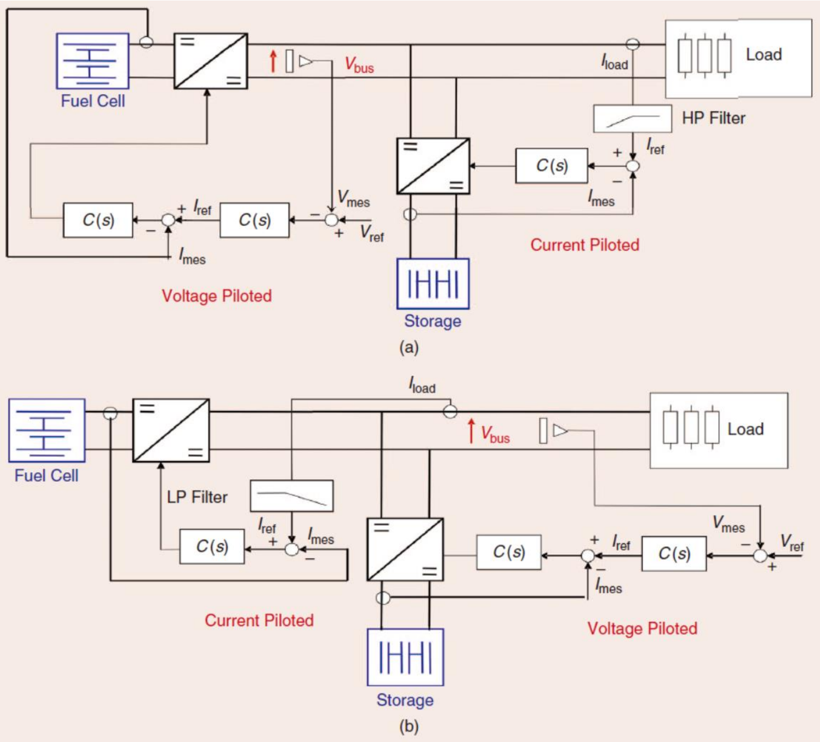
- ☺ Clean;
- ☺ Highly efficient;
- ☺ High energy density;
- ☹ Slow dynamics;
- ☹ Low power density;
- ☹ Unidirectional power flow.

Ultracapacitor (UC)

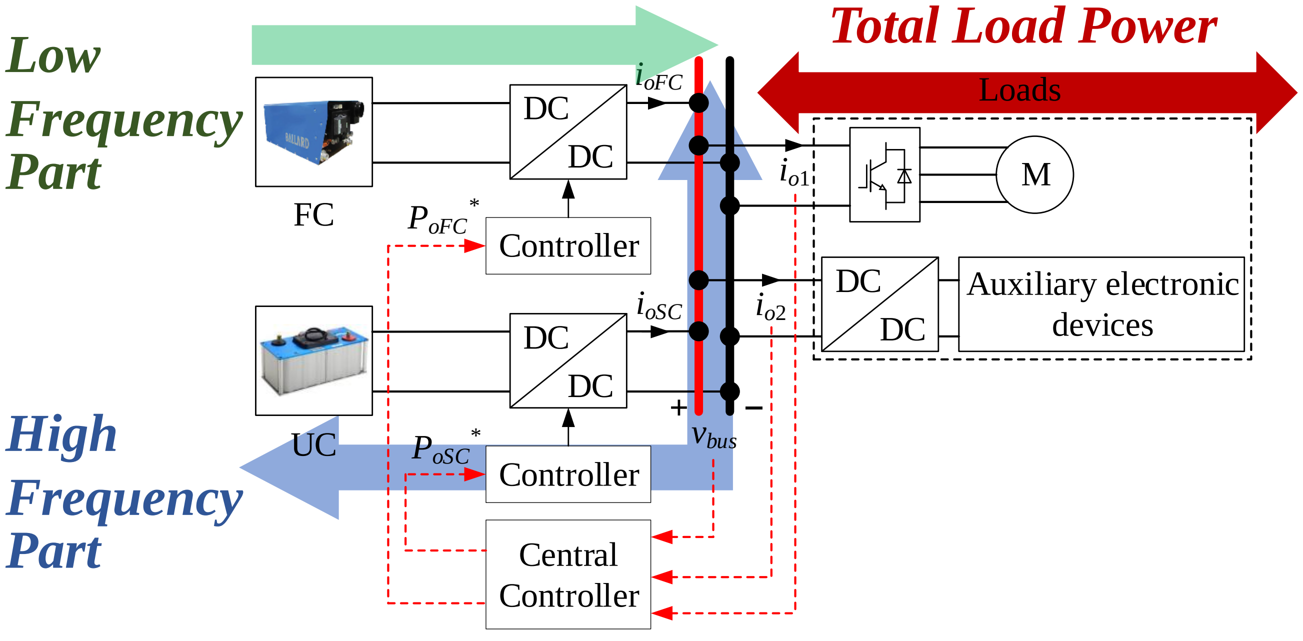
- ☺ Fast dynamic response;
- ☺ High power density;
- ☹ Low energy density.

* C. Turpin, B. Morin, E. Bru, O. Rallieres, X. Roboam, et al., “Power for aircraft emergencies: a hybrid proton-exchange membrane H2/O2 fuel cell and ultracapacitor system,” *IEEE Electrific. Mag.*, vol. 5, no. 4, pp. 72-85, 2017.

Problem Formulation



Operation Principle



Centralized EMS

Problems

Centralized Control Strategies

- ☹ Increased numbers of current or voltage sensors;
- ☹ Single-point-of-failure problem (Poor reliability);
- ☹ Compromised dynamic response for power allocation due to the existence of communication delay;
- ☹ Poor system flexibility and scalability.

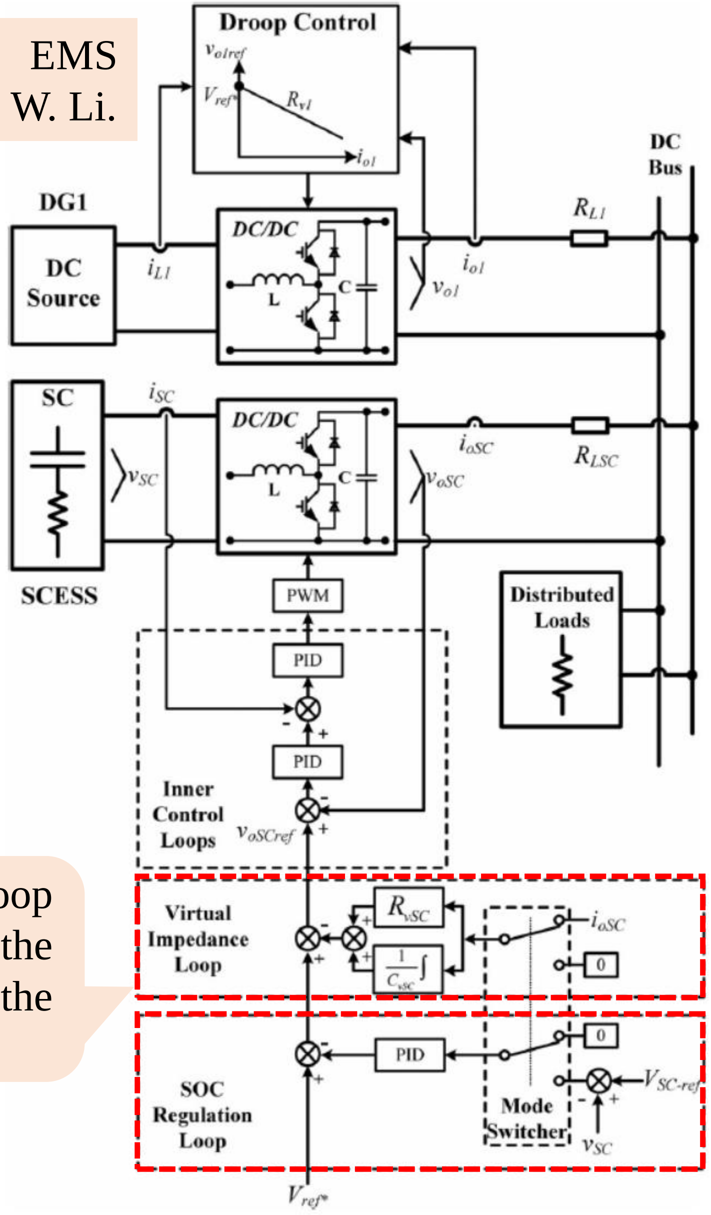
Solution

Decentralized Control Strategies

- ☺ Automatic fluctuating load power splitting;
- ☺ Extended the service life;
- ☺ Improved energy efficiency
- ☺ Improved system realibility

Problem Formulation

Possible decentralized EMS proposed by Y. Zhang & Y. W. Li.



A virtual capacitor droop control is proposed for the UC to make it buffer all the transient power.

SoC regulation loop

Existing Decentralized Dynamic Power Allocation Strategy

Key Features

☺ Dynamic load power allocation;

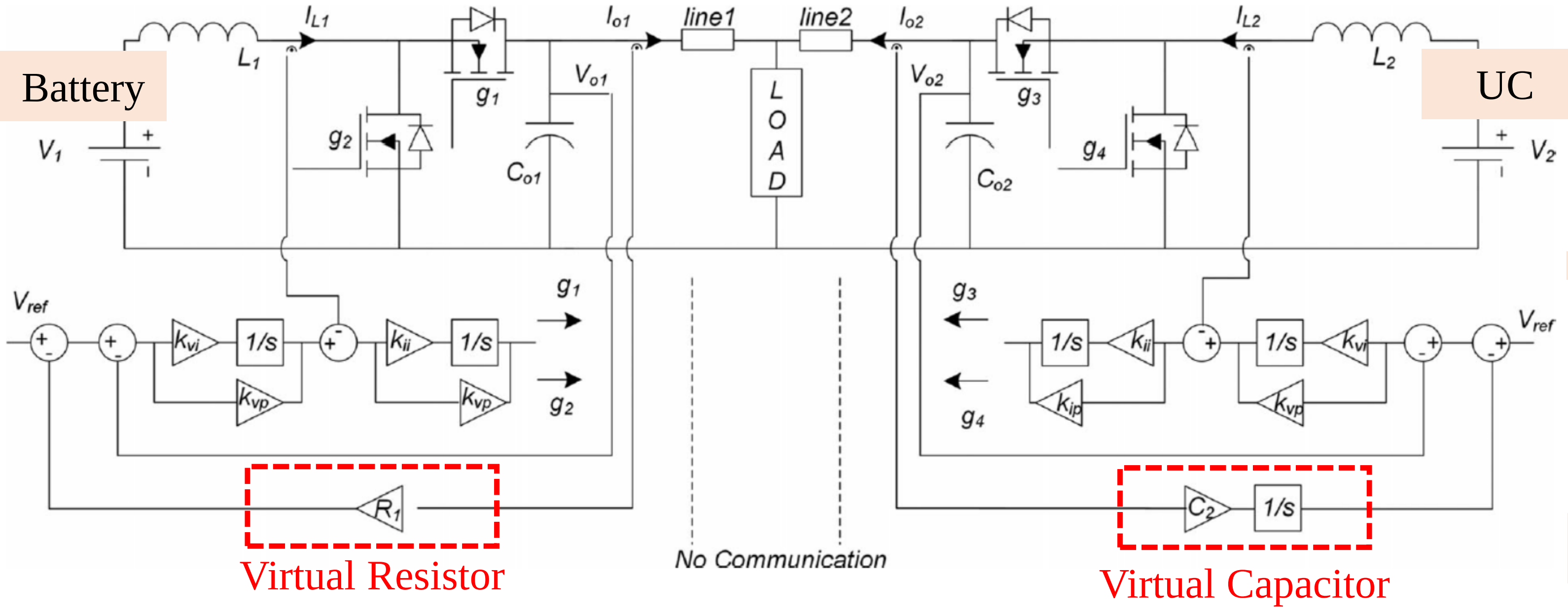
☺ SoC recovery of the UC;

☹ The UC loses the ability of buffering transient power in SoC regulation process;

☹ The virtual capacitor would block the path for the regenerative power.

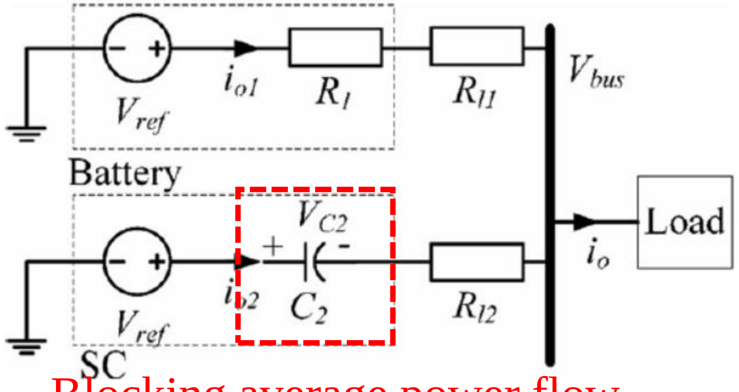
Y. Zhang and Y. W. Li, "Energy management strategy for supercapacitor in droop-controlled dc microgrid using virtual impedance," *IEEE Trans. Power Electron.*, vol. 32, no. 4, pp. 2704–2716, Apr. 2017.

Problem Formulation



Virtual Resistor

Virtual Capacitor



Blocking average power flow

Equivalent HESS with mixed droop control strategy

Possible decentralized EMS for HESS proposed by our research group.

Existing Dynamic Power Allocation Strategy

Key Features

☺ Dynamic load power allocation is achieved;

☹ The UC’s SoC can not be optimized;

☹ When applied to the FC-UC hybrid power supply system, the energy efficiency of the system could be low as the regenerative power (average part) is not able to be stored by the UC but has to be dissipated as heat by the damping circuit instead; (Lossless accommodation of regenerative power cannot be achieved)

[1] Q. Xu, et.al, “A decentralized dynamic power sharing strategy for hybrid energy storage system in autonomous dc microgrid,” *IEEE Trans. Ind. Electron.*, vol. 64, no. 7, pp. 5930–5941, Jul. 2017.

[2] Q. Xu, et. Al. , “A decentralized power management strategy for hybrid energy storage system with autonomous bus voltage restoration and state-of-charge recovery,” *IEEE Trans. Ind. Electron.*, vol.64, no.9, pp. 7098–7108, 2017.

Problem Formulation

Control objectives

◆ **Dynamic load power allocation.**

- It is desired that the UC buffers the pulsating or high-frequency load power while the FC only supplies the average or low-frequency power.

◆ **High flexibility, scalability and reliability**

- Decentralized architecture

◆ **Prolonged service life.**

- The service life of the FC can be prolonged by making it merely supply the average or low-frequency power.
- The service life of the UC could be optimized by maintaining its state-of-charge (SoC) within 25% and 90% (Normal Mode).

◆ **Increased energy efficiency.**

- By accommodating the regenerative energy generated in braking process in a lossless way, the energy efficiency could be much improved.

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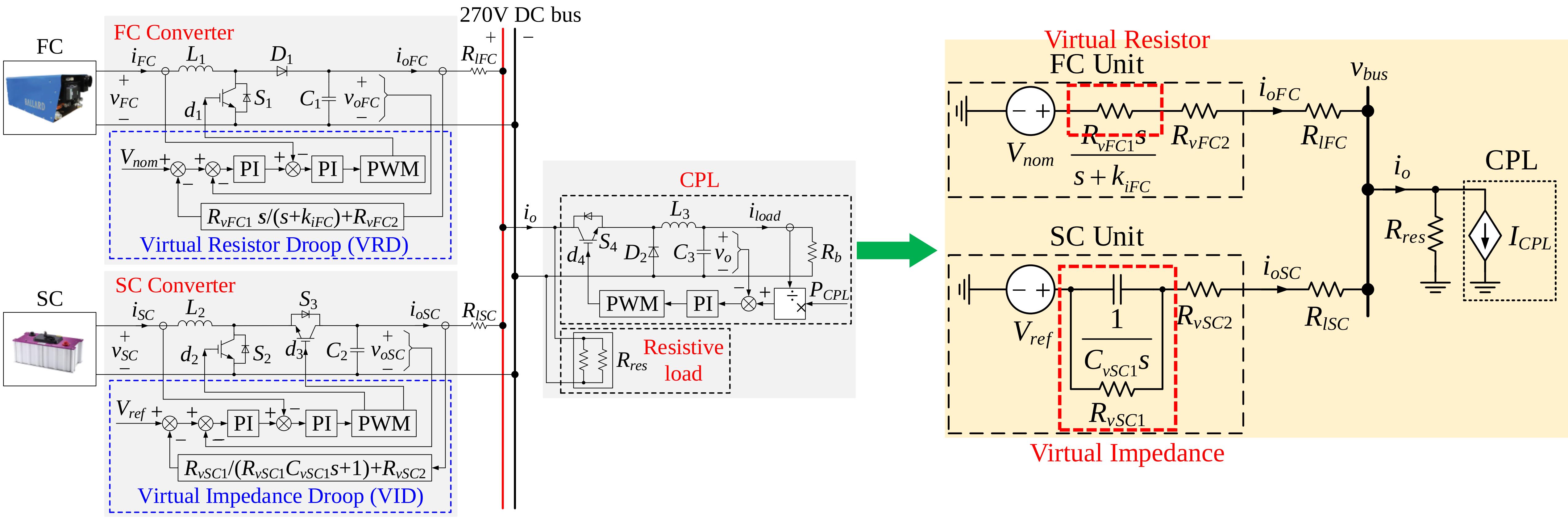
Decentralized Power Allocation Strategy

Decentralized Dynamic Power Allocation based on Mixed Impedance Droop Control: **Strategy 1**



Proposed decentralized control for FC-UC Hybrid Power System

Decentralized Power Allocation Strategy

Mixed Impedance Droop Control

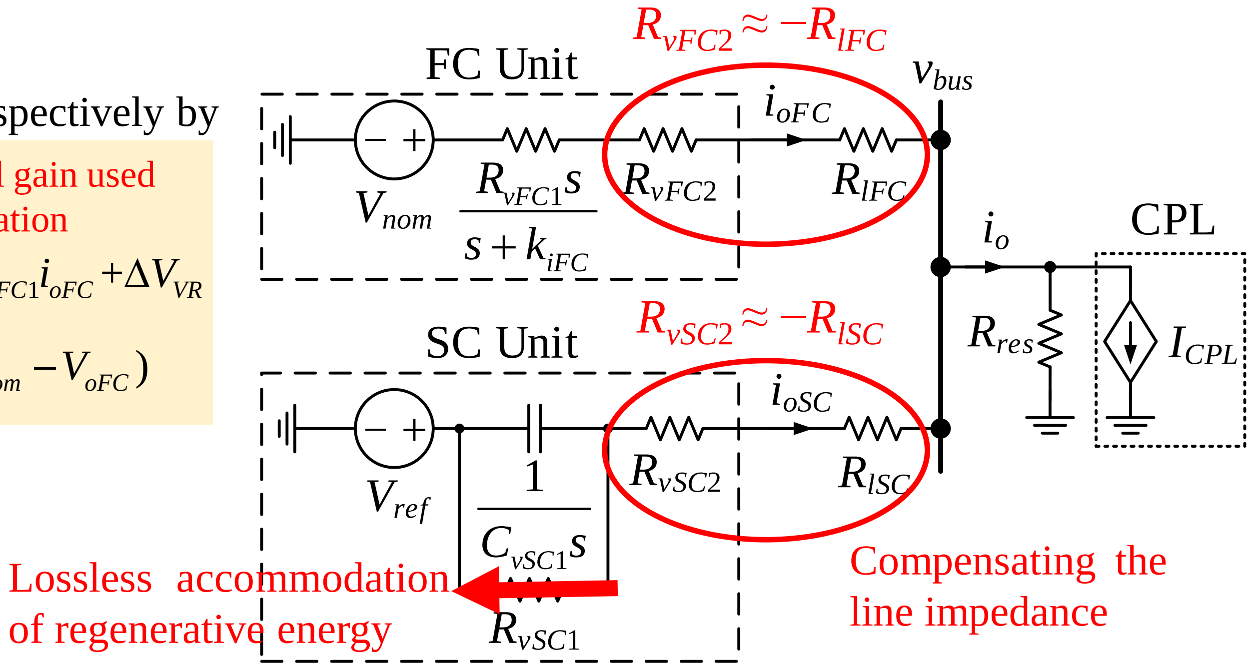
The droop characteristics of the FC and UC converters are given respectively by

$$v_{oFC}=V_{nom}-\left(\frac{R_{vFC1}s}{s+\underline{k_{iFC}}}+R_{vFC2}\right)i_{oFC}$$

$$v_{oSC}=V_{ref}-\left(\frac{R_{vSC1}}{R_{vSC1}C_{vSC1}s+1}+R_{vSC2}\right)i_{oSC}$$

k_{iFC} is the integral gain used for voltage restoration

$$\begin{cases} v_{oFC}=V_{nom}-R_{vFC1}i_{oFC}+\Delta V_{VR} \\ \Delta V_{VR}=\dfrac{k_{iFC}}{s}\left(V_{nom}-V_{oFC}\right) \end{cases}$$



Lossless accommodation of regenerative energy

Compensating the line impedance

Simplified FC/SC HPS with proposed control strategy

Based on the Kirchhoff’s voltage and current laws , we can deduce:

$$i_{oFC}=G_{FC}(s)i_o-G_c(s)\left(V_{ref}-V_{nom}\right)$$

$$i_{oSC}=G_{SC}(s)i_o+G_c(s)\left(V_{ref}-V_{nom}\right)$$

with

$$G_{FC}(s)=\frac{R_{vSC1}s+R_{vSC1}k_{iFC}}{R_{vSC1}R_{vFC1}C_{vSC1}s^2+\left(R_{vFC1}+R_{vSC1}\right)s+R_{vSC1}k_{iFC}}$$

2rd LPF

$$G_{SC}(s)=\frac{R_{vSC1}R_{vFC1}C_{vSC1}s^2+R_{vFC1}s}{R_{vSC1}R_{vFC1}C_{vSC1}s^2+\left(R_{vFC1}+R_{vSC1}\right)s+R_{vSC1}k_{iFC}}$$

2rd HPF

HPF and LPF are automatically added to achieve dynamic power allocation

$$G_c(s)=\frac{R_{vSC1}C_{vSC1}s^2+\left(1+R_{vSC1}C_{vSC1}k_{iFC}\right)s+k_{iFC}}{\left(R_{vSC1}R_{vFC1}C_{vSC1}s^2+\left(R_{vFC1}+R_{vSC1}\right)s+R_{vSC1}k_{iFC}\right)s}$$

In Steady State

$$I_{oFC}=I_o-\left(V_{ref}-V_{nom}\right)/R_{vSC1}$$

$$I_{oSC}=\left(V_{ref}-V_{nom}\right)/R_{vSC1}$$

UC’s SoC could be maintained within normal mode

Setting

$$V_{ref}=\begin{cases} V_{nom}-\Delta V & SoC<25\% \\ V_{nom} & 25\%\le SoC\le 90\% \\ V_{nom}+\Delta V & SoC>90\% \end{cases}$$

Decentralized Power Allocation Strategy

Impedance Design: The real output impedances of the converters have to be designed to closely follow the desired shapes.

Enabling Technique: Impedance shaping strategy.

Expected Output Impedance

$$Z_{o1}^{*}(s) = \frac{R_{v\mathrm{FC}1}s}{s + k_{i\mathrm{FC}}}$$

$$Z_{o2}^{*}(s) = \frac{R_{v\mathrm{SC}1}}{R_{v\mathrm{SC}1}C_{v\mathrm{SC}1}s + 1}$$

$$Z_{o}^{*}(s) = \frac{Z_{o1}^{*}(s) \cdot Z_{o2}^{*}(s)}{Z_{o1}^{*}(s) + Z_{o2}^{*}(s)}.$$

Real Output Impedance

$$Z_{o1}(s) = Z_{o1}^{*}(s) \cdot T_1(s)$$

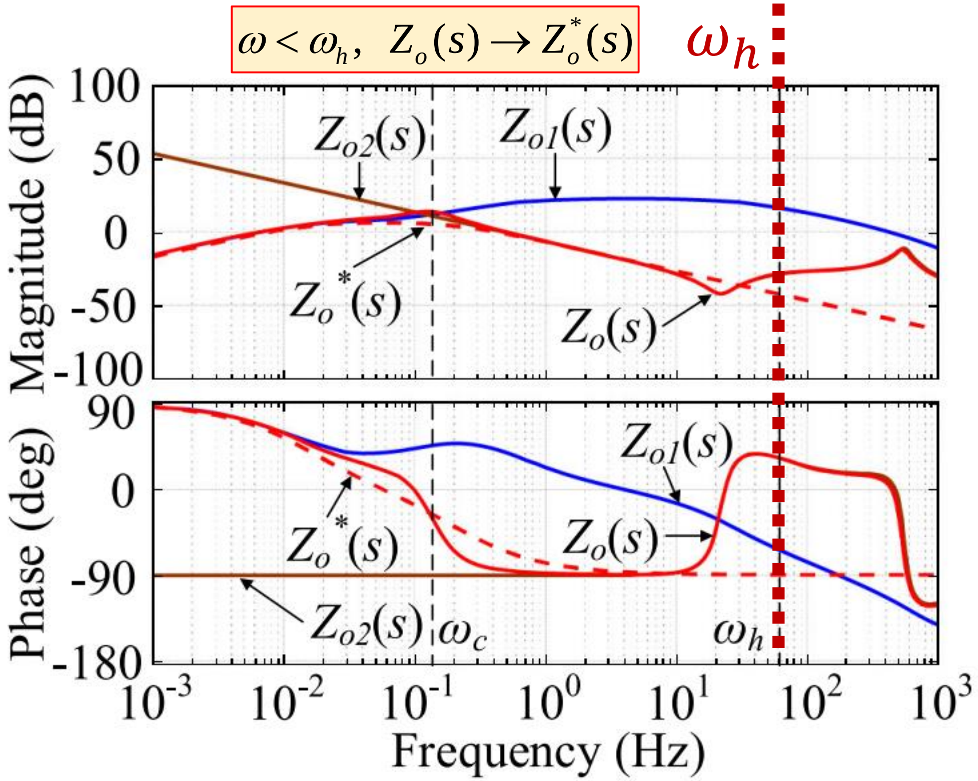
$$Z_{o2}(s) = Z_{o2}^{*}(s) \cdot T_2(s)$$

$$Z_{o}(s) = \frac{Z_{o1}(s)\, Z_{o2}(s)}{Z_{o1}(s) + Z_{o2}(s)}$$

$$T_1(s) = \frac{a_{15}s^5 + a_{14}s^4 + a_{13}s^3 + a_{12}s^2 + a_{11}s + a_{10}}{b_{15}s^5 + b_{14}s^4 + b_{13}s^3 + b_{12}s^2 + b_{11}s + b_{10}}$$

$$T_2(s) = \frac{a_{25}s^5 + a_{24}s^4 + a_{23}s^3 + a_{22}s^2 + a_{21}s + a_{20}}{b_{24}s^4 + b_{23}s^3 + b_{22}s^2 + b_{21}s + b_{20}}$$

$T_1(s)$ and $T_2(s)$ should be carefully designed to make the real output impedance track the expected value.



Impedance Design

Stability Analysis

Remarks: As the output impedance of the HPSS has already designed. It is quite convenient to use **Middlebrooks's Stability Criterion** to judge the system stability.

Output Impedance of the HPSS

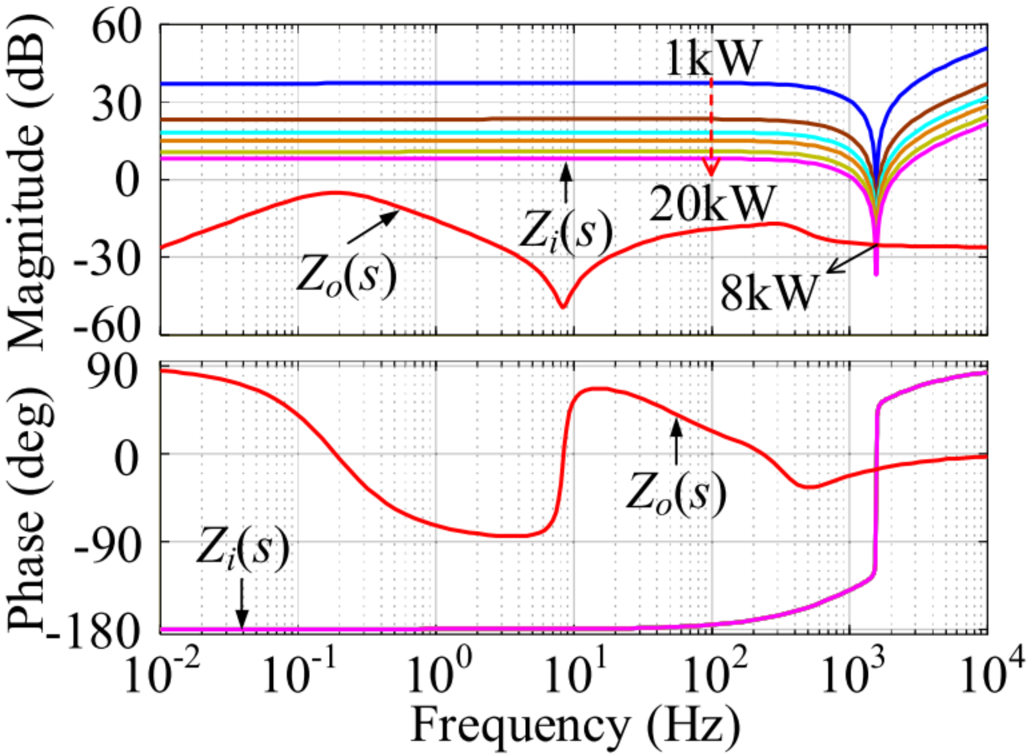
$$Z_o(s) = \frac{Z_{o1}(s)\, Z_{o2}(s)}{Z_{o1}(s) + Z_{o2}(s)}$$

Input Impedance of a CPL (Buck converter driving loads)

$$Z_i(s) = \frac{{V_{\mathrm{bus}}}^2 \left[R_b L_3 C_3 s^3 + L_3 s^2 + R_b\left(1 + k_{p3} V_{\mathrm{bus}}\right) s + R_b k_{i3} V_{\mathrm{bus}}\right]}{P_{\mathrm{CPL}} R_b \left[R_b C_3 s^2 + \left(1 - k_{p3} V_{\mathrm{bus}}\right) s - k_{i3} V_{\mathrm{bus}}\right]}$$

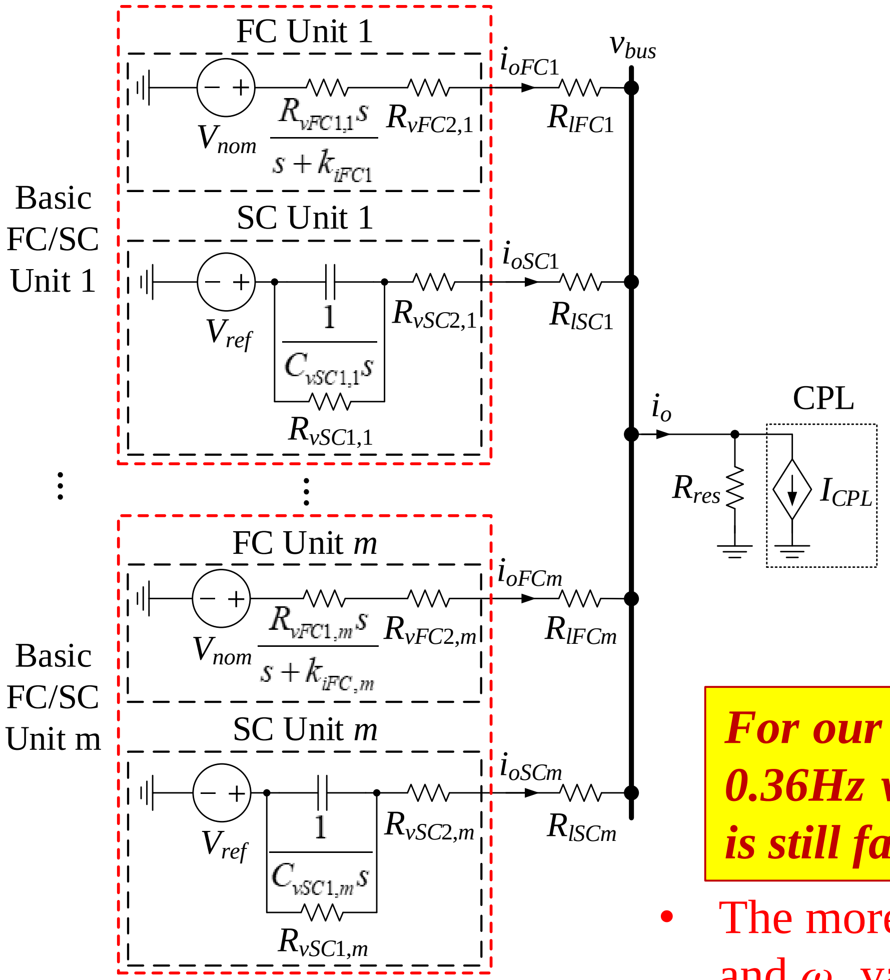
For our system, which is 5kW, the system is stable in the whole operation range.

The system becomes unstable when the load power exceeds 8kW.



Stability analysis

Scalability and Reliability Features



Guidelines for adding new FC/SC unit:

$$\begin{cases} R_{vFC1,k} = R_{vFC1} \\ k_{iFCk} = k_{iFC} \\ R_{vFC2,k} \approx -R_{lFCk} \end{cases} \quad \begin{cases} C_{vSC1,k} = C_{vSC1} \\ R_{vSC1,k} = R_{vSC1} \\ R_{vSC2,k} \approx -R_{lSCk} \end{cases} \Rightarrow \boxed{\begin{cases} R_{vFC1,eq} = R_{vFC1}/m \\ k_{iFC,eq} = k_{iFC} \\ C_{vSC1,eq} = mC_{vSC1} \\ R_{vSC1,eq} = R_{vSC1}/m \end{cases}} \Rightarrow \boxed{\omega_{c,eq} = \omega_c}$$

A single SC unit of a basic FC/SC unit is disconnected from the system:

$$\begin{cases} R_{vFC1,eq} = R_{vFC1}/m \\ k_{iFC,eq} = k_{iFC} \\ C_{vSC1,eq} = (m-1)C_{vSC1} \\ R_{vSC1,eq} = R_{vSC1}/(m-1) \end{cases} \Rightarrow \boxed{\omega_{c,eq} = \omega_{n,eq}\sqrt{\left(1-2\zeta_{eq}^2+\frac{\omega_{n,eq}^2}{k_{iFC}^2}\right)+\sqrt{\left(1-2\zeta_{eq}^2+\frac{\omega_{n,eq}^2}{k_{iFC}^2}\right)+1}}}$$

$$\zeta_{eq} = \frac{\sqrt{(m-1)/m}R_{vFC1}+\sqrt{m/(m-1)}R_{vSC1}}{R_{vFC1}+R_{vSC1}}\zeta$$

$$\omega_{n,eq} = \sqrt{\frac{m}{m-1}}\omega_n$$

For our system, $\omega_{c,eq}$ increases from 0.2Hz to 0.36Hz when one SC is down (worst case). It is still far less than 5Hz.

- The more the basic FC/SC units, the smaller ω_n, ζ, and ω_c varies; worst case, two basic FC/SC units.
- Plugging out an SC unit
  $\omega_{c,eq}$ would **slightly increase**, making the FC pick some high-frequency load power.
  However, as the frequency increase is very small, the power picked up could be ignored.

Summarize of Strategy 1

Current Sharing Relationship

$$i_{oFC} = \boxed{G_{FC}(s)}\, i_o - G_c(s)\left(V_{ref} - V_{nom}\right)$$

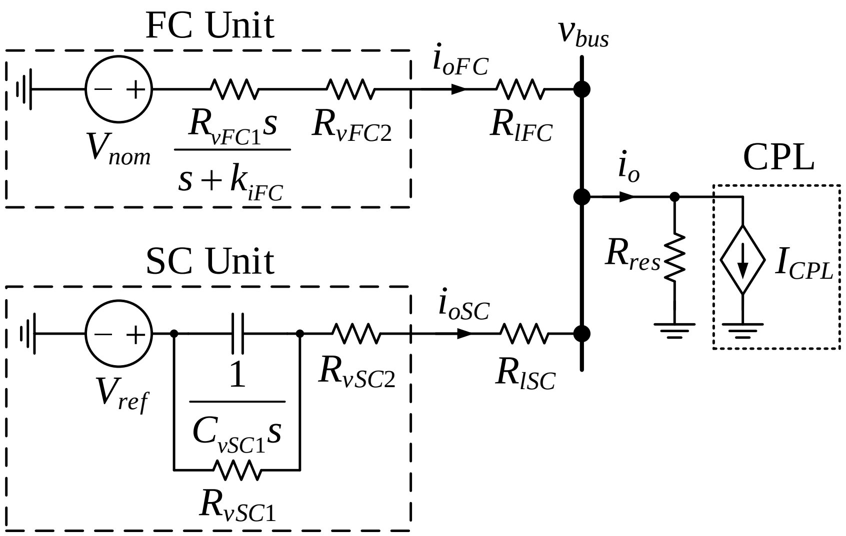
$$i_{oSC} = \boxed{G_{SC}(s)}\, i_o + G_c(s)\left(V_{ref} - V_{nom}\right)$$

$$G_{FC}(s) = \frac{R_{vSC1}s + R_{vSC1}k_{iFC}}{R_{vSC1}R_{vFC1}C_{vSC1}s^2 + \left(R_{vFC1} + R_{vSC1}\right)s + R_{vSC1}k_{iFC}}$$

2rd LPF

$$G_{SC}(s) = \frac{R_{vSC1}R_{vFC1}C_{vSC1}s^2 + R_{vFC1}s}{R_{vSC1}R_{vFC1}C_{vSC1}s^2 + \left(R_{vFC1} + R_{vSC1}\right)s + R_{vSC1}k_{iFC}}$$

2rd HPF



Simplified FC/SC HPS with proposed control strategy 1

Features:

- ☹ high-order filters are added, too many parameters need to be designed.
- ☹ It is quite hard to do the impedance shaping as there are too many parameters that need to be tuned.

How to decrease the order of the system and simplify the design?

Decentralized Power Allocation Strategy

Decentralized Dynamic Power Allocation based on Mixed Impedance Droop Control: **Strategy 2**

The droop characteristics of the FC and UC converters are given respectively by

$$v_{oFC} = V_{nom} - \boxed{L_{vFC1} s} \cdot i_{oFC}$$
$$v_{oSC} = V_{ref} - \boxed{R_{vSC1}} i_{oSC}$$

Virtual inductor and resistor droop

Combined with equivalent FC/UC-APU, we have

$$\begin{cases} i_{oFC} = G_{FC}(s) \cdot i_o - Y(s) \cdot (V_{ref} - V_{nom}) \\ i_{oSC} = G_{SC}(s) \cdot i_o + Y(s) \cdot (V_{ref} - V_{nom}) \end{cases}$$

with

$$G_{FC}(s) = \frac{R_{vSC1}}{L_{vFC1} s + R_{vSC1}}$$

1rd LPF

$$G_{SC}(s) = \frac{L_{vFC1} s}{L_{vFC1} s + R_{vSC1}}$$

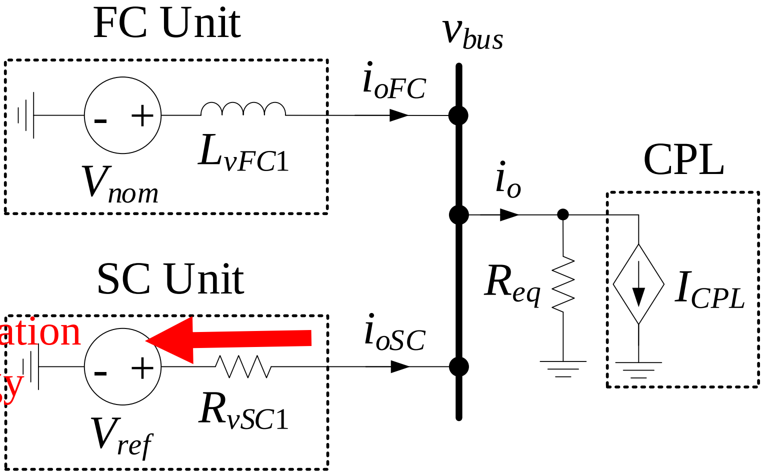
1rd HPF

$$Y(s) = \frac{1}{\left(L_{vFC1} s + R_{vSC1}\right) s}$$

Dynamic power allocation

In steady state

$$\begin{cases} I_{oFC} = I_o - \left(V_{ref} - V_{nom}\right) / R_{vSC1} \\ I_{oSC} = \left(V_{ref} - V_{nom}\right) / R_{vSC1} \end{cases}$$



Lossless accommodation of regenerative energy

Simplified FC/SC-APU with proposed control strategy

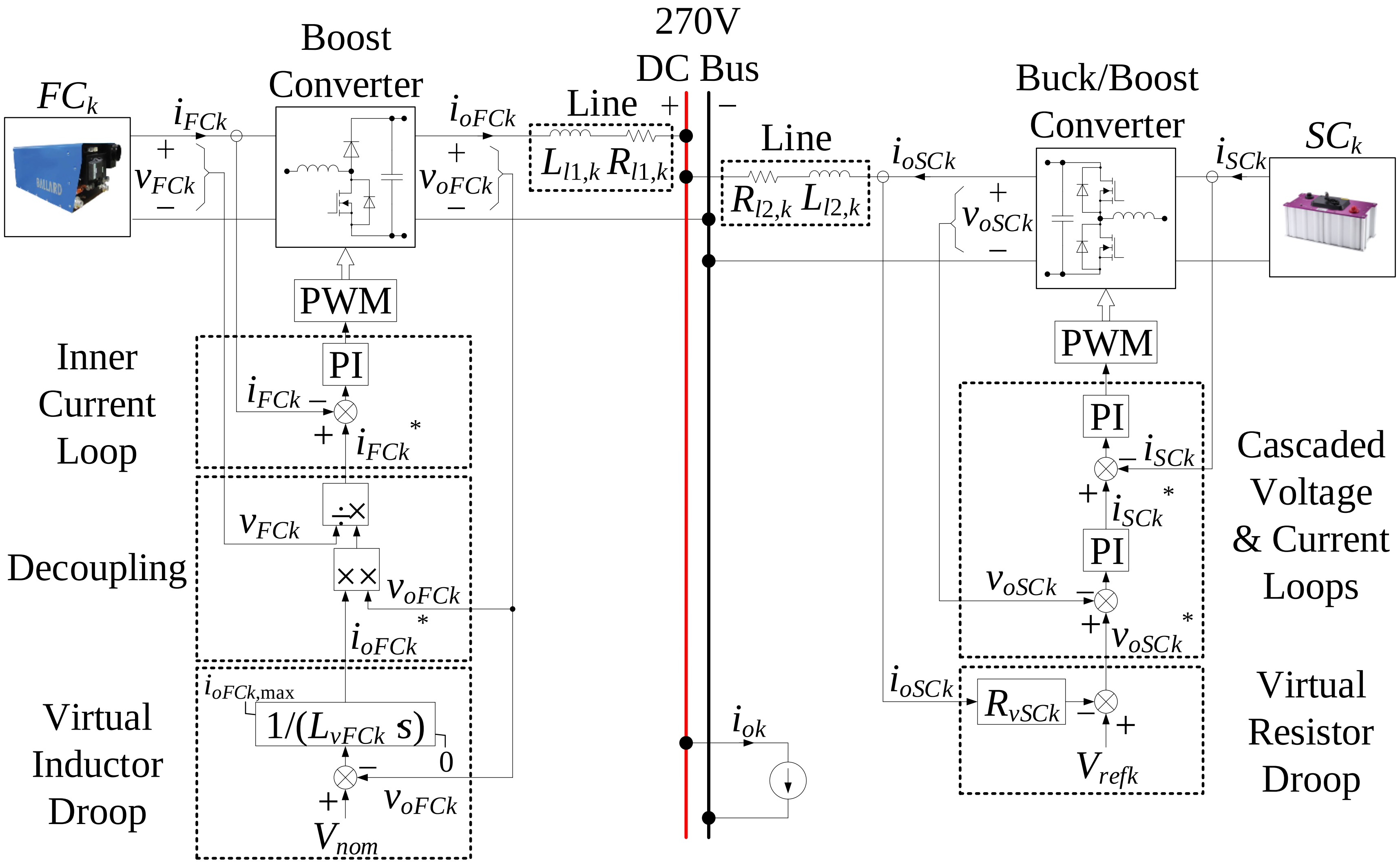
$$\text{Setting } V_{ref} = \begin{cases} V_{nom} - \Delta V & SoC < 25\% \\ V_{nom} & 25\% \le SoC \le 90\% \\ V_{nom} + \Delta V & SoC > 90\% \end{cases}$$

Limiting the UC's SoC

* J. Chen, Q. Song, S. Yin, and J. Chen, "On the decentralized energy management strategy for the all-electric APU of future more electric aircraft composed of multiple fuel cells and supercapacitors," *IEEE Trans. Ind. Electron.*, to be published, doi: 10.1109/TIE.2019.2937069.

Decentralized Energy Management Strategy

Implementation



Structure of the FC/SC-APU with proposed control strategy

Impedance Design and Stability Analysis

Expected Output Impedance

$$Z^*_{oFCk}(s) = L_{vFCk}\,s$$

$$Z^*_{oSCk}(s) = R_{vSCk}$$

$$Z^*_{ok}(s) = \frac{Z^*_{oFCk}(s)\,Z^*_{oSCk}(s)}{Z^*_{oFCk}(s) + Z^*_{oSCk}(s)}.$$

$$T_{FCk}(s) = \frac{a_2 s^2 + a_1 s + a_0}{b_4 s^4 + b_3 s^3 + b_2 s^2 + b_1 s + b_0}$$

$$T_{SCk}(s) = \frac{c_3 s^3 + c_2 s^2 + c_1 s + c_0}{d_4 s^4 + d_3 s^3 + d_2 s^2 + d_1 s + d_0}$$

- $T_{FCk}(s)$ and $T_{SCk}(s)$ should be carefully designed to make the real output impedance track the expected value.

  $\boxed{\omega < \omega_h,\ \ Z_o(s) \rightarrow Z_o^*(s)}$

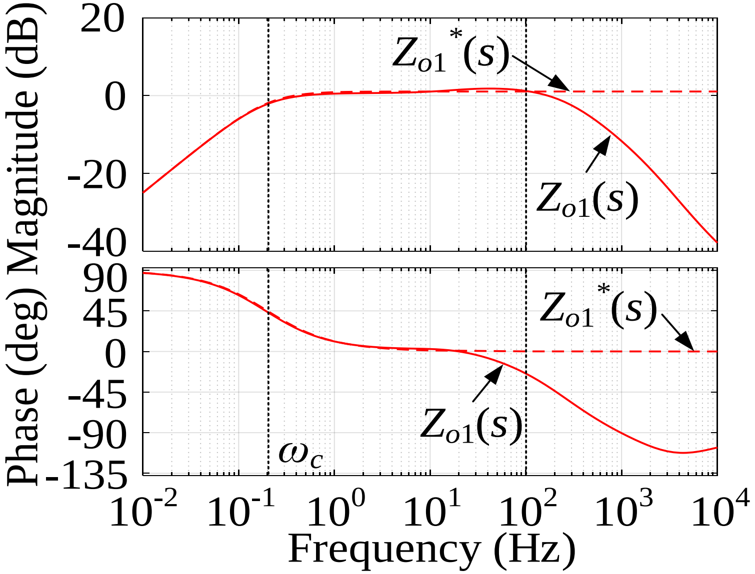
- Compared with Strategy 1, the system order decreased.

Real Output Impedance

$$Z_{oFCk}(s) = Z^*_{oFCk}(s) \cdot T_{FCk}(s)$$

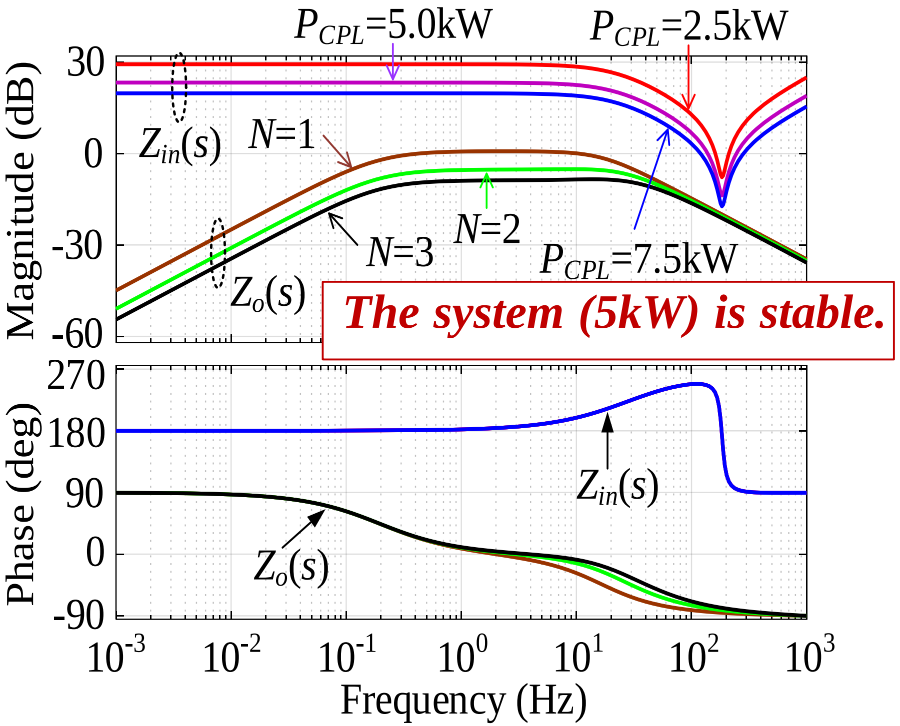
$$Z_{oSCk}(s) = Z^*_{oSCk}(s) \cdot T_{SCk}(s)$$

$$Z_{ok}(s) = \frac{Z_{oFCk}(s)\,Z_{oSCk}(s)}{Z_{oFCk}(s) + Z_{oSCk}(s)}$$



Impedance Design for Strategy 2

Middlebrooks's Stability Criterion Used



The system (5kW) is stable.

Stability analysis and design

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* J. Chen and Q. Song, "A decentralized dynamic load power allocation strategy for fuel cell/supercapacitor-based APU of large more electric vehicles," *IEEE Trans. Ind. Electron.*, vol. 66, no. 2, pp. 865–875, Feb. 2019.

J. Chen, Q. Song, S. Yin, and J. Chen, "On the decentralized energy management strategy for the all-electric APU of future more electric aircraft composed of multiple fuel cells and supercapacitors," *IEEE Trans. Ind. Electron.*, to be published, doi: 10.1109/TIE.2019.2937069.

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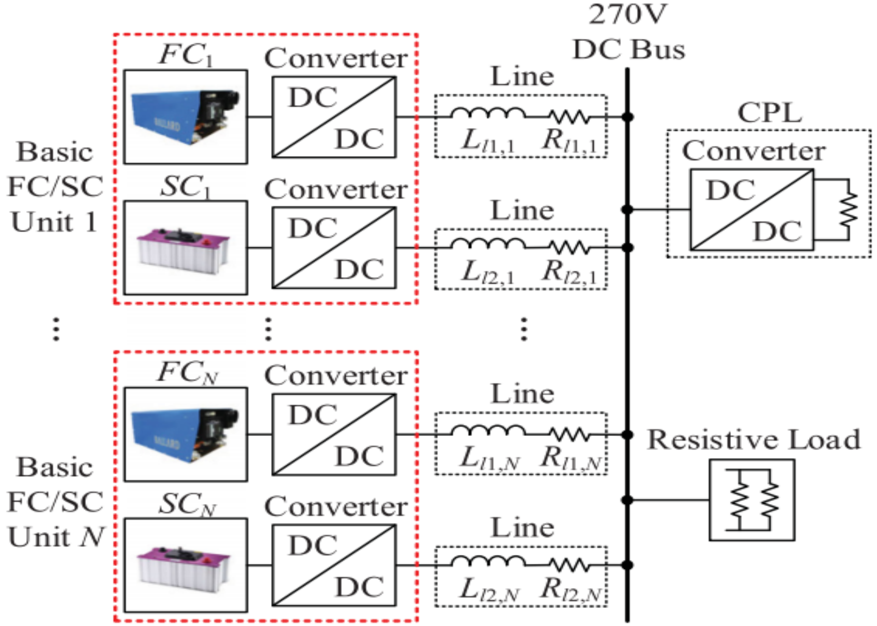
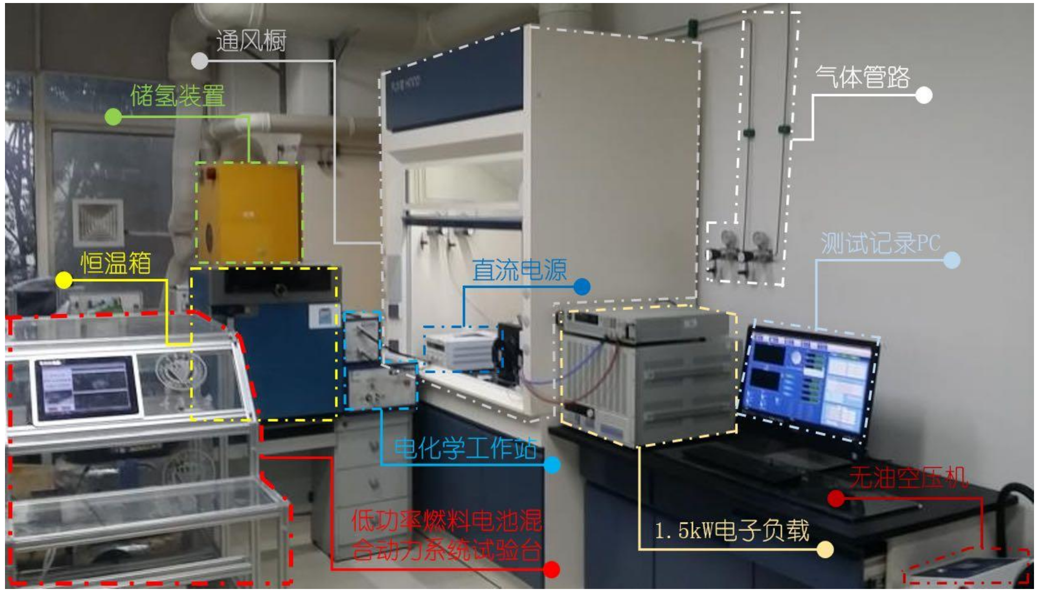
Experimental Verification

Simplified Structure of the System



Test rig Setup



System Parameters

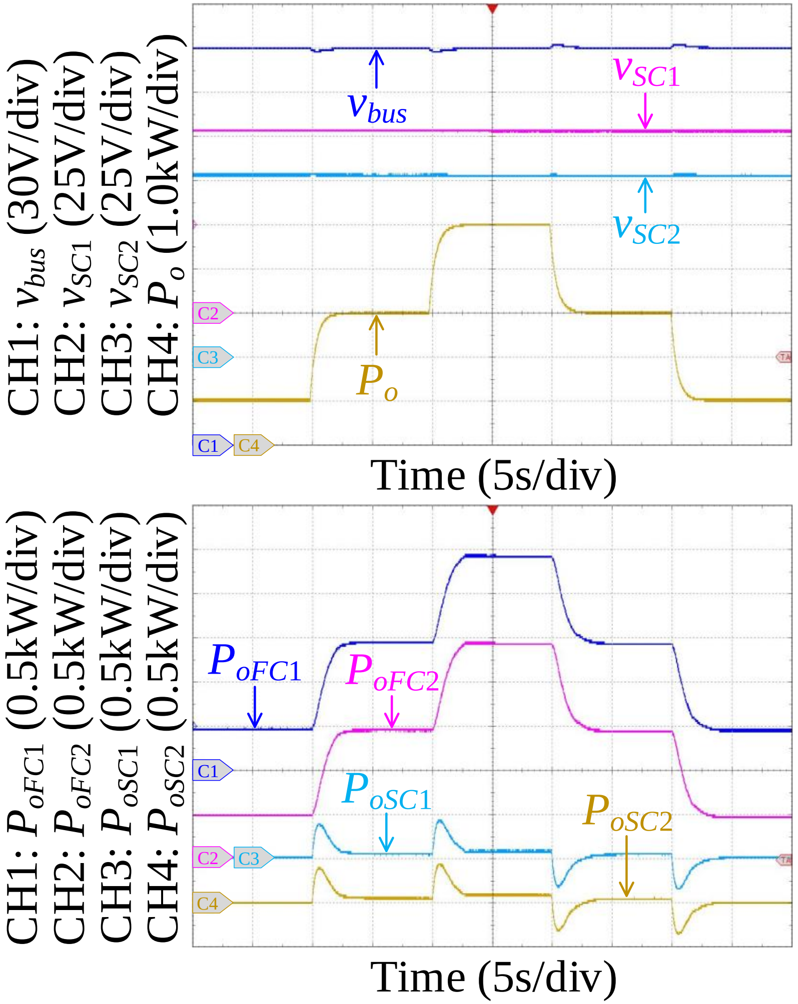
Variable	Description	Value
V_{nom}	Nominal dc bus voltage	270V
V_{FC1}	FC nominal voltage	90V
P_{FC1}	Power rating of the FC	3kW
V_{SC1}	SC nominal voltage	125V
C_{SC1}	Rated capacitance of the SC	63F
ω_c	Cut-off frequency	2π×0.2rad/s
R_{lFC1}, R_{lFC2}	Line resistance of FC units	0.2Ω
R_{lSC1}, R_{lSC2}	Line resistance of SC units	0.05Ω
R_b	Load resistor of buck converter	15Ω
$R_{vFC2,1}$, $R_{vFC2,2}$	Negative virtual resistance of FC units	-0.2Ω
$R_{vSC2,1}$, $R_{vSC2,2}$	Negative virtual resistance of SC units	-0.05Ω
R_{vFC1}	Virtual resistance of FC units	1.5Ω
k_{iFC}	Voltage restoration gain for FC units	2.2247
C_{vSC1}	Virtual capacitance of SC units	0.9675F
R_{vSC1}	Virtual resistance of SC units	0.8Ω
ΔV	Increment of reference voltage	3.0V
f_s	Switching frequency	20kHz
L_1	Filter inductor of FC converter	0.6mH
C_1	Output capacitor of FC converter	1410μF
L_2	Filter inductor of SC converter	0.6mH
C_2	Output capacitor of SC converter	2820μF
L_3	Filter inductor of buck converter	0.8mH
C_3	Output capacitor of buck converter	1000μF
k_{vp1}	Proportional gain of voltage controller	0.1420
k_{vi1}	Integral gain of voltage controller	0.8921
k_{vp2}	Proportional gain of voltage controller	20.3667
k_{vi2}	Integral gain of voltage controller	3839.0
k_{ip1}	Proportional gain of current controller	0.0179
k_{ii1}	Integral gain of current controller	2.2487
k_{ip2}	Proportional gain of current controller	0.0814
k_{ii2}	Integral gain of current controller	35.8209
k_{p3}	Proportional gain of the buck controller	0.28
k_{i3}	Integral gain of buck controller	3.03

Experimental Verification

Different Power Sharing Ratios

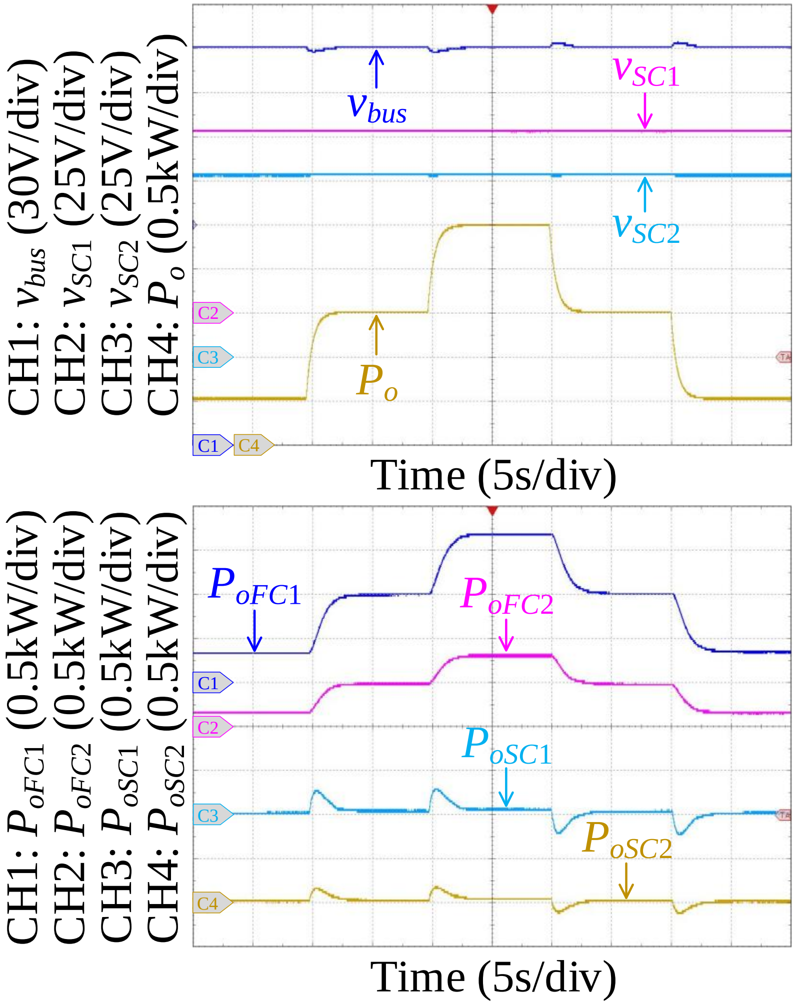
$$\begin{cases} \frac{L_{vFCk}}{L_{vFC1}} = \frac{P_{FC\max 1}}{P_{FC\max k}} = \frac{m_1}{m_k} \\ \frac{R_{vSCk}}{R_{vSC1}} = \frac{Q_{SC1}}{Q_{SCk}} = \frac{n_1}{n_k} \end{cases}$$

Load Power: 1kW→3kW →5kW →3kW →1kW



m_1:m_2=n_1:n_2=1:1

Load Power: 1kW→3kW →5kW →3kW →1kW



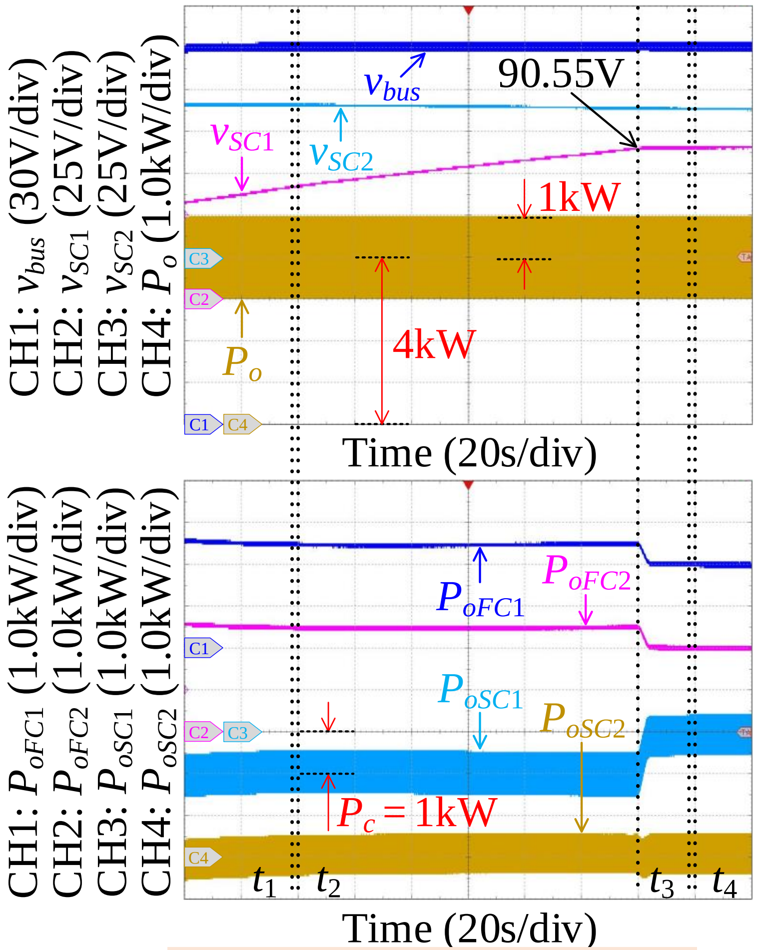
m_1:m_2=n_1:n_2=2:1

Experimental Verification

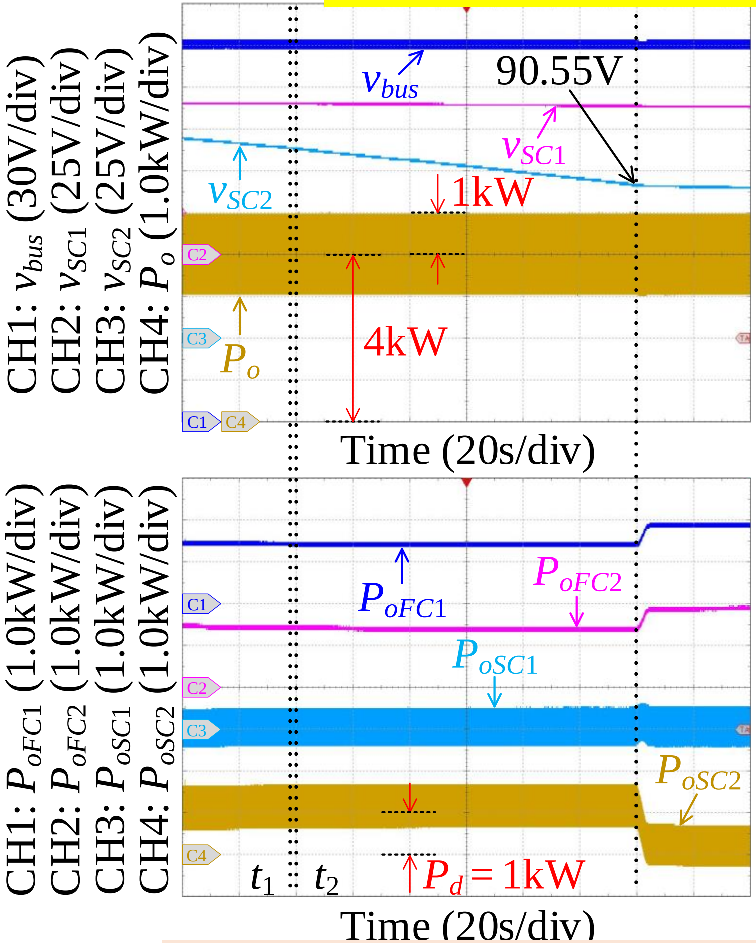
Operation in different modes of UC

Load Power: 4kW Average+2kW Pulsating

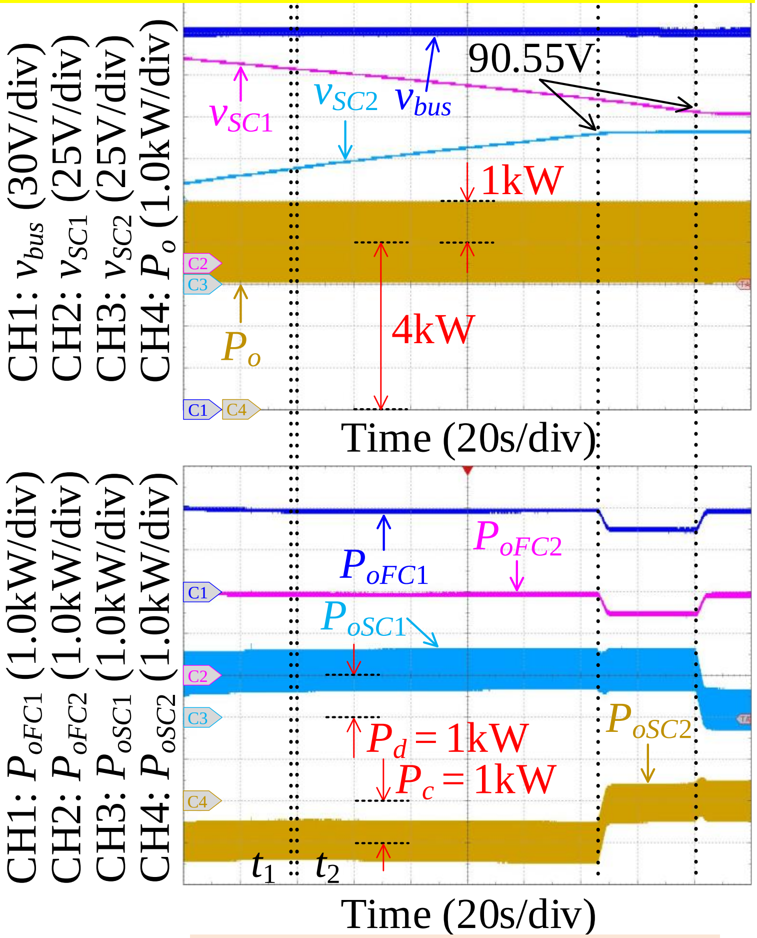
- FC provides average part + UC provides pulsating part
- SoC of the UC doesn’t impact the dynamic power allocation
- SoC recovery is achieved



UC: UC1 and UC2 both in Normal mode



UC: UC1 in Normal mode/UC 2 in Discharge mode



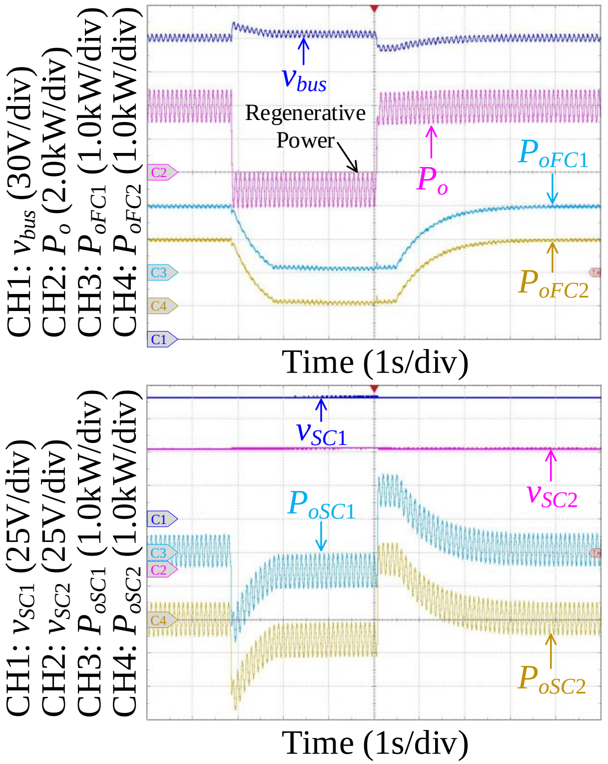
UC: UC1 in Discharge mode/UC 2 in Charge mode

Experimental Verification

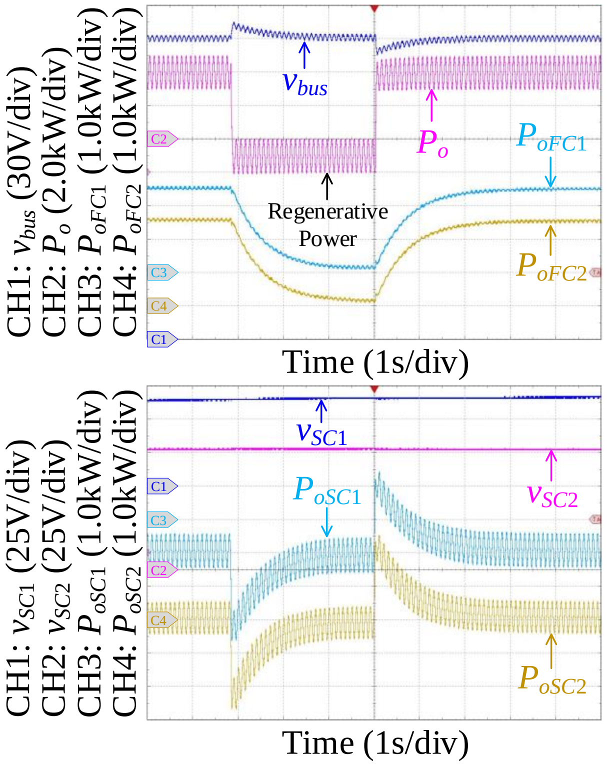
Operation in regeneration process (in different operation modes)

- Lossless accommodation of regeneration
- System performance is irrelevant to the SoC of UC

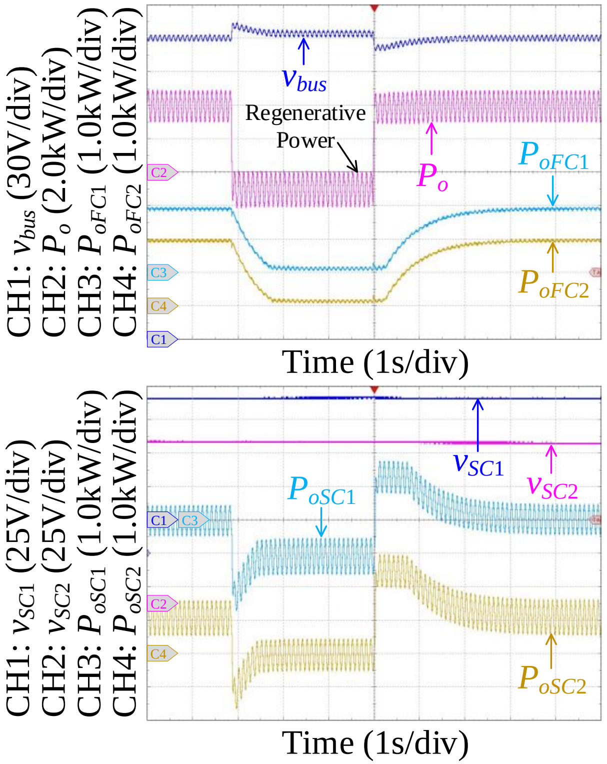
Load Power: (4kW → 1kW → 4kW) Average + 2kW Pulsating



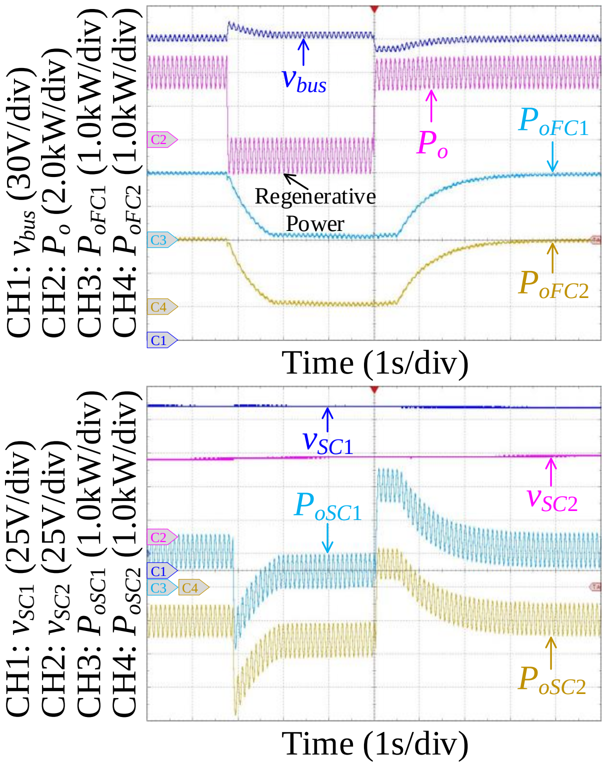
Normal mode



UC unit 1 in charge mode



UC unit 2 in discharge mode

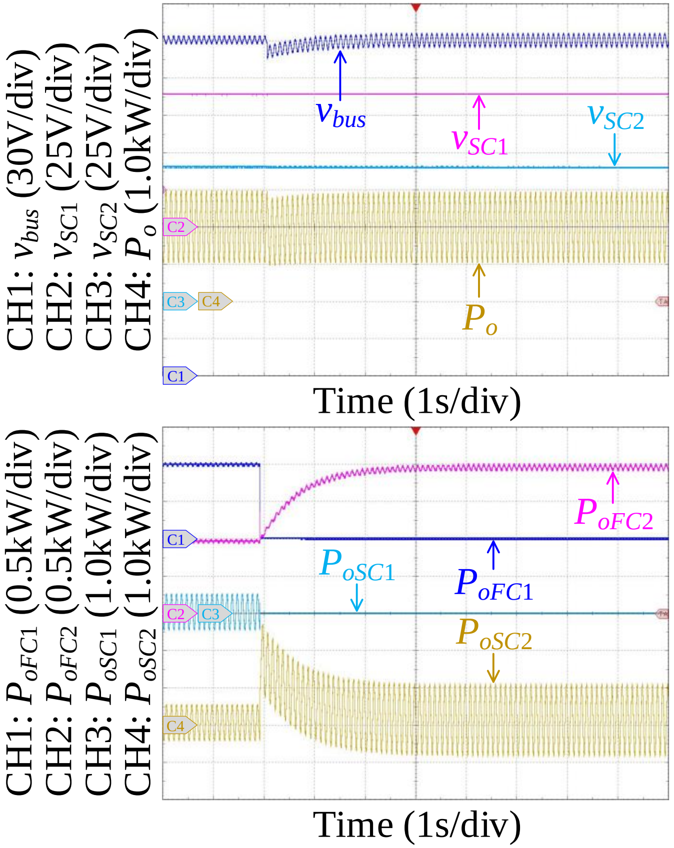


UC unit 1 in discharge mode,
UC unit 2 in charge mode

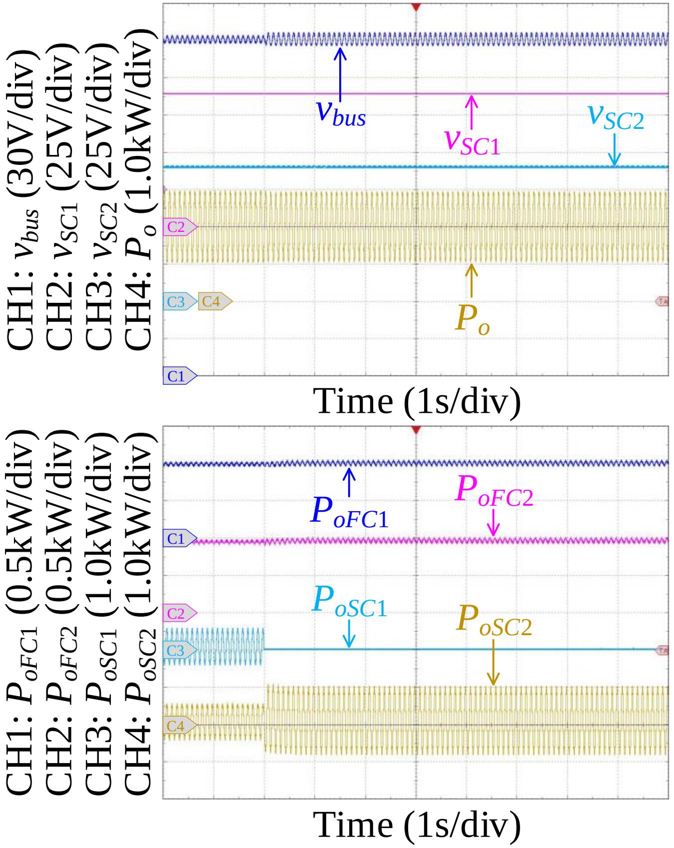
Experimental Verification

Operation at the outage of some source units.

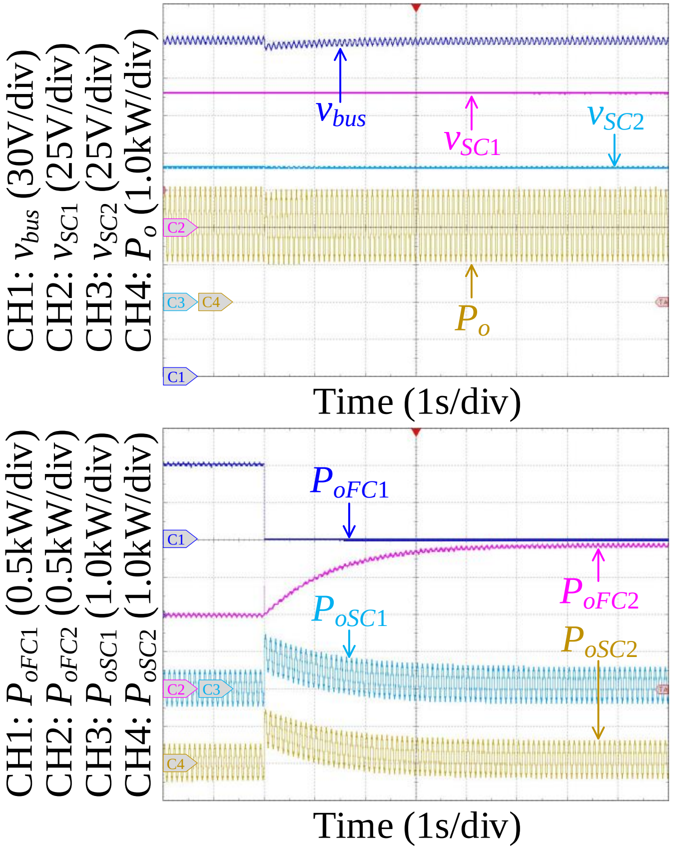
- High reliability achieved.



Outage of FC unit 1 and the UC unit 1



Outage of UC unit 1



Outage of FC unit 1

Contents

- Problem Formulation
- Decentralized Energy Management Strategy
- Experimental Verification
- Conclusions

Conclusions

- An advanced decentralized dynamic power allocation based on modified MDC was proposed for the powertrain system of the FC-UC Hybrid Electric Vehicle.
- With the help of the proposed power allocation strategy, the control objectives, including optimized dynamic load power allocation, extended service life of the system, improved energy efficiency and guaranteed system stability, are realized at the same time in a decentralized way.
- No communication nor common signals are needed for the implementation of the proposed strategy, which indicates high reliability and flexibility.
- The effectiveness and feasibility of the proposed dynamic power allocation system are verified by experiments.

Thank you very much!

Any Questions?