茨城大学
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Switched Capacitor Converter-Based PWM Plus Phase-Shift Control Multiport Converter with Differential Power Processing Capability for Photovoltaic Systems

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Highlights

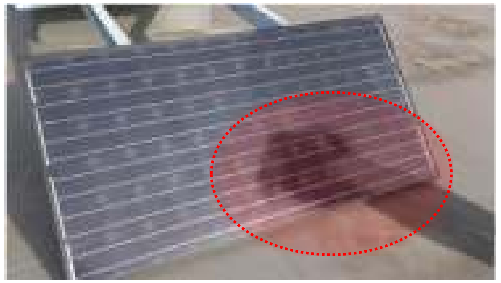
- Integration of three dc-dc converts into a single unit
- 93.7% full-load efficiency at 150 W
- Demonstrated the efficacy of DPP capability

Outline

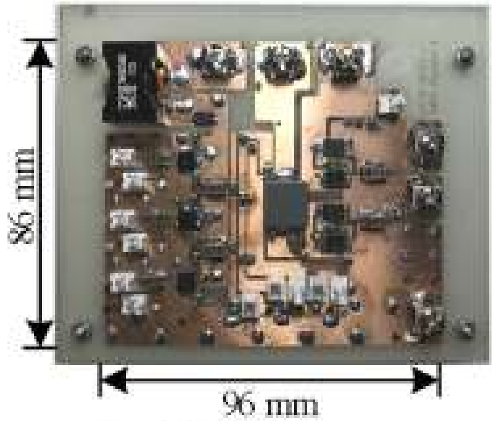
◆ Background
- ➢ Problems of standalone PV systems
- ➢ Differential Power Processing (DPP) capability
- ➢ Multi-port converter

◆ Proposed Multi-Port Converter
- ➢ Derivation and features
- ➢ Control scheme

◆ Experimental Verification
- ➢ DPP Capability under Partial Shading Condition
- ➢ Output characteristics

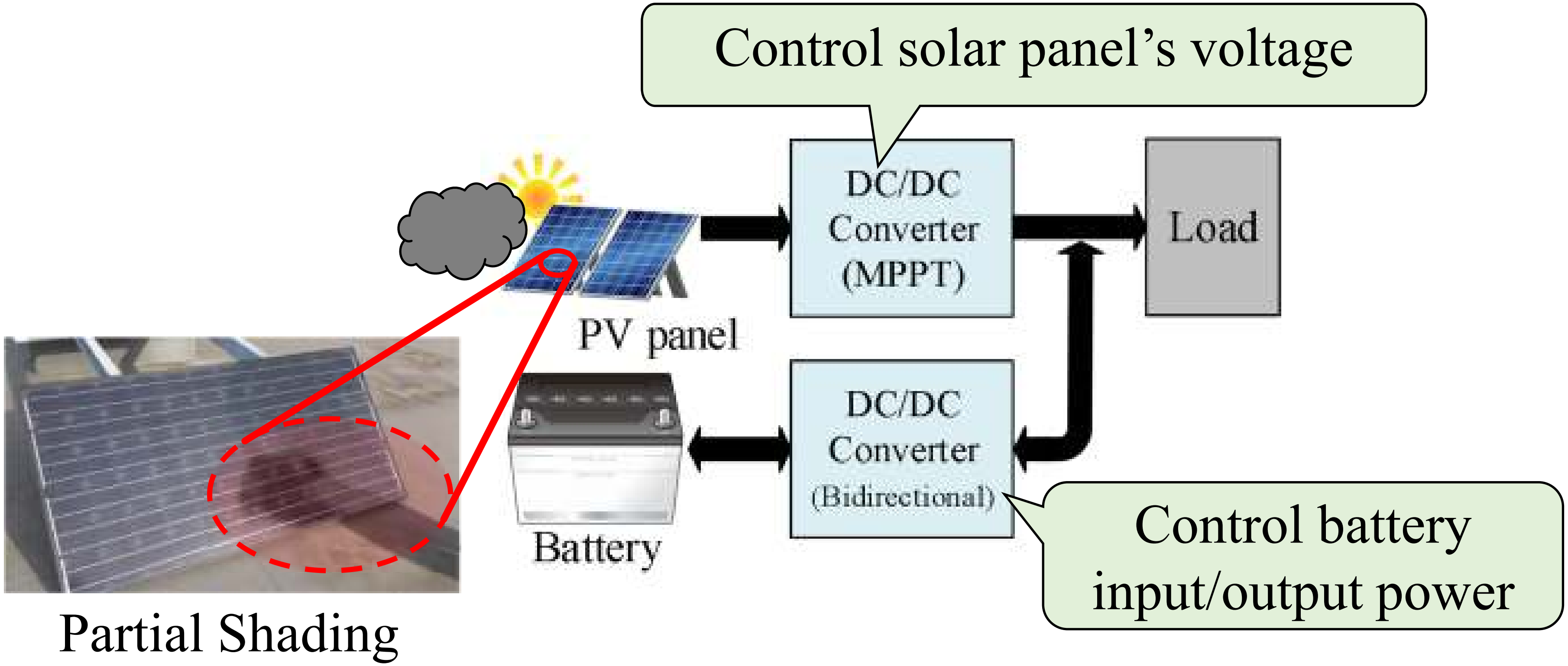


Partial shading issue



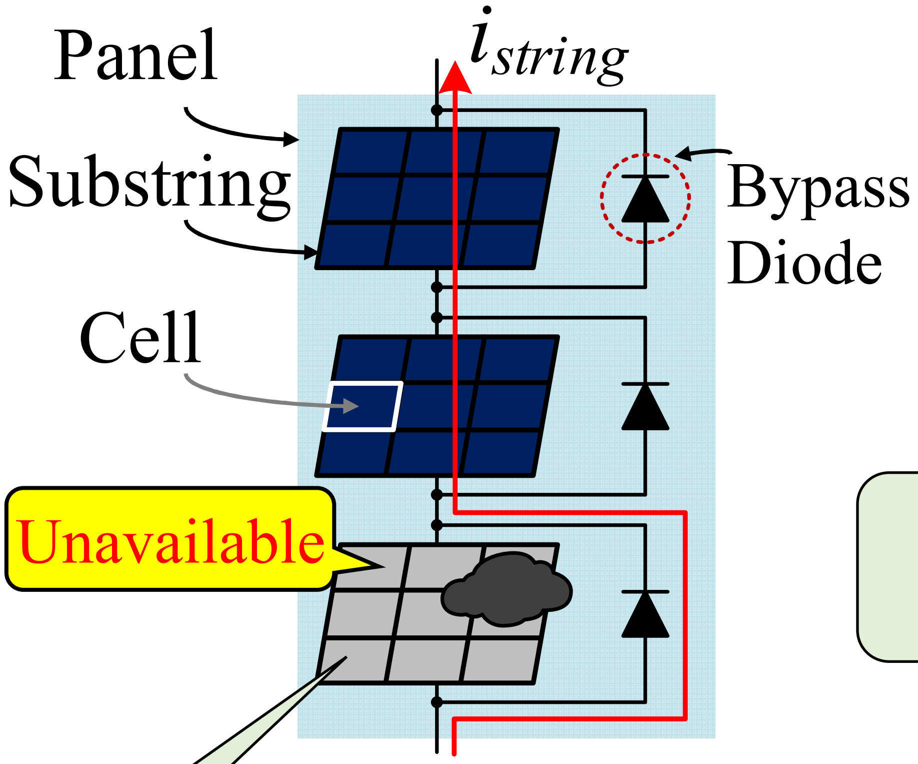
150-W Prototype

Standalone Photovoltaic System



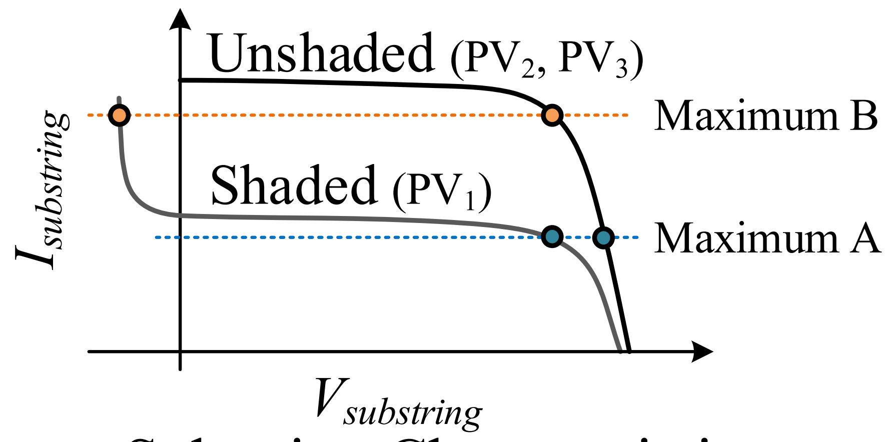
☹ Partial shading causes a significant reduction in power yield

Partial Shading Issues



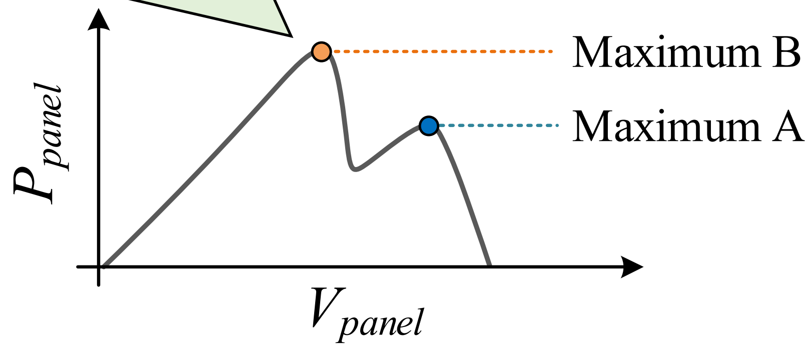
Substring with Partial Shading

Significant reduction in power yield



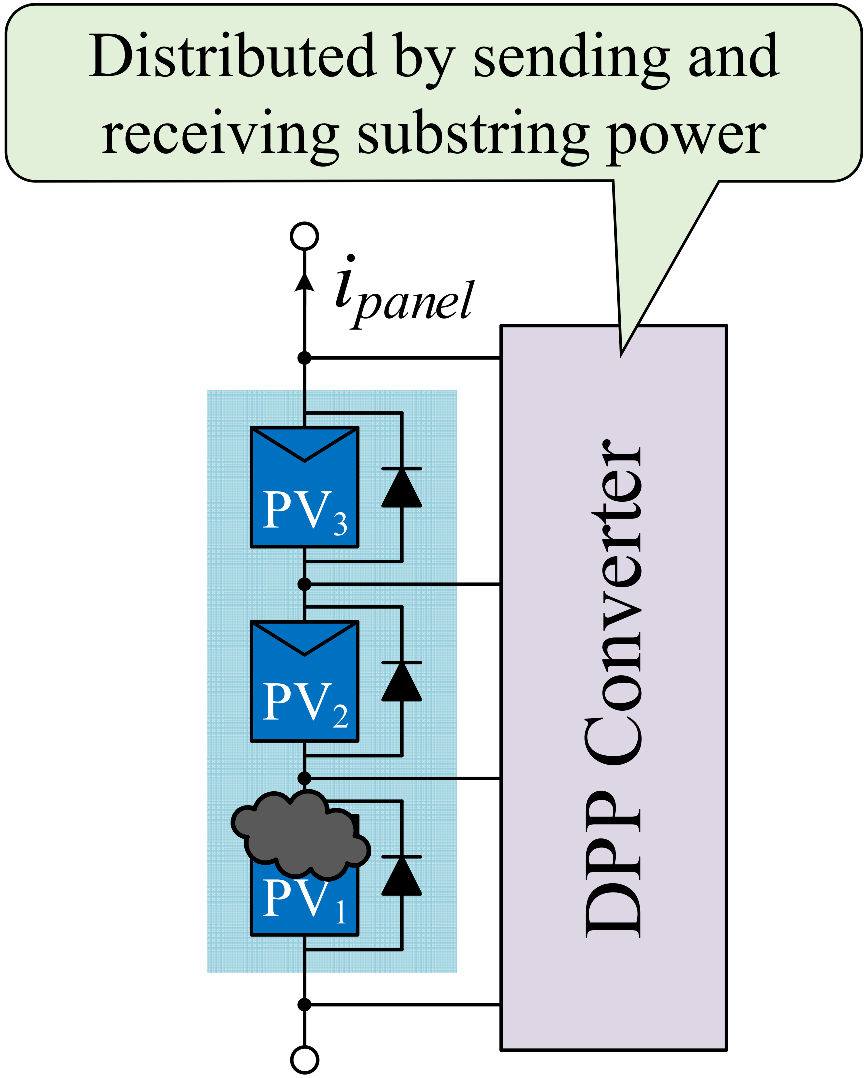
Substring Characteristics

Occurrence of multiple maximum power points (MPPs)

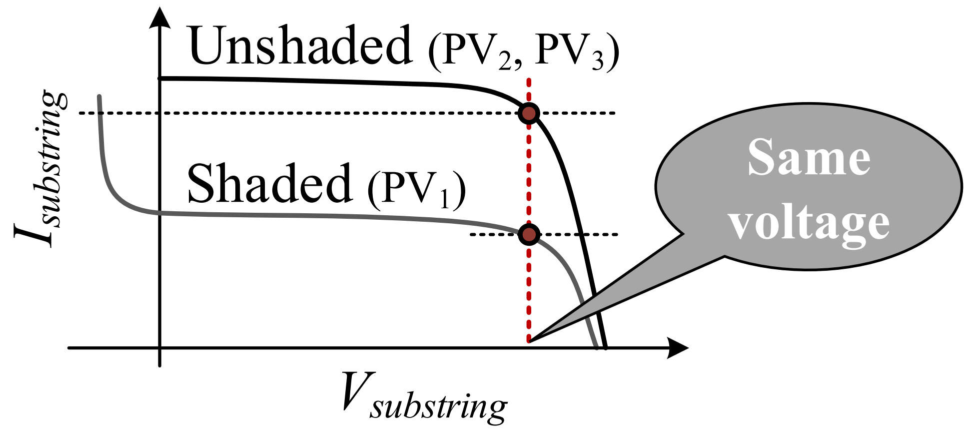


Panel Characteristics

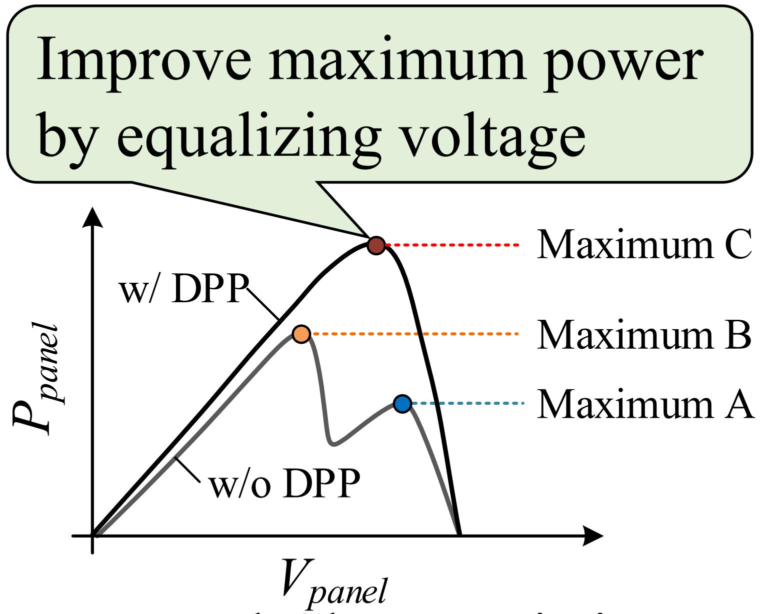
Differential Power Processing (DPP) Converter



Substring with DPP

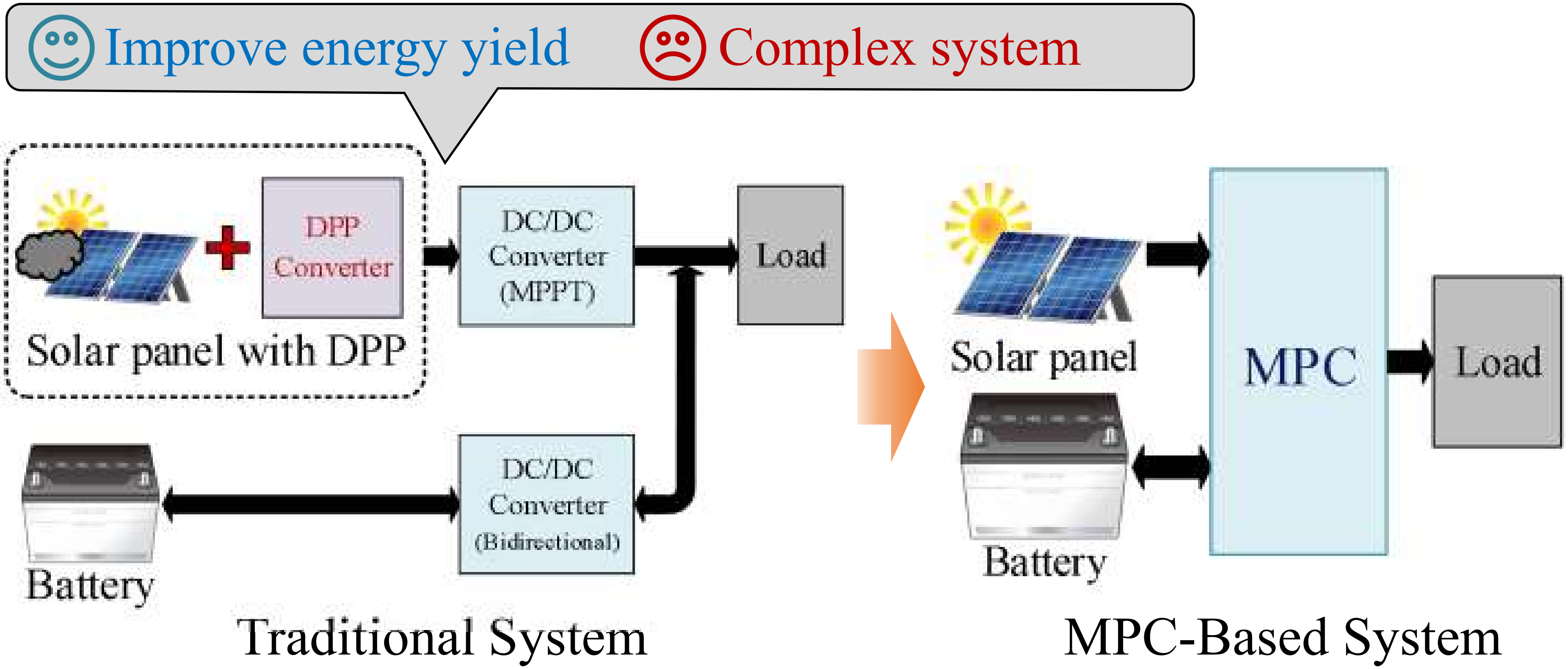


Substring Characteristics



Panel Characteristics

Multi-Port Converter (MPC)

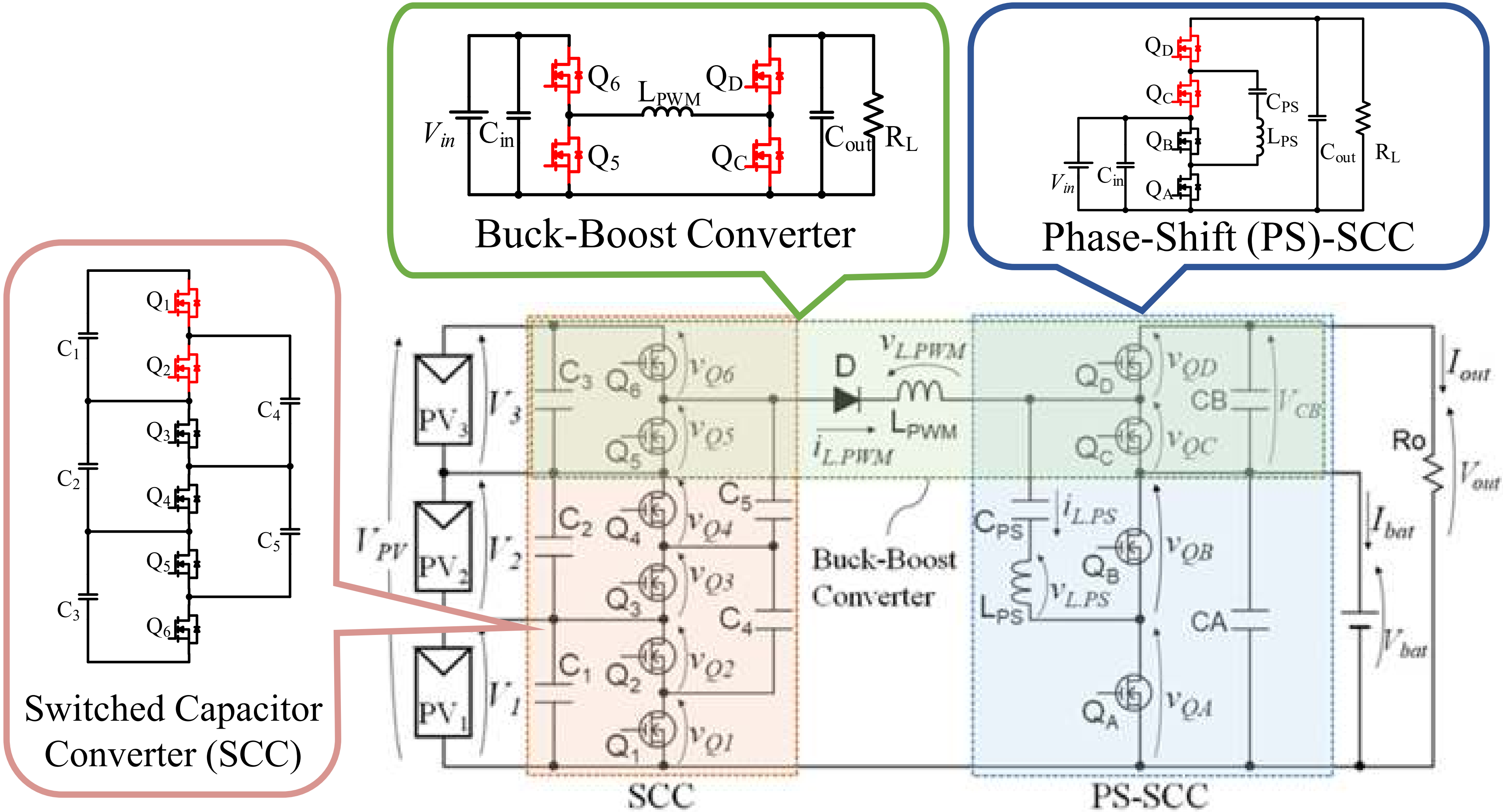


Integration of multiple converters into a single unit

Simplified system at lower cost

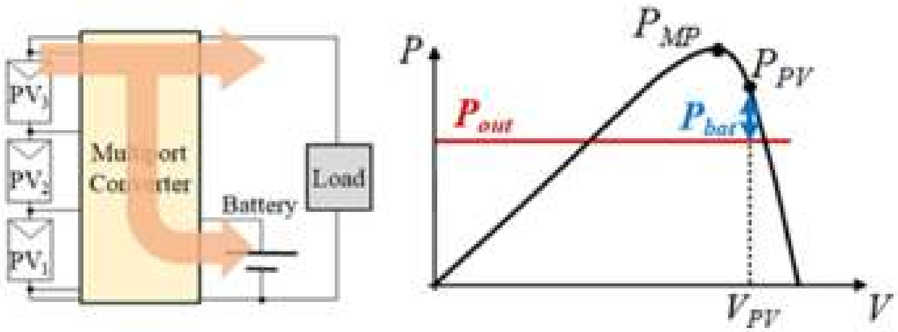
Proposed MPC

Derivation of Proposed MPC



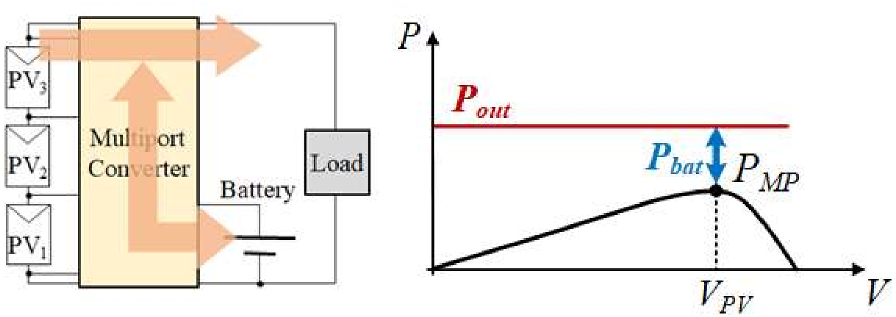
Shared switches

Power Balance Among Three Ports



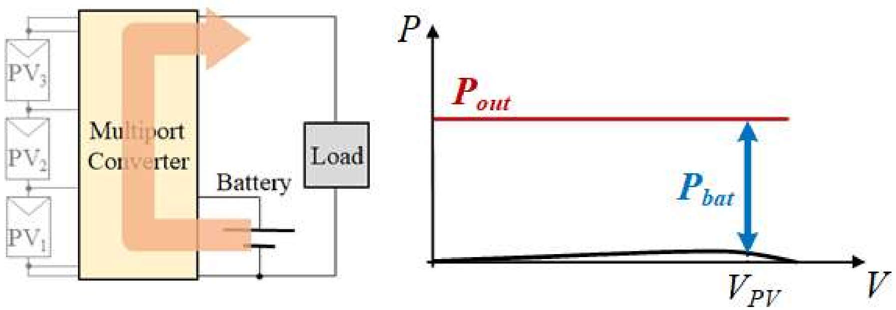
CC−CV battery charging mode

◆ PV panel provides the entire load power $\boldsymbol{P_{out}}$



MPPT mode

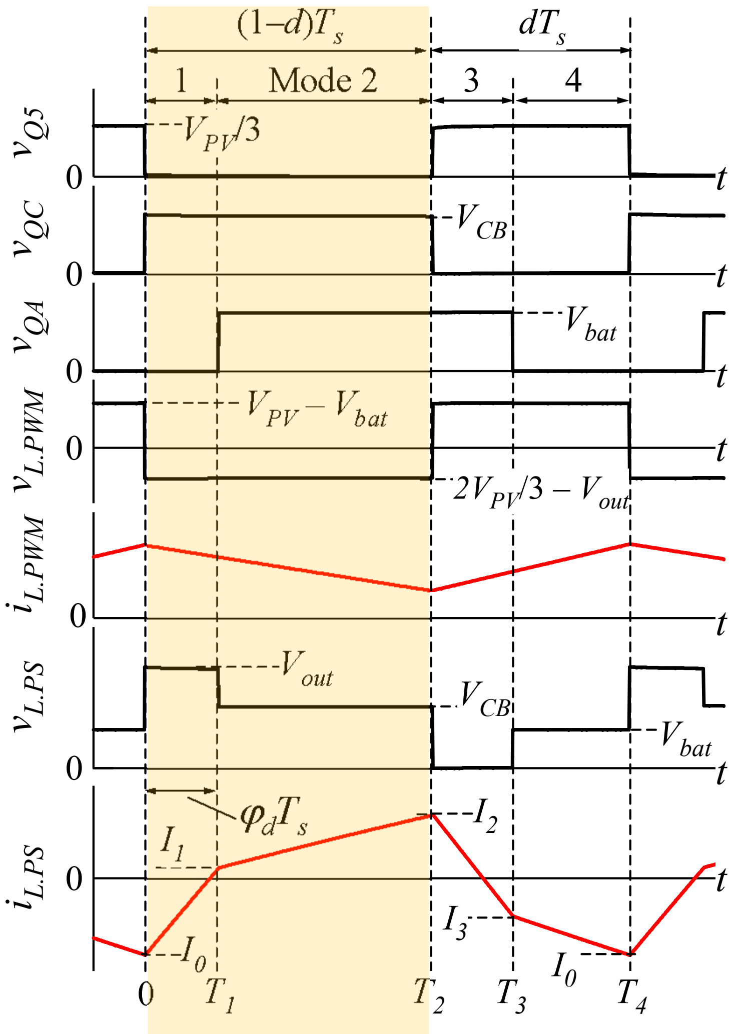
◆ Battery is charged or discharged depending on power balance between $\boldsymbol{P_{PV}}$ and $\boldsymbol{P_{out}}$

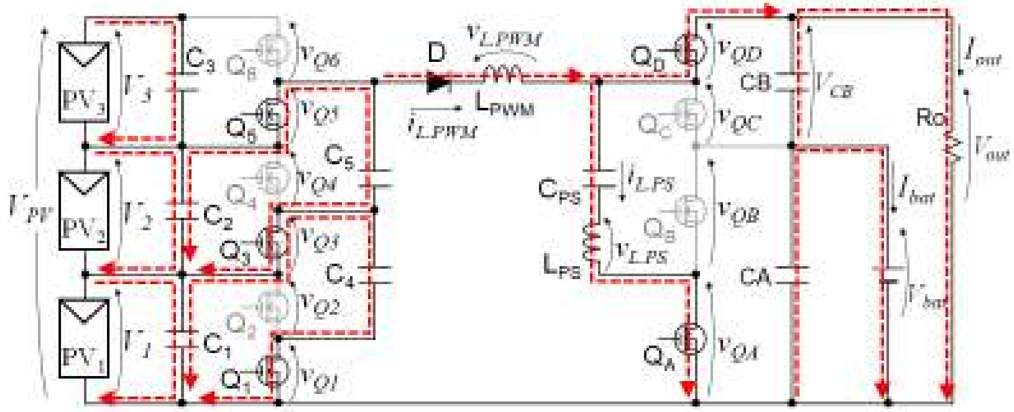


Battery discharging mode

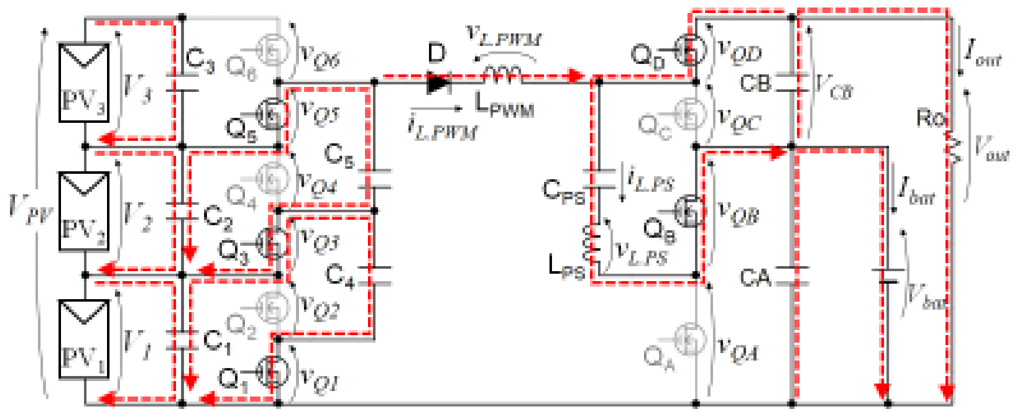
◆ PV panel generates no power, and battery supplies $\boldsymbol{P_{out}}$

Operation: CC–CV Battery Charging Mode (1)



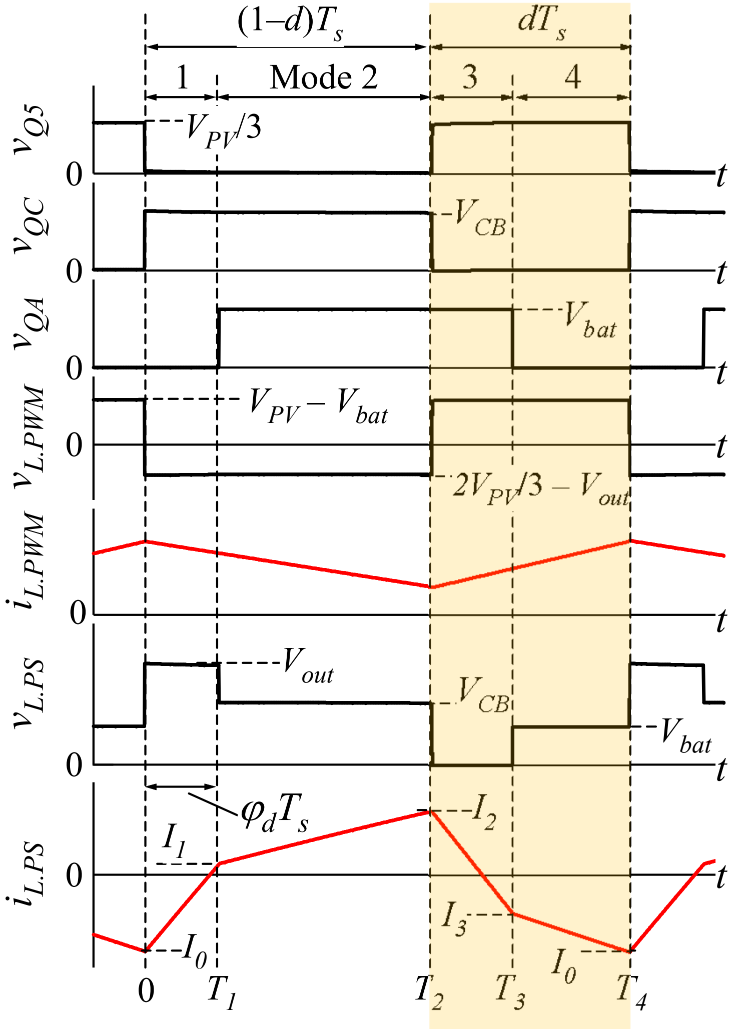


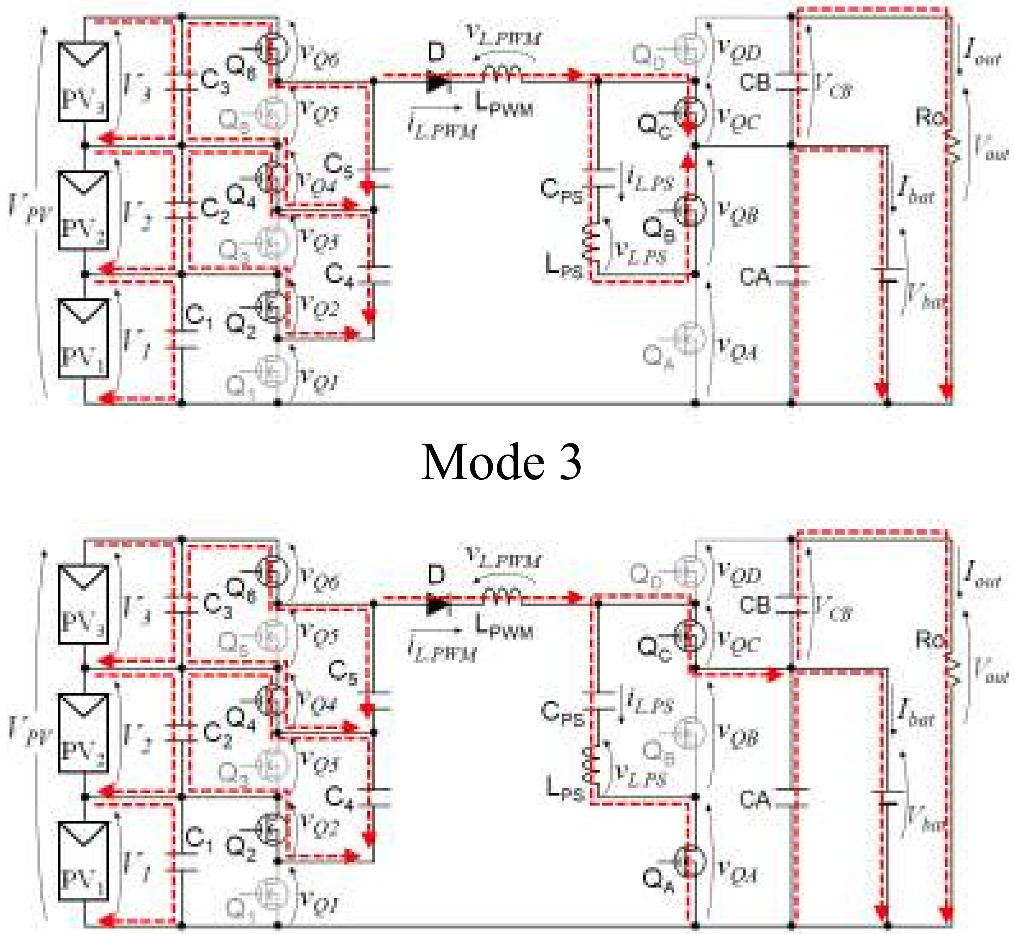
Mode 1



Mode 2

Operation: CC–CV Battery Charging Mode (2)

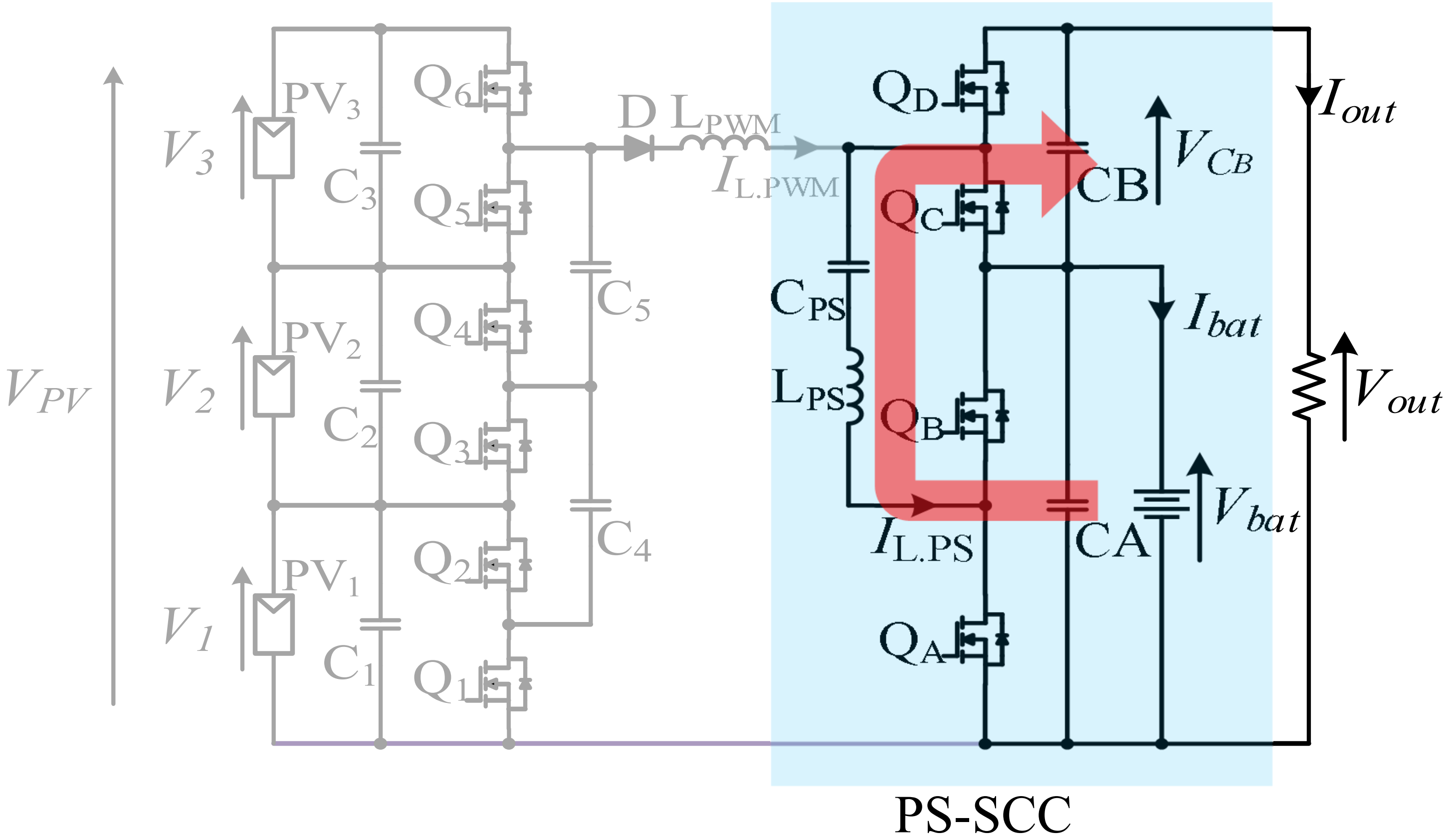




Mode 3

Mode 4

Operation: Battery Discharging Mode



- PV panel generates no power
- Battery supplies P_{out}

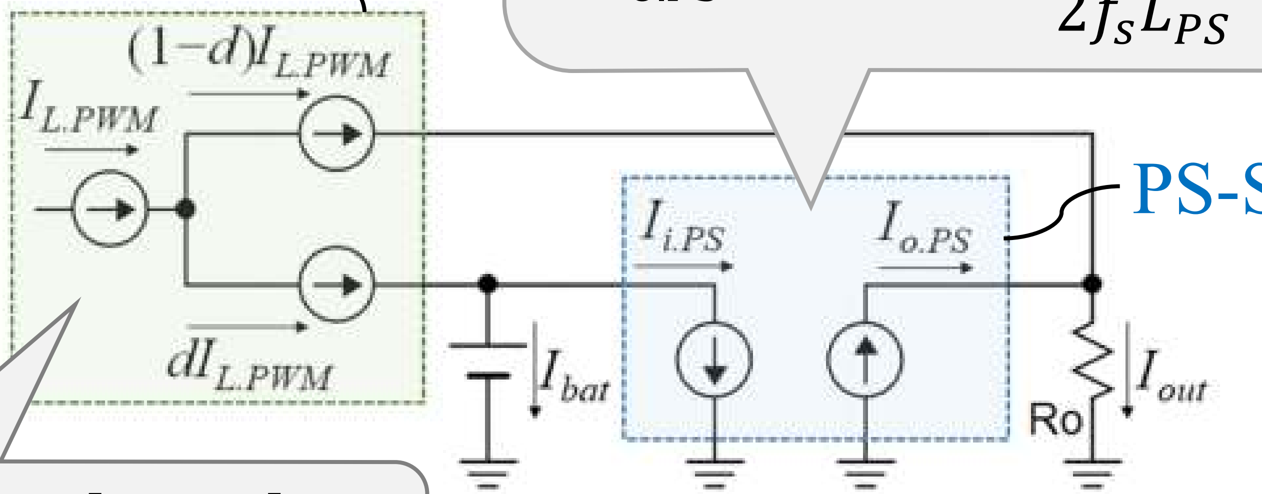
$$P_{bat} = \frac{V_{bat} V_{out}}{2 f_{sw} L_{PS}} \varphi(-2d^2 + 2d + \varphi)$$

Equivalent Circuit of Buck-Boost Converter and PS-SCC

$$I_{i.PS} = \frac{d_\varphi V_{out}\{d_\varphi - 2d(1-d)\}}{2 f_s L_{PS}}$$

$$I_{o.PS} = \frac{d_\varphi V_{bat}\{d_\varphi - 2d(1-d)\}}{2 f_s L_{PS}}$$

Buck-Boost Converter

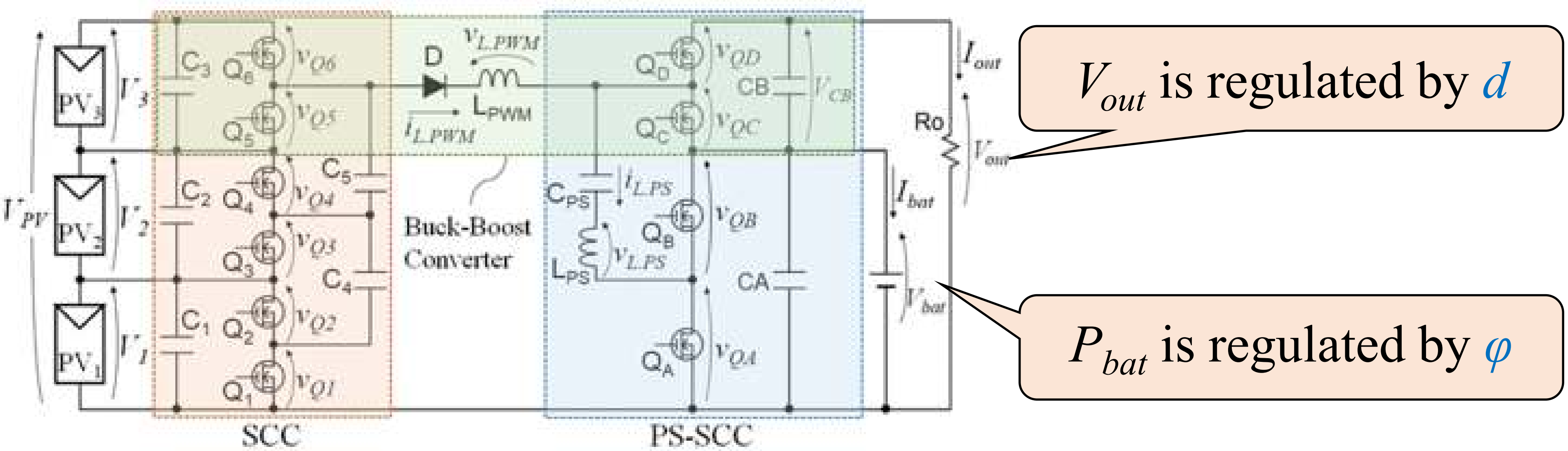


PS-SCC

$$I_{L.PWM} = \frac{I_{out} - I_{o.PS}}{1-d}$$

$$P_{bat} = (d I_{L.PWM} - I_{i.PS}) V_{bat}$$

Control Scheme : Output Ports



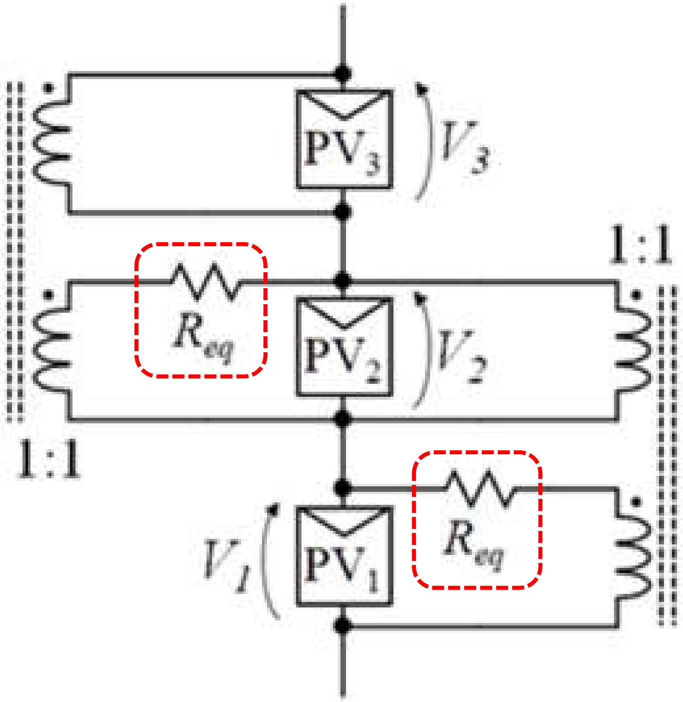
Load Voltage

$$V_{out} = \frac{2+d}{3(1-d)} V_{PV} - \frac{d}{1-d} V_{bat}$$

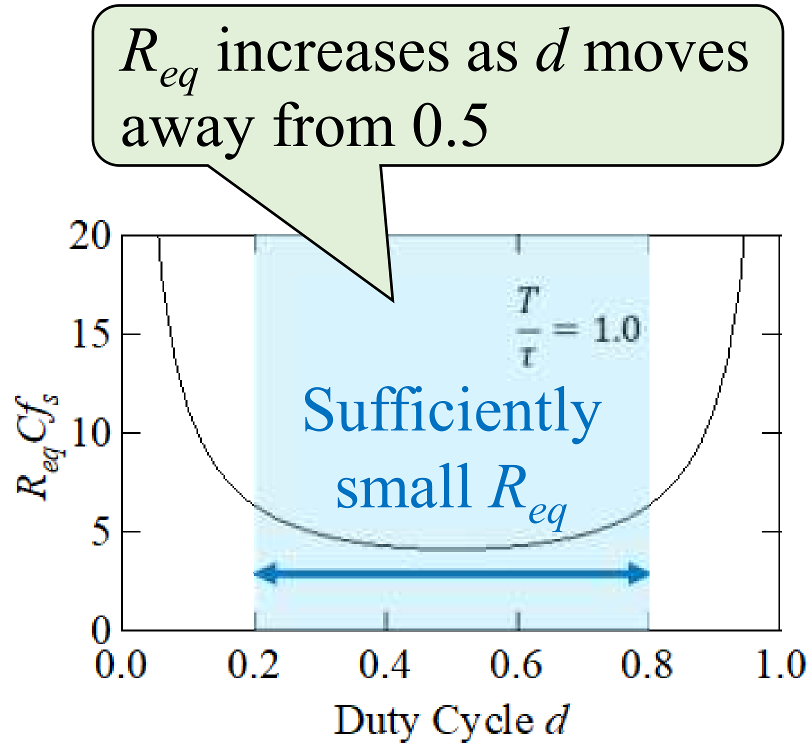
Battery Power

$$P_{bat} = (dI_{L.PWM} - I_{i.PS}) V_{bat}$$

Feature of Switched Capacitor Converter (SCC)



Equivalent Circuit of SCC

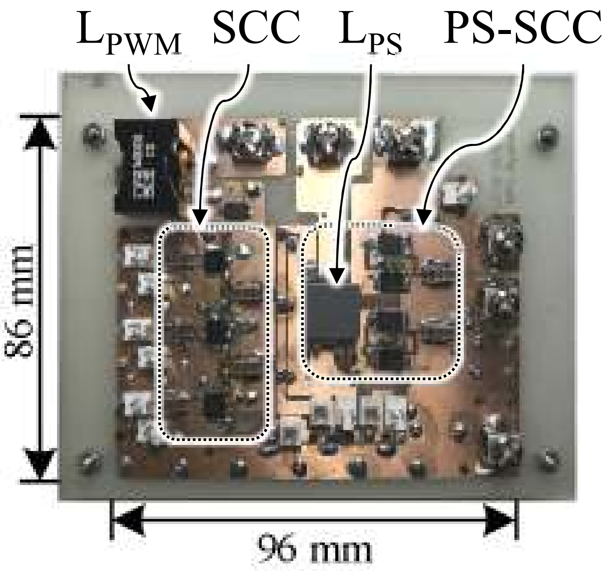


Normalized R_{eq} as a Function of d.

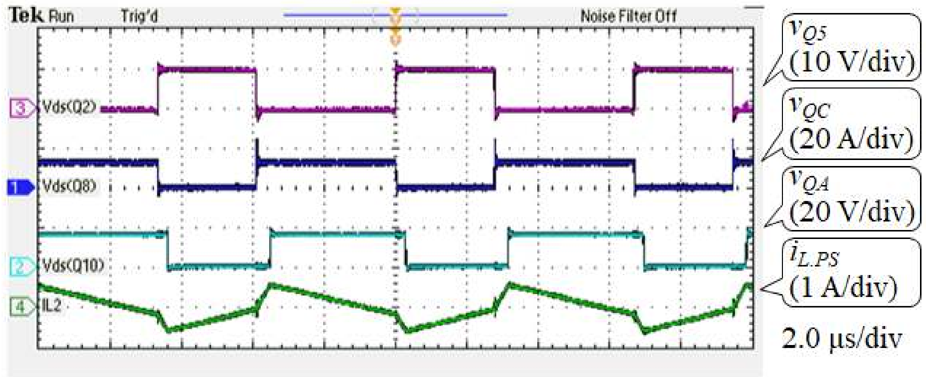
$$\boldsymbol{R_{eq}} = \frac{1}{Cf_s} \frac{exp\left(\frac{T}{\tau}\right) - 1}{\left\{exp\left(\frac{dT}{\tau}\right) - 1\right\}\left\{exp\left(\frac{(1-d)T}{\tau}\right) - 1\right\}}$$

Experimental Results

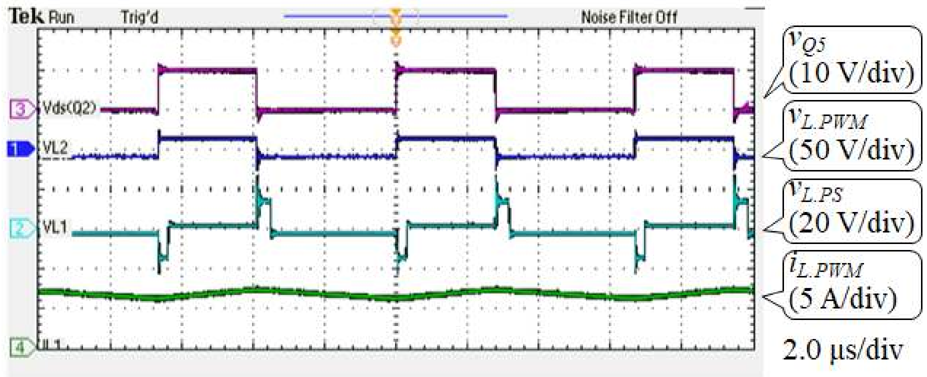
Experimental Verification



150-W Prototype



Waveforms : v_{Q5}, v_{QC}, v_{QA}, $i_{L.PS}$



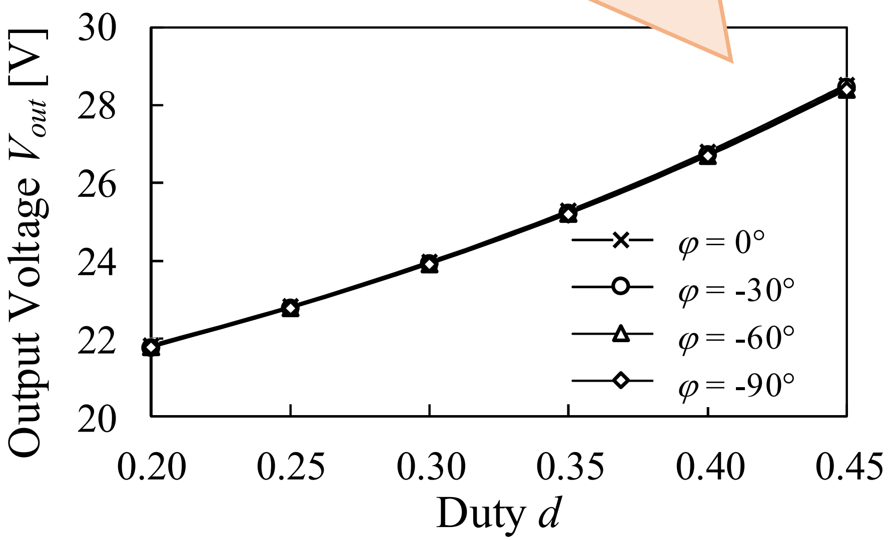
Waveforms : v_{Q5}, $v_{L.PWM}$, $v_{L.PS}$, $i_{L.PWM}$

- Switching frequency : f_{sw} = 150 kHz
- Input voltage : V_{PV} = 30 V
- Load voltage : V_{out} = 28 V
- Battery voltage : V_{bat} = 16 V

93.7% full-load efficiency at 150 W (load 100 W, battery 50 W)

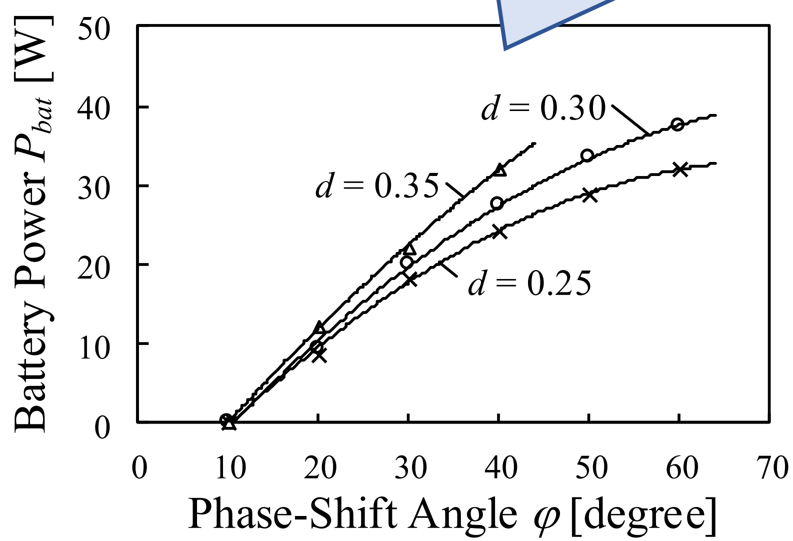
Output Ports Characteristics

V_{out} was regulated by ***d***, and not influenced by φ



Load Port

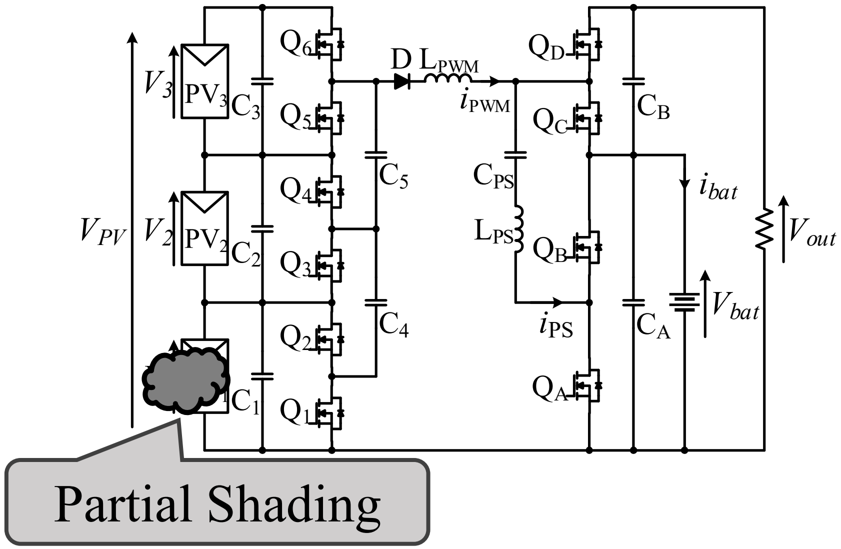
P_{out} varied with φ, but was slightly dependent on d

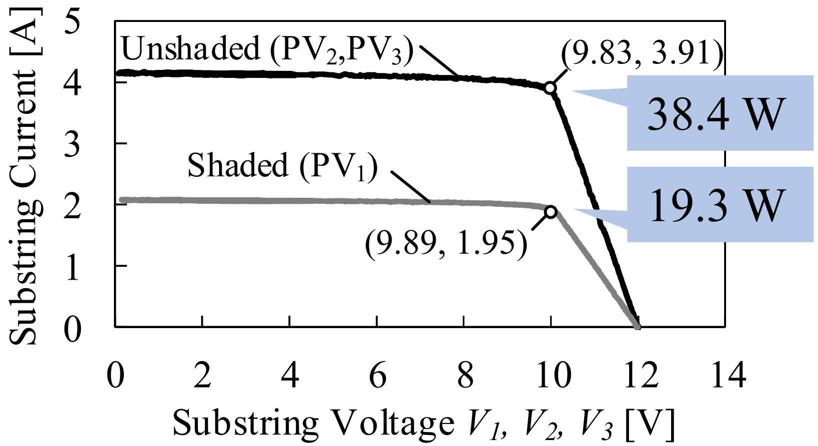


Battery Port

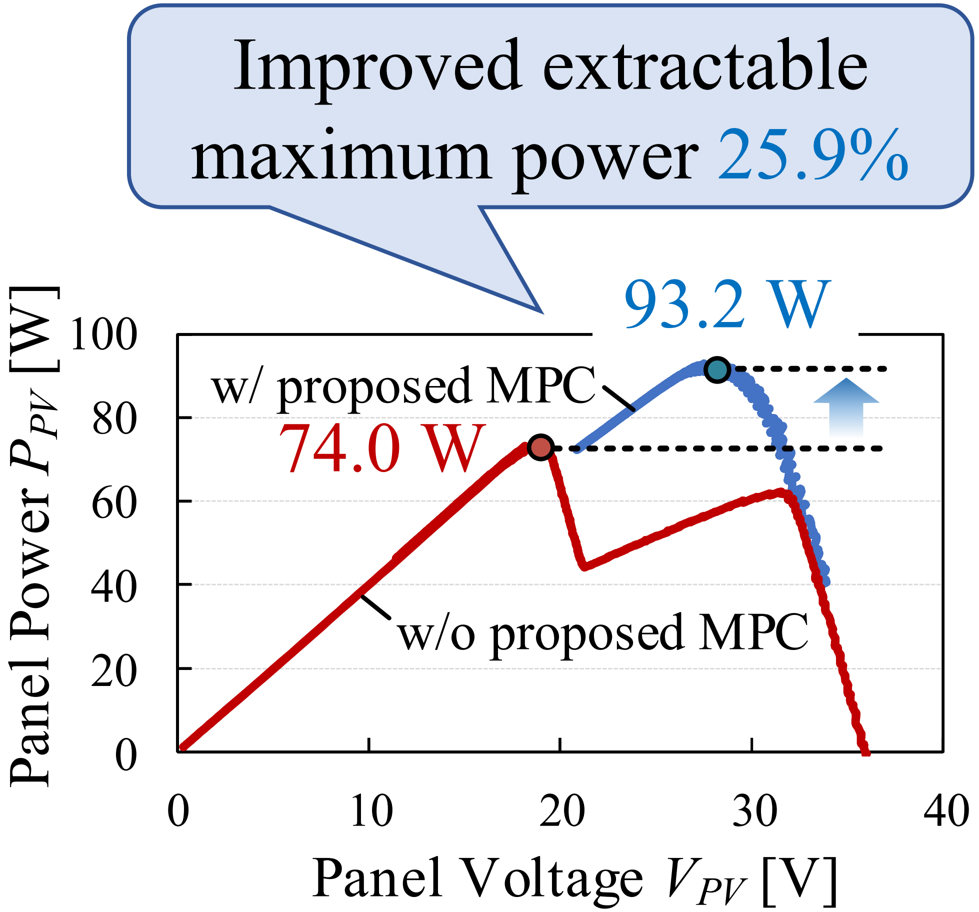
Output ports could be regulated by d and φ

DPP Capability under Partial Shading Condition

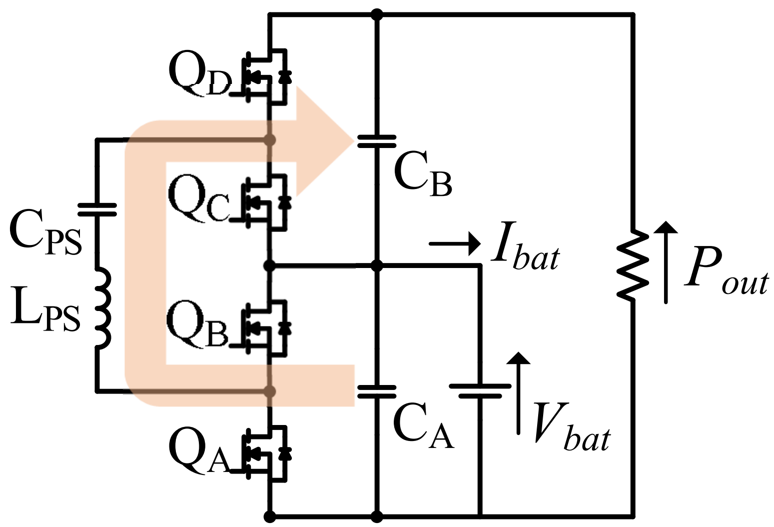




Substring Characteristics

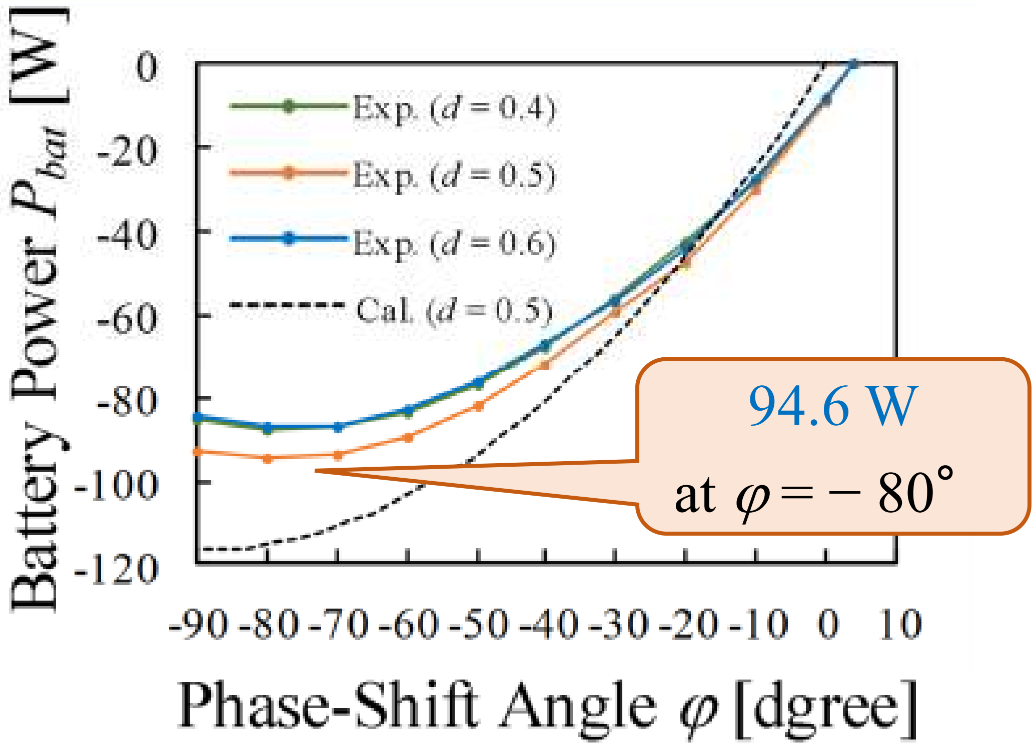


Battery Discharging Mode Characteristics



Power Flow

- $V_{bat} = 16$ V
- $V_{out} = 28$ V
- $f_{sw} = 100$ kHz



$$P_{bat} = \frac{V_{bat}V_{out}}{2f_{sw}L_{PS}}\varphi(-2d^2 + 2d + \varphi)$$

P_{out} **varied with φ, but was slightly dependent on d**

Conclusions

- **Proposed Multi-Port Converter**
  - Integration of three DC/DC converts into a single unit
  - Analysis of load port characteristics

- **Experimental Verification**
  - Both battery and load ports could be regulated by PWM plus Phase-Shift control
  - Demonstrated the validity of the DPP capability by the improvement of extractable maximum power