FC Power Dispatching: Voltage-mode vs. Current-mode

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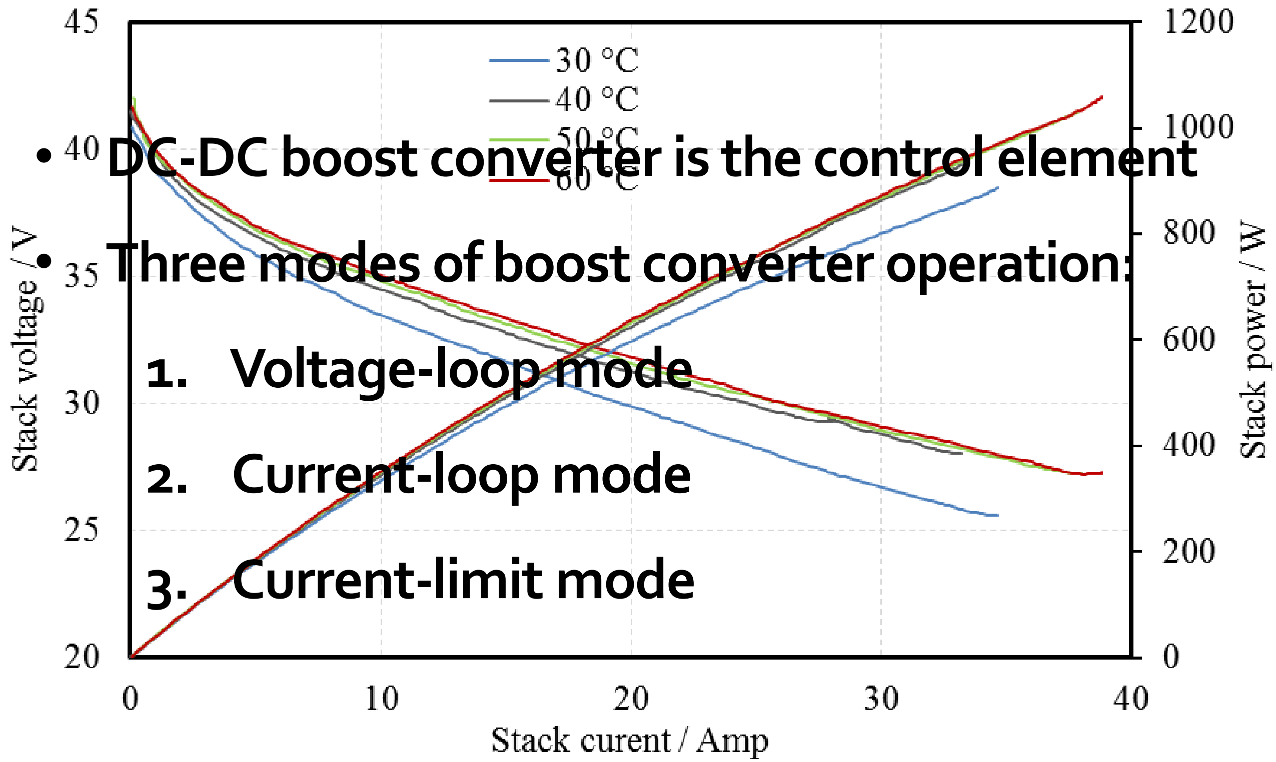
FC Power Conditioning

Why?

- Variable FC voltage



- DC-DC boost converter is the control element
- Three modes of boost converter operation:
  1. Voltage-loop mode
  2. Current-loop mode
  3. Current-limit mode

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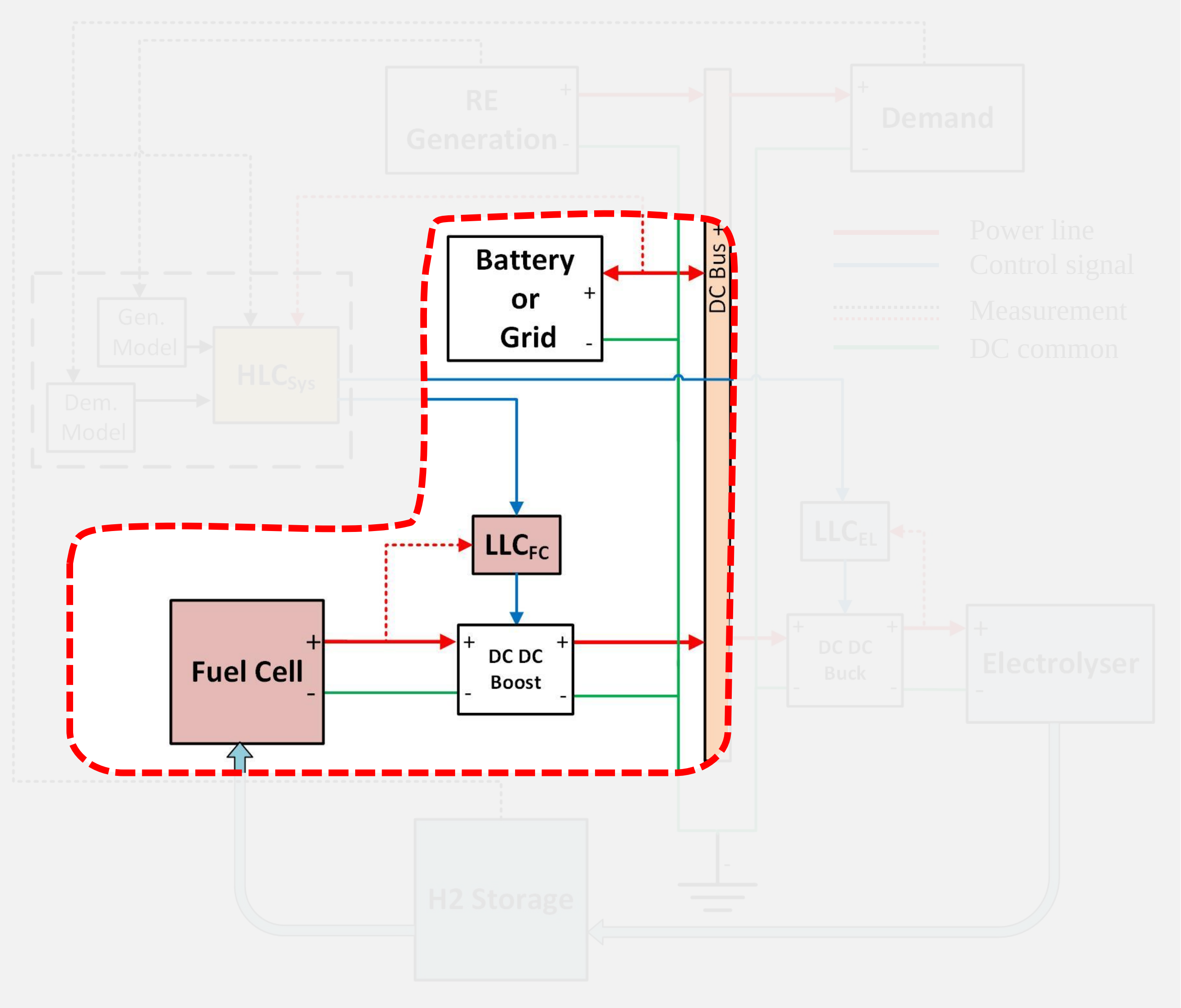
Example of FC application

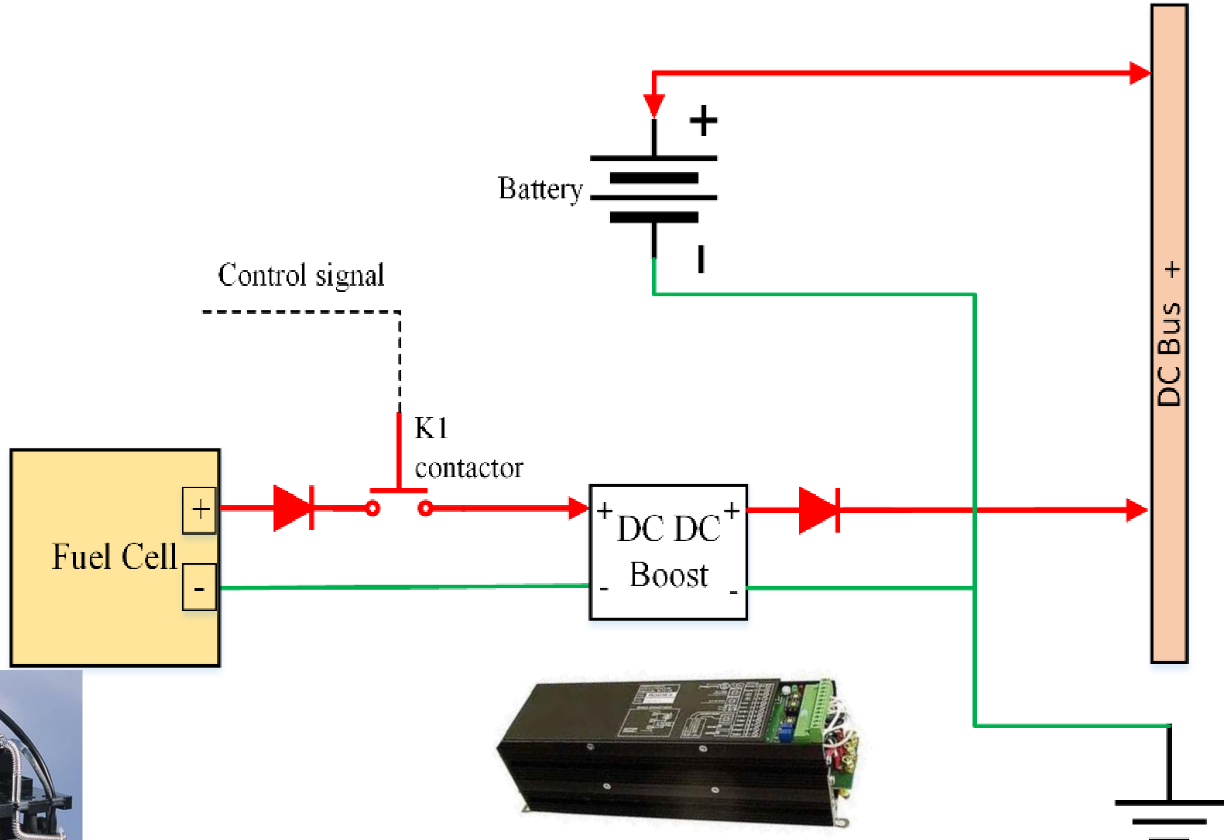
RE/Grid Balancing

- System architecture (stand-alone/integrated)
- Shared DC bus
- FC response to deficit events
- FC & (Battery/Grid) interaction
- DC bus stability
- Active load on DC bus



1- Voltage-loop mode

FC Power Line



DC boost converter
"model DC6350F-SU 125kHz"

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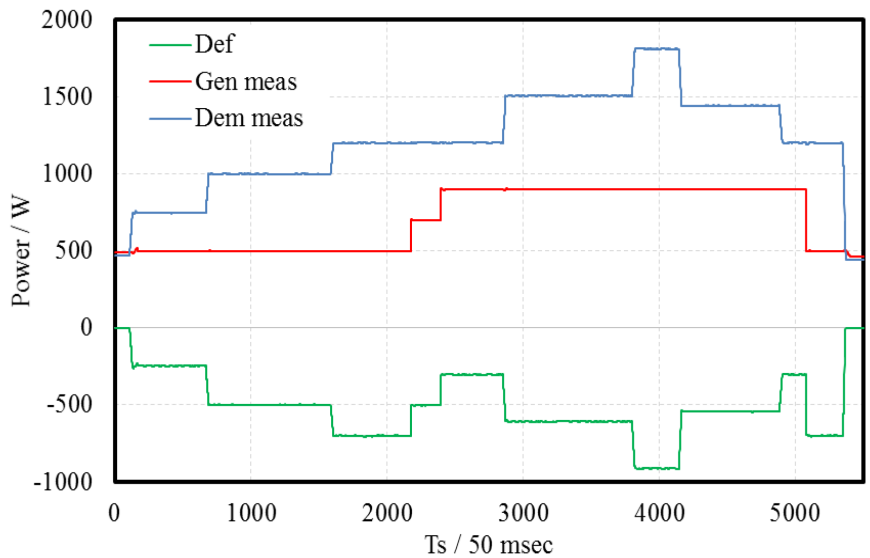
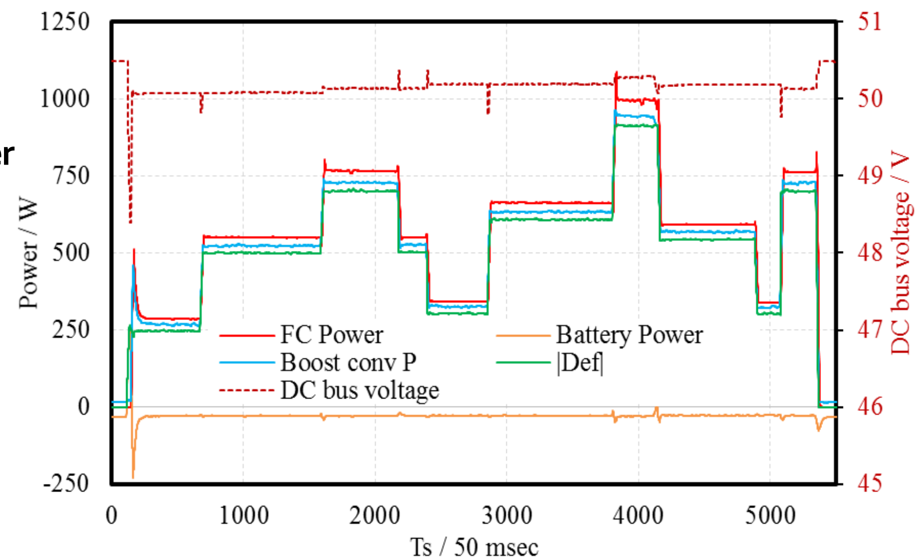
Voltage-loop mode

1.2kW FC stack
+
DC boost converter "model DC6350F-SU 125kHz"



- Responsive
- Simple
- No Control Algorithm
- NO supervisory HLC
- Isolated system

- NO Grid-connection
- Uncontrolled FC power
- Uncontrolled Battery power
- Overload protection
- Power filters (Ripples)



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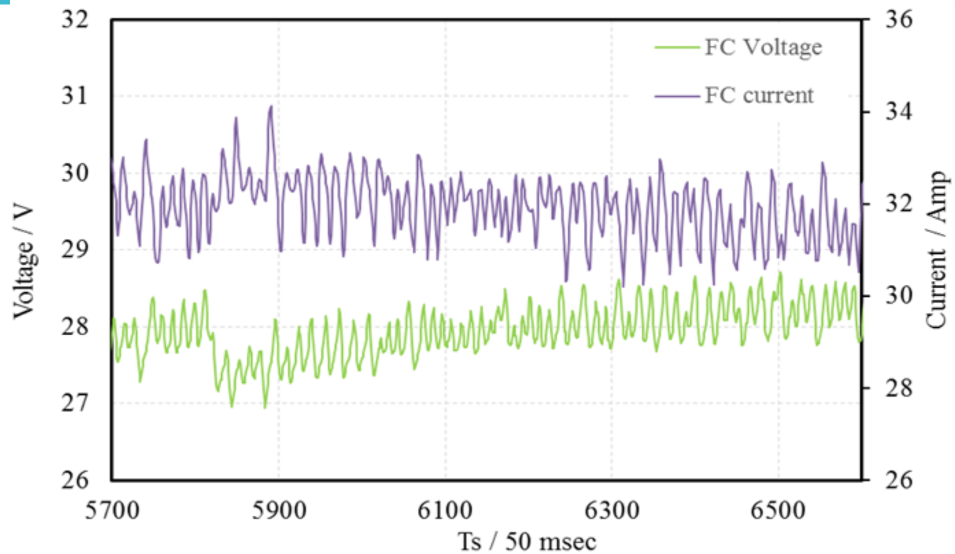
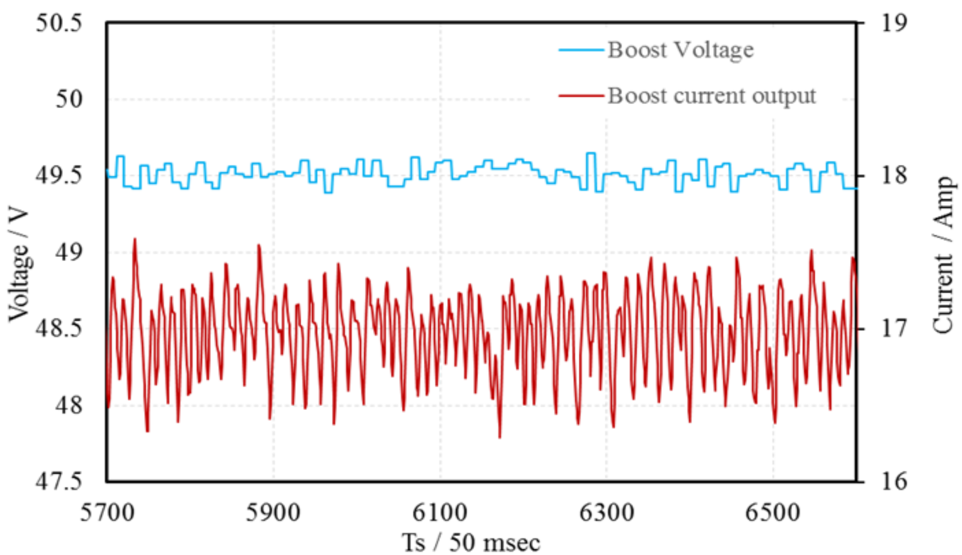
Voltage-loop mode

1.2kW FC stack + DC boost converter "model CCH63250-SSU 31.25kHz"





Peak-to-peak ripples	FC Stack	Boost converter output
Current	8.5%	9.2%
Voltage	3.5%	0.4%
Power	9.9%	6.5%

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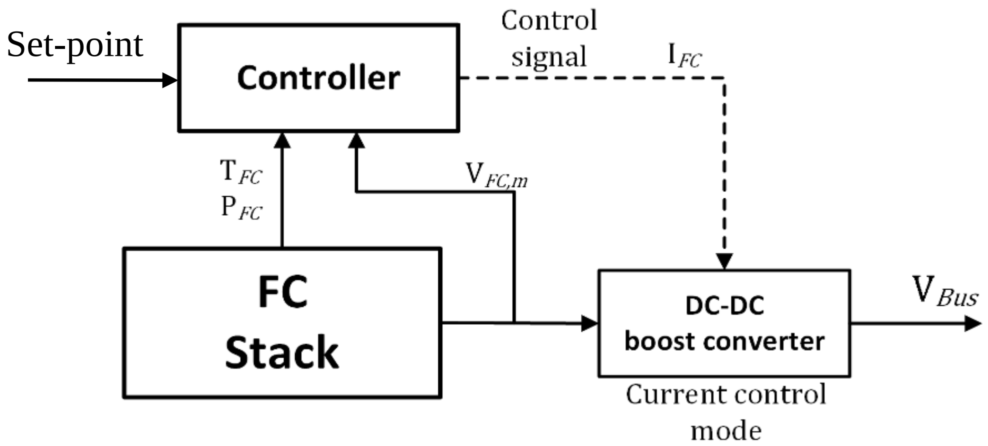
FC power line current controlled

2- Current-loop mode



- Grid-connected and stand-alone power systems
- Control Algorithm (MPC)
- Supervisory HLC (Power management)
- Inductor current is MV
- Controlled FC power (constrained dispatching)
- Controlled Battery/Grid Power
- Reduced ripples

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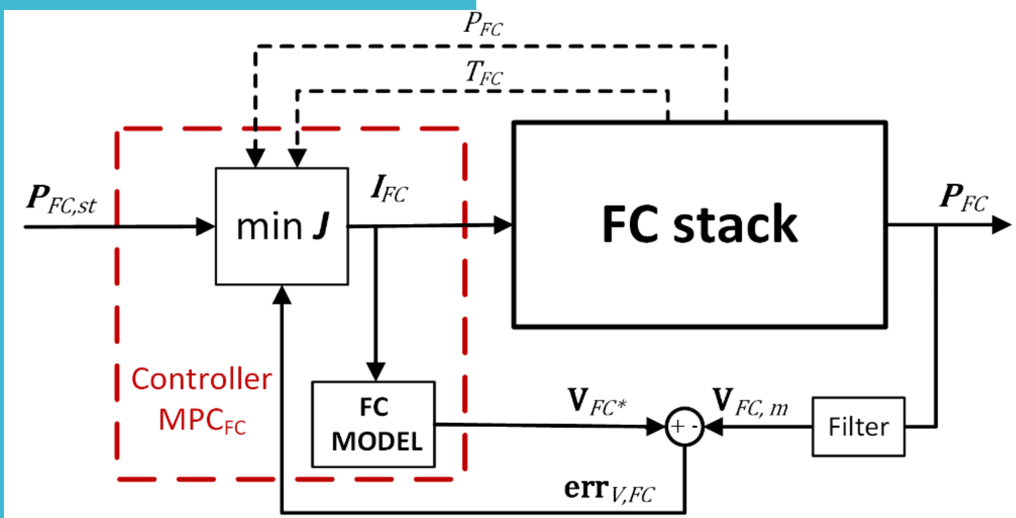
Current-loop mode

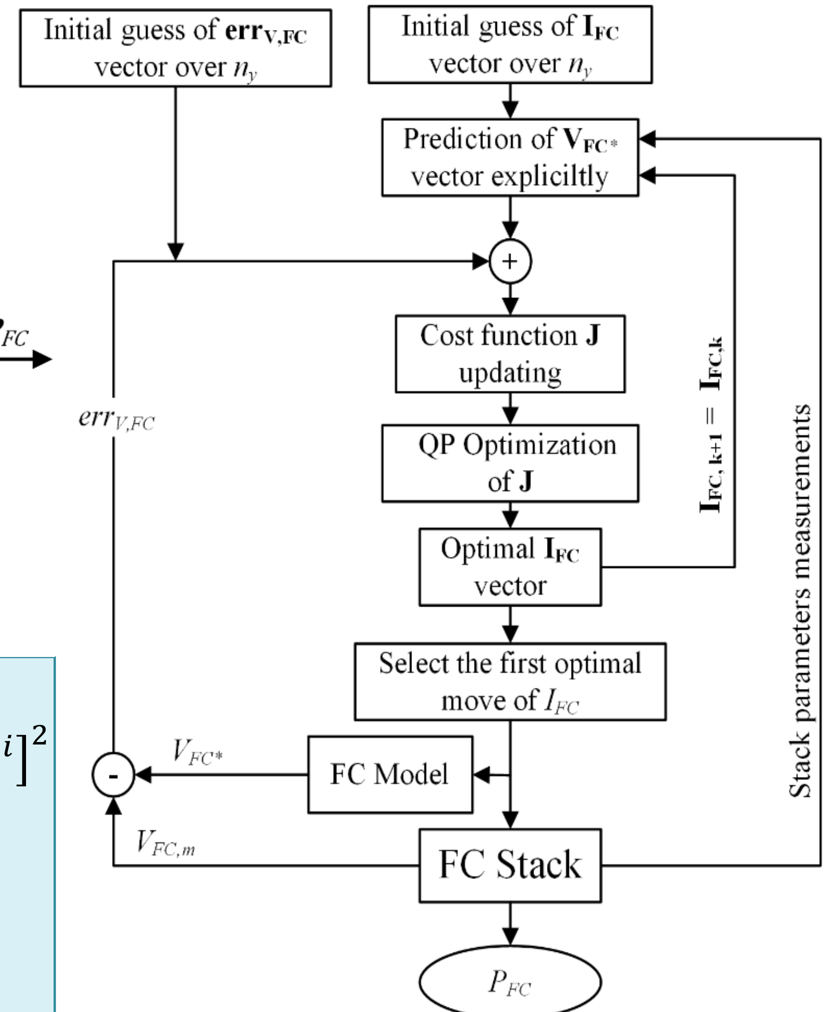
Control Algorithm (MPC)



$$\min_{\substack{subjected\\ to\ constraints}} \quad \mathbf{J} = \sum_{i=1}^{n_y} \left[P_{FC,st}^{k+i} - \left(V_{FC*}^{k+i-1} + \mathrm{err}_{V,FC}^{k+i-1}\right)\, I_{FC}^{k+i}\right]^2$$

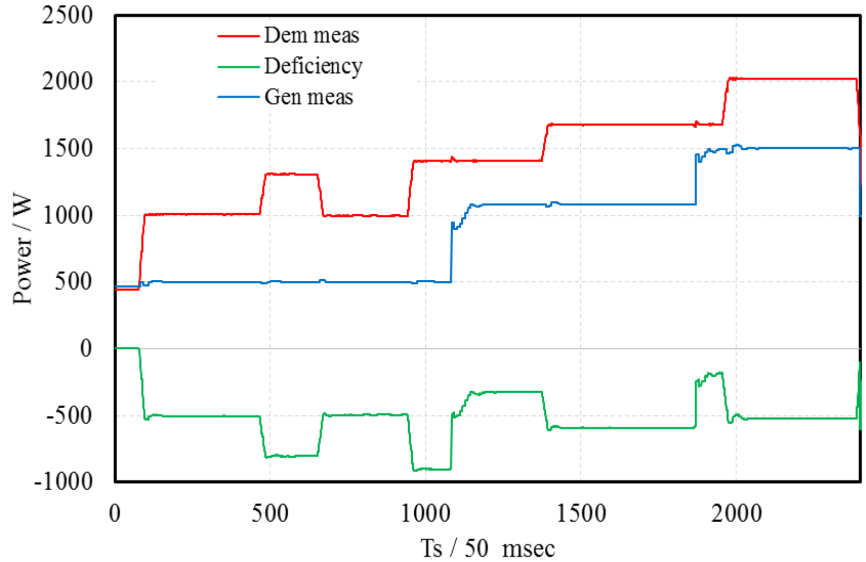
$$0 \le I_{FC} \le I_{FC,max}$$

$$\Delta I_{FC,min} \le \Delta I_{FC} \le \Delta I_{FC,max}$$

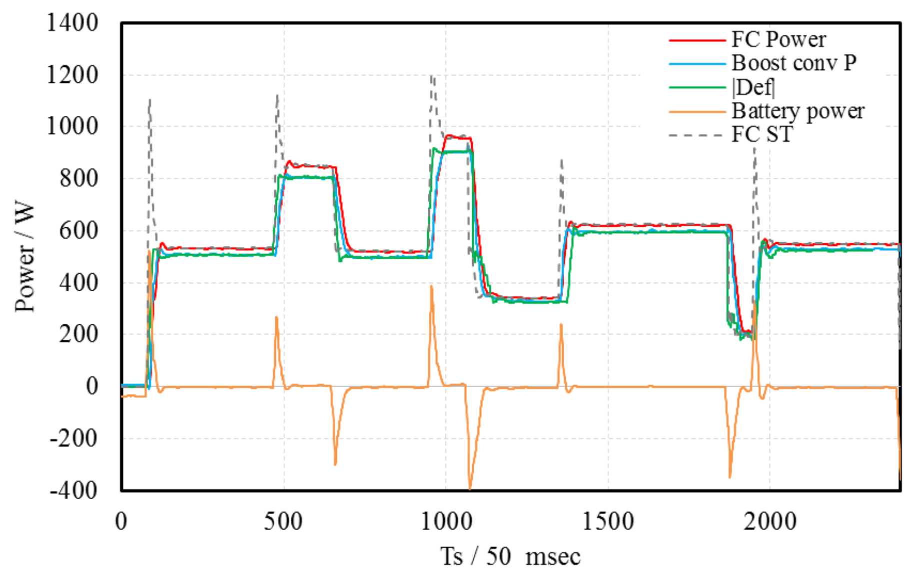


Current-loop mode

1.2kW FC stack
+
DC boost converter "model DC6350F-SU 125kHz"



- FC ST from HLC
- HLC Apply EMS
- Conv. Eff. losses --- considered by HLC



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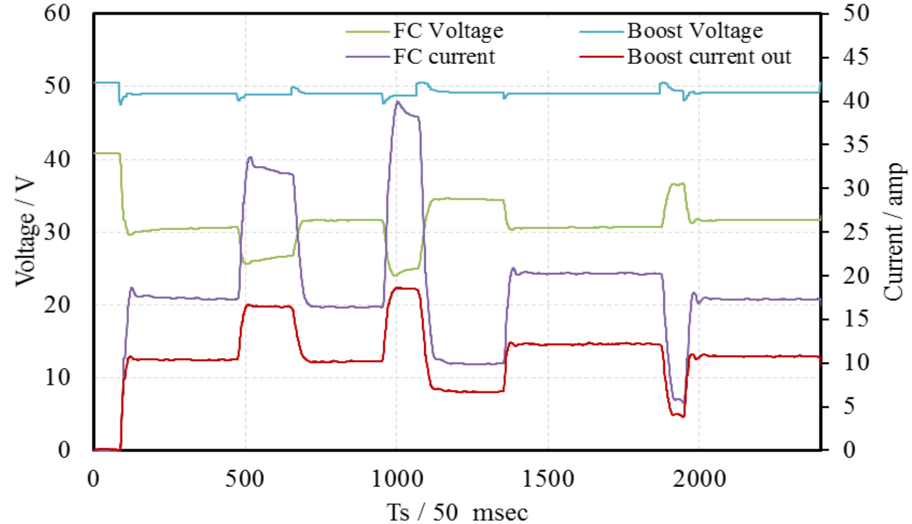
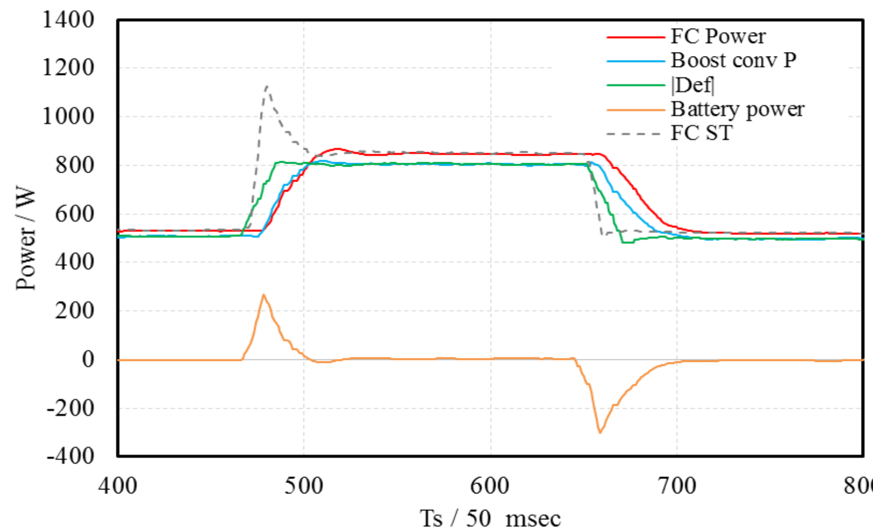
Current-loop mode

1.2kW FC stack + DC boost converter "model DC6350F-SU 125kHz"

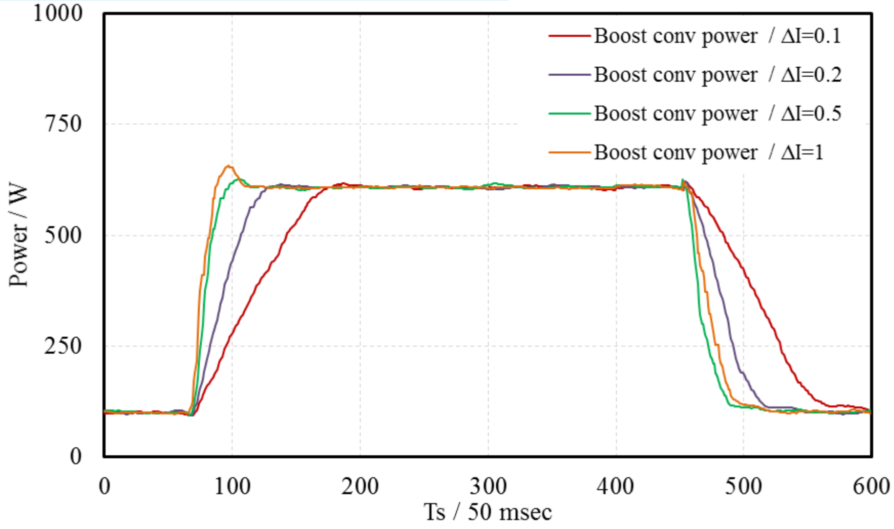
Parameter		Value
$I_{FC,max}$		50 Amp
$I_{FC,min}$		0 Amp
$\Delta I_{FC,max}$		0.5 Amp
$\Delta I_{FC,min}$		-0.5 Amp
Sampling time		50 msec
Optimization algorithm		Interior point
Optimization stopping criteria	Function tolerance	10^{-8}
	Variable tolerance	10^{-6}
	Gradient tolerance	10^{-6}
	Max. iteration	10^{4}
	Max. function calls	10^{4}

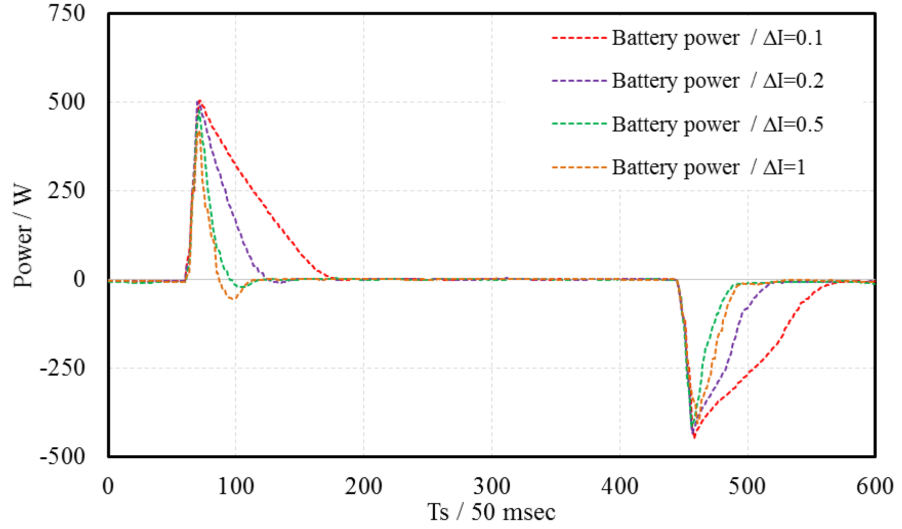




- **Reduced ripples**
- **Battery + Boost conv. = Deficit load**
- **Voltage saturation (possible)**

FC Response Tuning

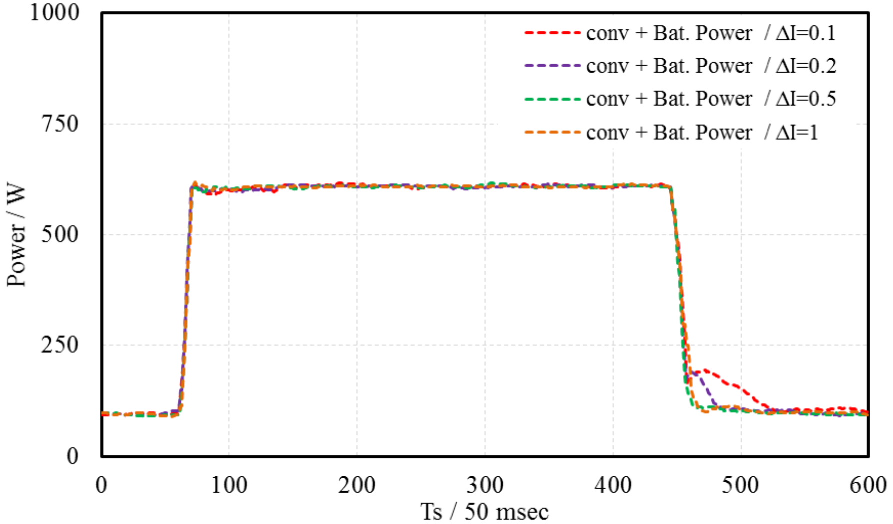




Battery Power+ Boost conv. Power =

Deficit load

Controlled Battery contribution

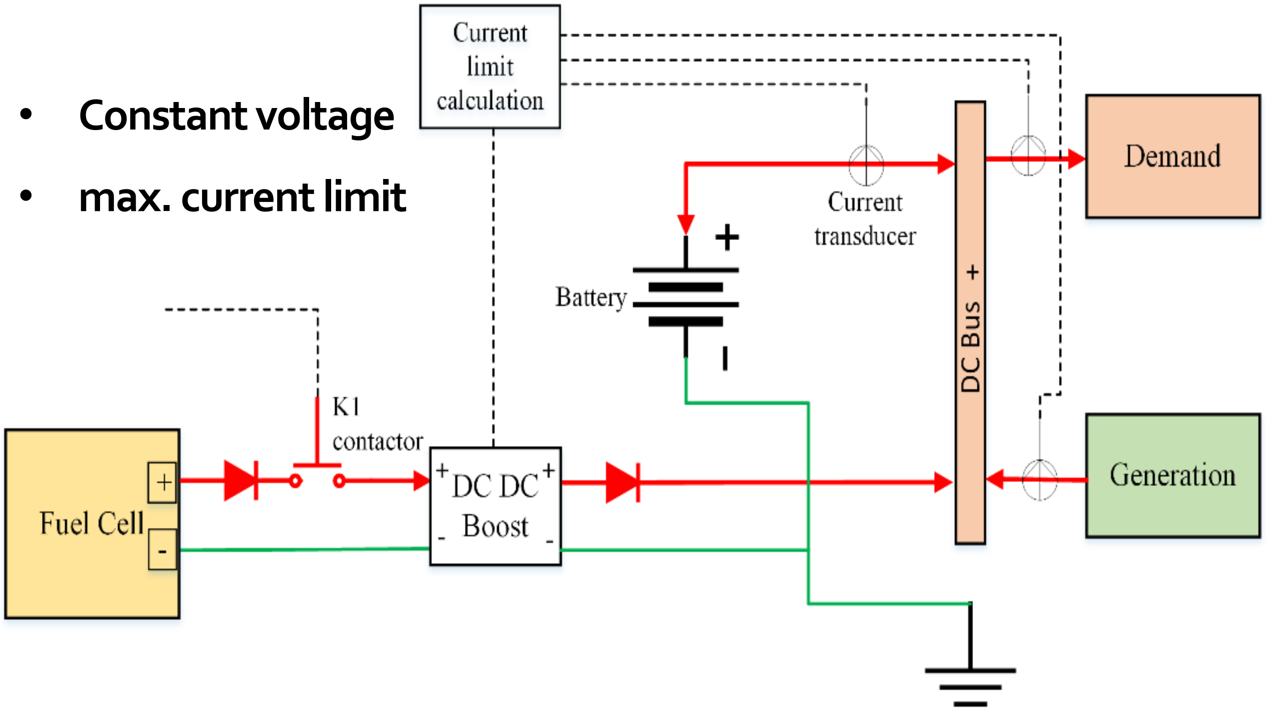


3- Current-limit (CL) mode

FC power line current-limit mode

DC boost converter "model CCH63250-SSU 31.25kHz"

- Constant voltage
- max. current limit



Two approaches:

- CL mode without HLC
- CL mode with HLC

1- CL mode without HLC

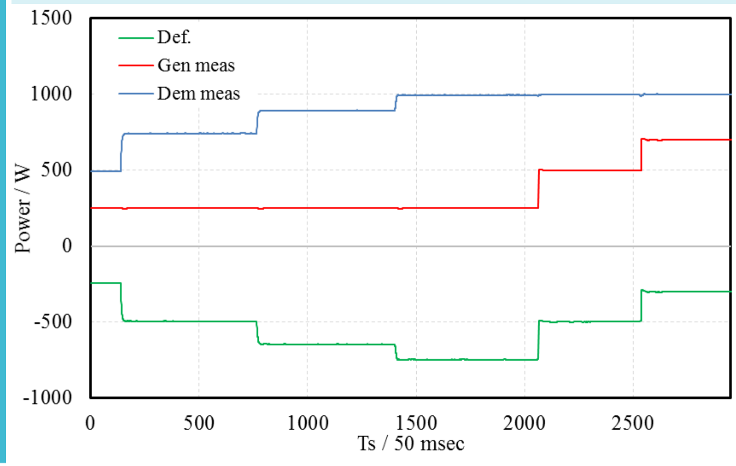
1.2kW FC stack
+
DC boost converter "model CCH63250-SSU 31.25kHz"

$$K_p = 0.2, \quad K_i = 0.02$$

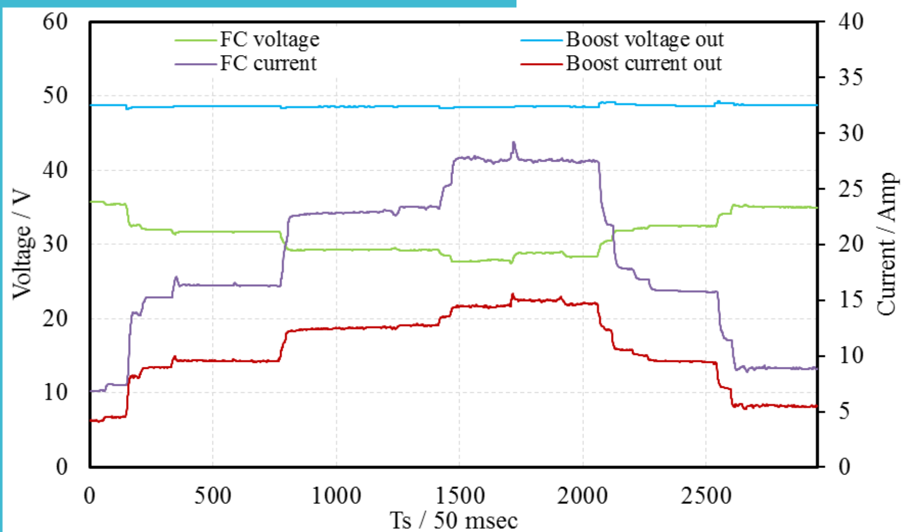
$$K_{calib.} = 34$$

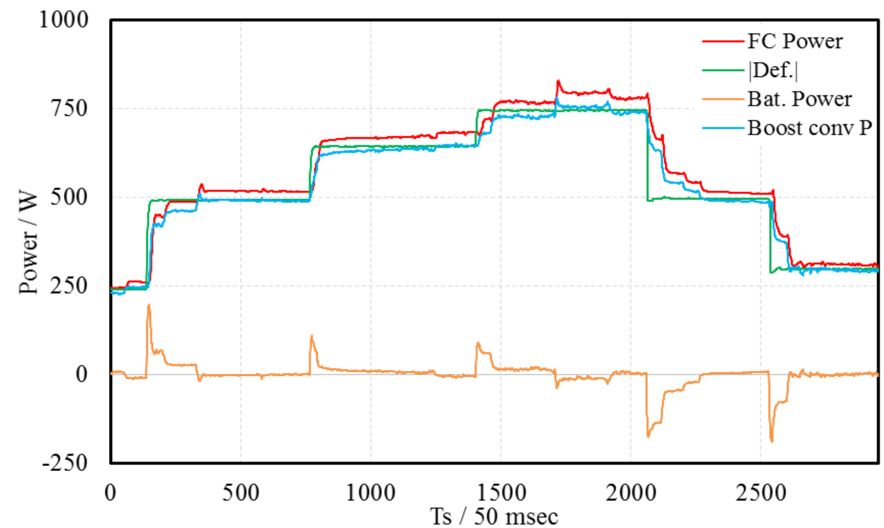
$$I_{CL} = (I_{Dem} - I_{Gen}) + \left[K_p I_{Bat} + K_i \int I_{Bat}\right] + K_{calib.}$$

Control signal formula



- **Responsive**
- **Reduced ripples**
- **NO HLC**





2- CL mode with HLC

Control Algorithm (MPC) with CL control mode

- Similar to current-loop mode
- CL of boost conv. is MV (instead of conv. input current)
- Control Algorithm required
- HLC required
- Compensator for control signal of CL

$$\min_{\substack{sub.\\ to\ const.}} \ \mathrm{J} = \sum_{\mathrm{i=1}}^{\mathrm{n_y}} \left[P_{FC,st}^{k+i} - \left(V_{FC*}^{k+i-1} + \mathrm{err}_{V,FC}^{k+i-1}\right)\left(I_{CL}^{k+1} - \mathrm{CL}_{cor}^{k}\right)\right]^2$$

$$\mathrm{CL}_{cor}^{k} = \left(K_p I_{Bat}^{k} + K_i \int_0^k I_{Bat}\right) + K_{calib.}$$

CL compensator formula

Constraints
$$\begin{cases} K_{calib.} \leq I_{CL} \leq I_{FC,max} + K_{calib.} \\ \Delta I_{CL,min} \leq \Delta I_{CL} \leq \Delta I_{CL,max} \end{cases}$$

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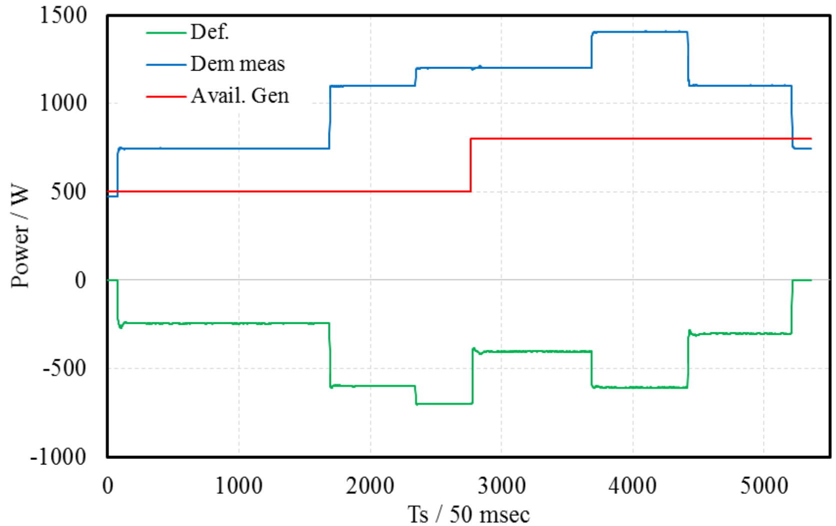
CL mode with HLC

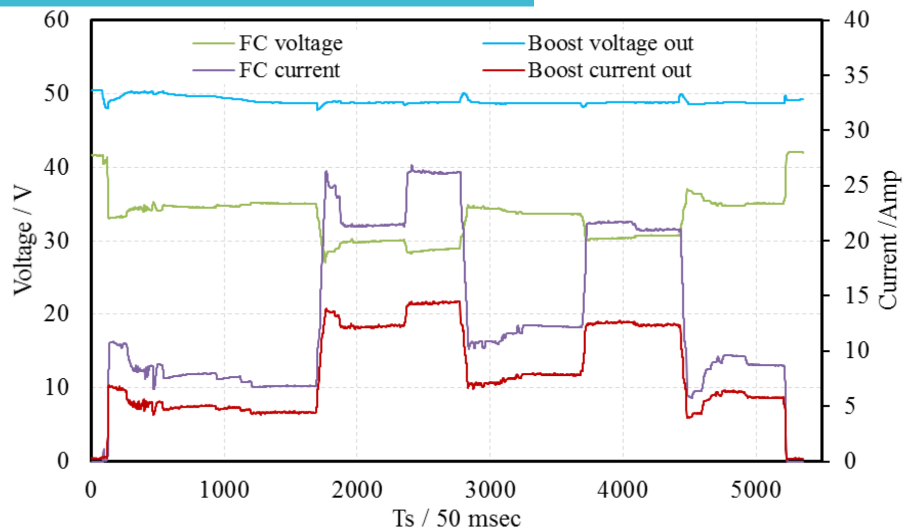
1.2kW FC stack + DC boost converter "model CCH63250-SSU 31.25kHz

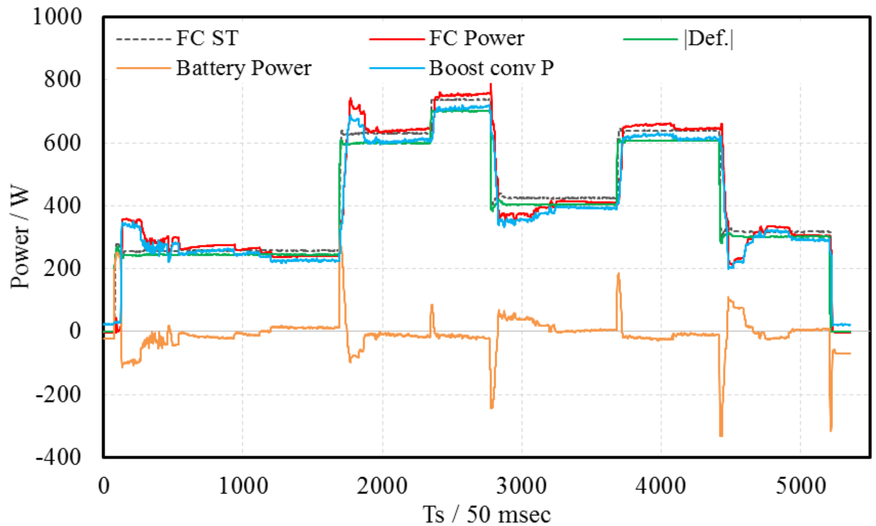
$K_p = 0.5$, $K_i = 0.01$

$K_{calib.} = 34$, $\Delta I_{CL,max} = 0.5\text{Amp}$



- **Responsive**
- **Reduced ripples**
- **Controlled Battery/Grid Power**
- **FC ST from HLC**
- **NO voltage saturation**





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Proc & Cons of Boost converter Control-modes

	Voltage-loop mode	Current-loop mode	Current-limit mode
Applicability	stand-alone and isolated systems	Stand-alone and grid-connected	Stand-alone and grid-connected
Control algorithm	Not required	Required	Both
FC power control	Uncontrolled (Responsive)	Controlled (Tuneable)	Both
Supervision	HLC not required	HLC required	Both
Current ripples	Ripples possible (Power filter required)	Ripples reduced	Ripples reduced

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THANK YOU

QUESTIONS ???

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