Power Management Techniques for Energy Harvesting Embedded Systems

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My Talks in Previous MPSoC

- Efficiency
  - Generating efficiency
    - Harvesting device efficiency
  - Consuming efficiency
    - Consumer device efficiency
  - Transferring efficiency
    - DC-DC converter efficiency
    - Charger efficiency
      - Harvested energy is not constant
      - Power is not available on-demand
      - High peak power is not available

My talk at MPSoC 2009
"Multi-Performance Processor"

My talk at MPSoC 2011
"Scratchpad management"

My talk at MPSoC 2012
"Loop-cache management"

This talk

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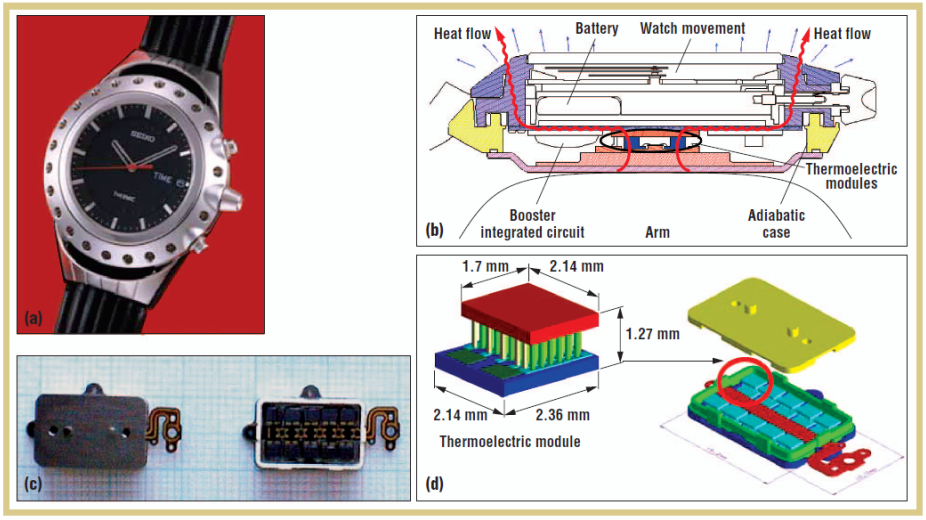
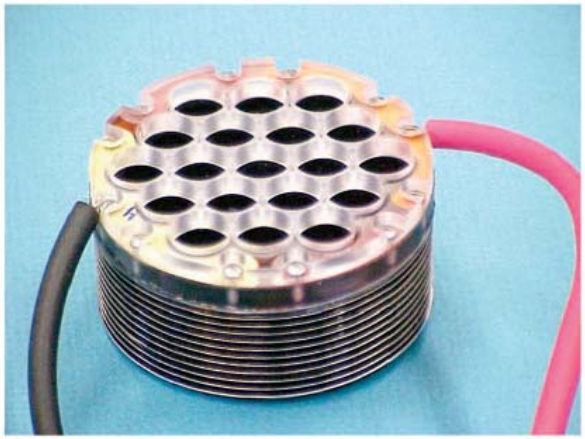
Energy Harvesting Devices

10 thermoelectric modules
generates microwatts



10m/s wind speed generates 100W
electrical power with 1m rotor diameter



800mW per shoe
at a pace of two
steps per second

1m/s water speed
generates 1W with
0.1m rotor diameter

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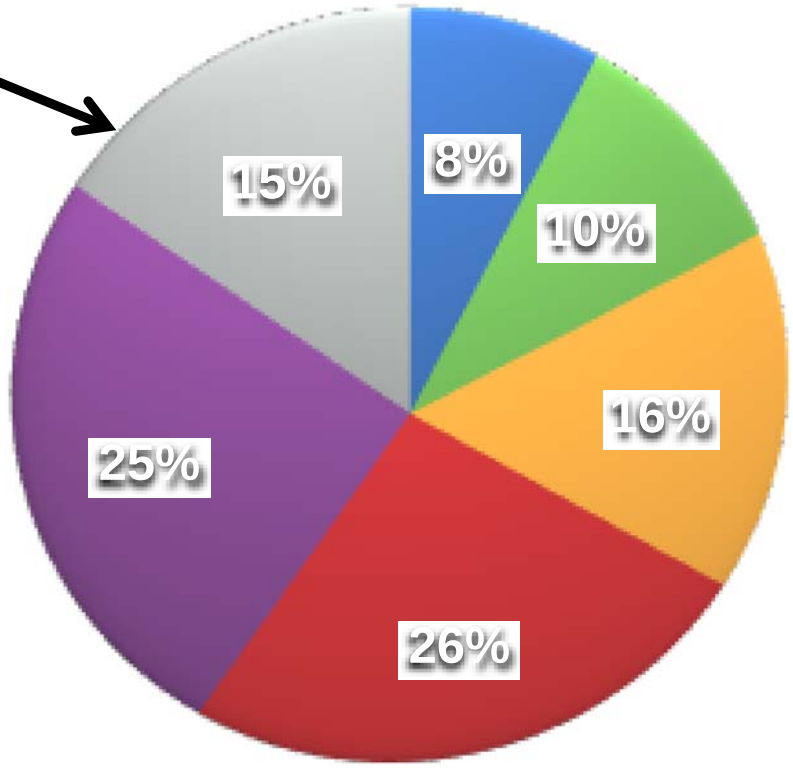
Power Transferring Loss in Portable System

Power breakdown in portable audio player

Up to 15% of power is dissipated in DC-DC converters



H. Shim, Y. Cho and N. Chang, "Power Saving in Hand-held Multimedia Systems Using MPEG-21 Digital Item Adaptation," in ESTIMedia, 2004

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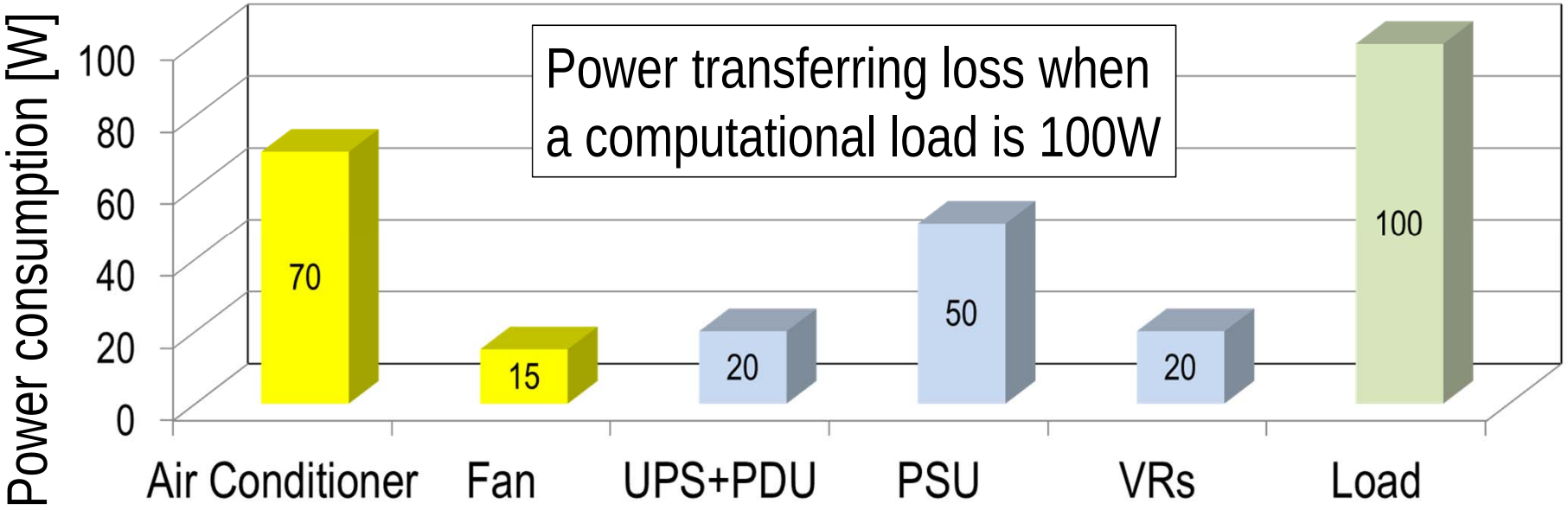
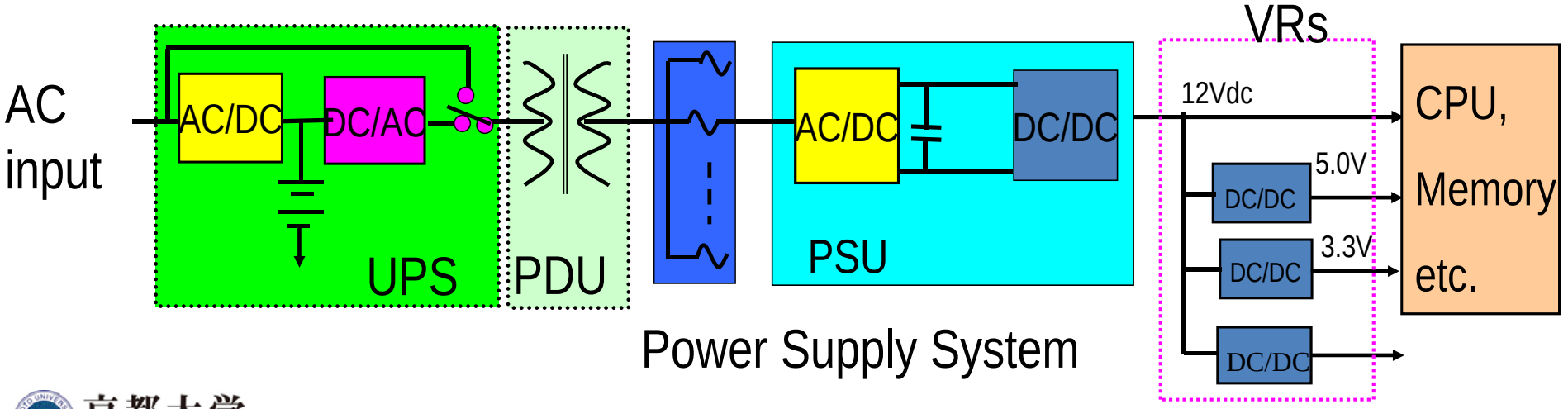
Power Transferring Loss in Data Center





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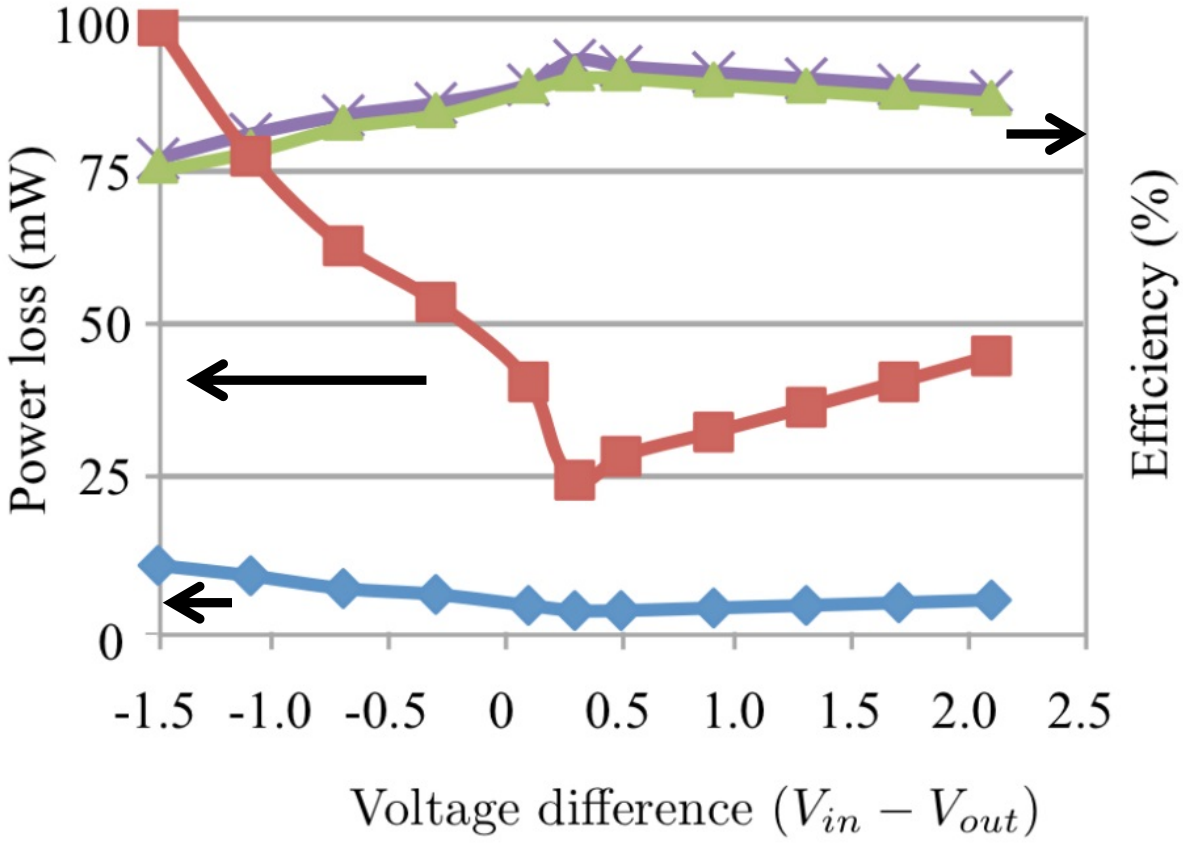
Source: DC Power for Improved Data Center Efficiency, LBNL

Power Loss in Voltage Conversion

- Power loss depends on
  - ✓ Boost-up or drop-down
  - ✓ Voltage difference
  - ✓ Output power

input → DC-DC → output

$$Power\ Loss \propto (100 - Efficiency) \cdot P_{input}$$



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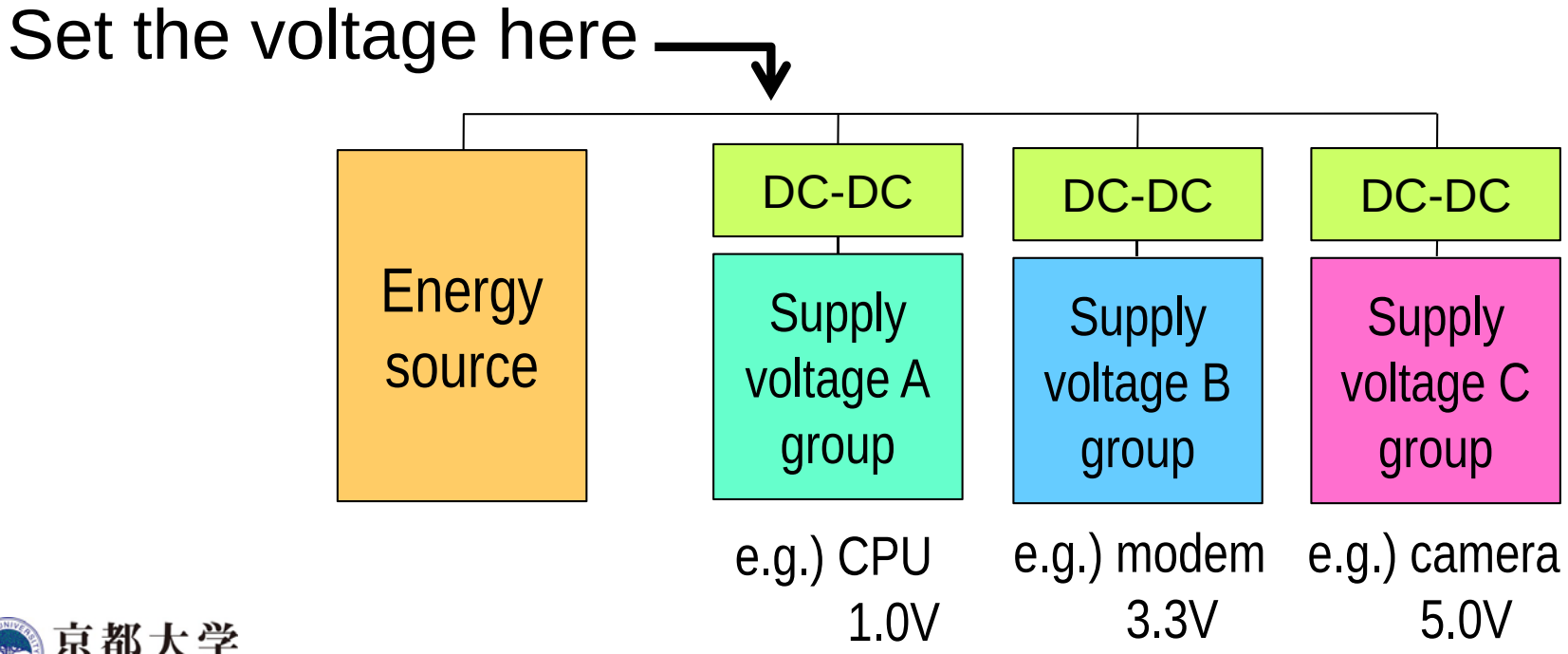
TPS63030 datasheet. http://www.ti.com/lit/ds/symlink/tps63030.pdf.

Motivations

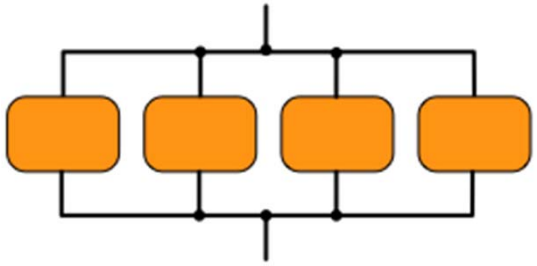
- Many DC-DC converters are used in a system
  - Different components use different voltages
- Large power loss in the DC-DC converters
  - Voltage difference between source and load is large



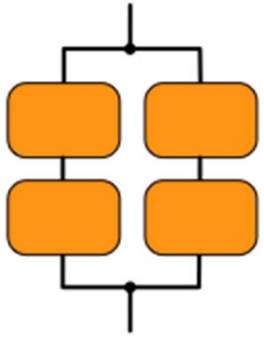
Reconfigurable Array

- An example for a configurable array
  - 3 configurations with 4 photovoltaic (PV) cells or super-capacitor cells
  - Each cell has 0.5V, 80mA output

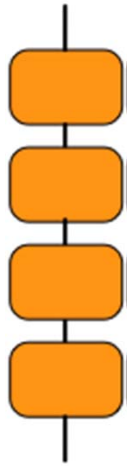
Reduce the difference between the input and output voltages in a DC-DC converter



(4,1): 0.5V, 320mA output



(2,2): 1V, 160mA output



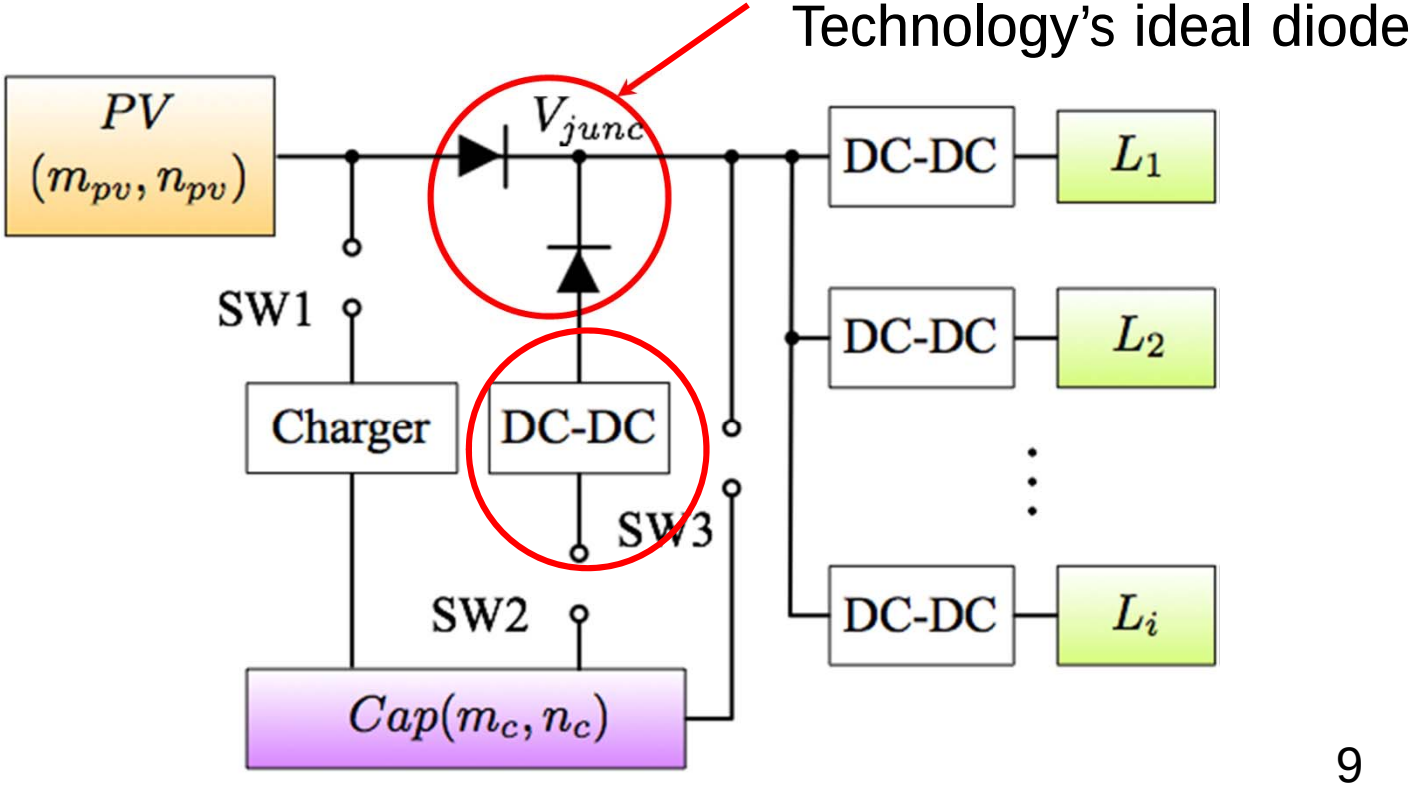
(1,4): 2V, 80mA output

M. Uno, “Series-parallel reconfiguration technique for supercapacitor energy storage systems,” in Proc. of TENCON, 2009.

Y. Kim, et al. “Balanced Reconfiguration of Storage Banks in a Hybrid Electrical Energy Storage System,” in Proc. of ICCAD, pp.624-631, November 2011.

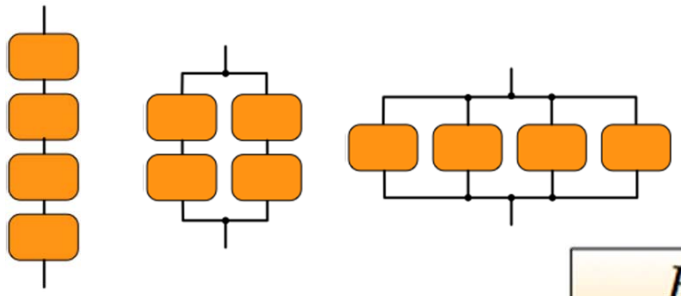
Proposed System Architecture

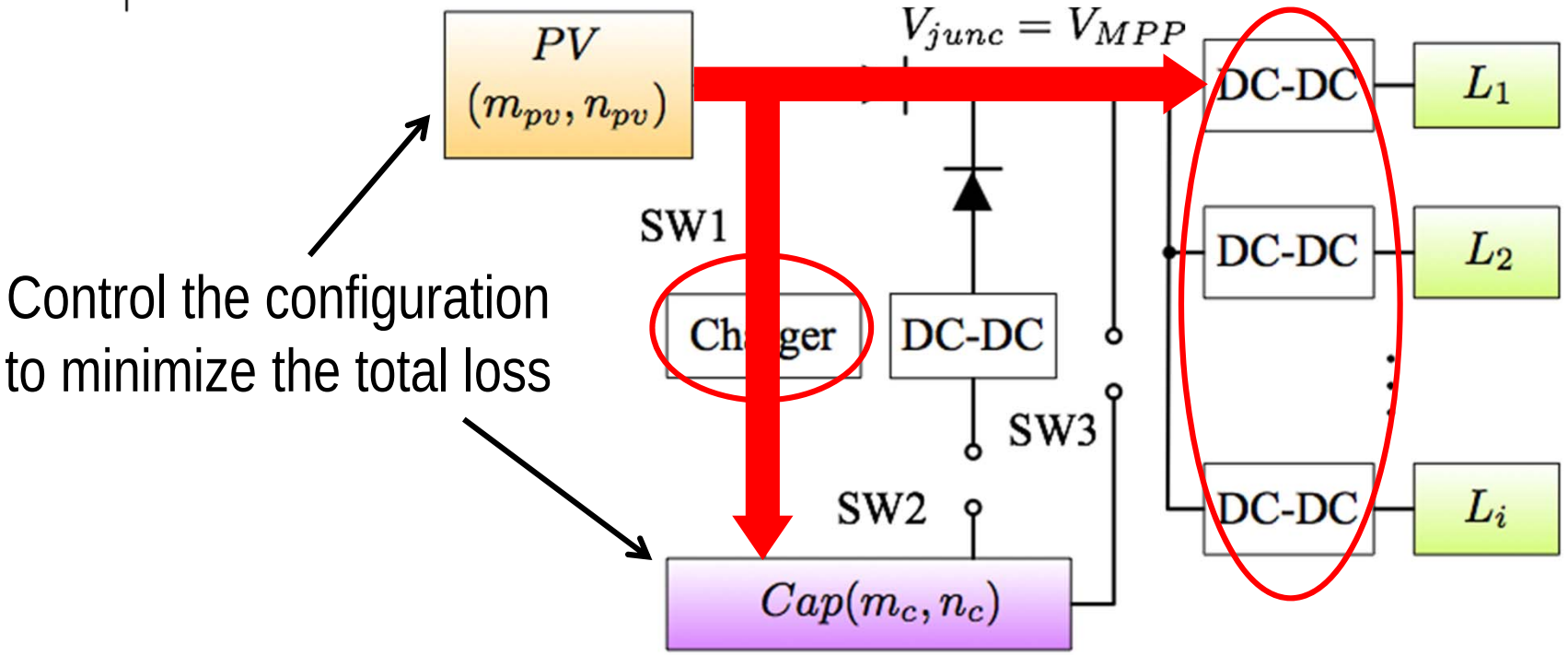
- System block diagram
  - Good harvest mode
  - Hybrid mode
  - Bad harvest mode



Good Harvest Mode

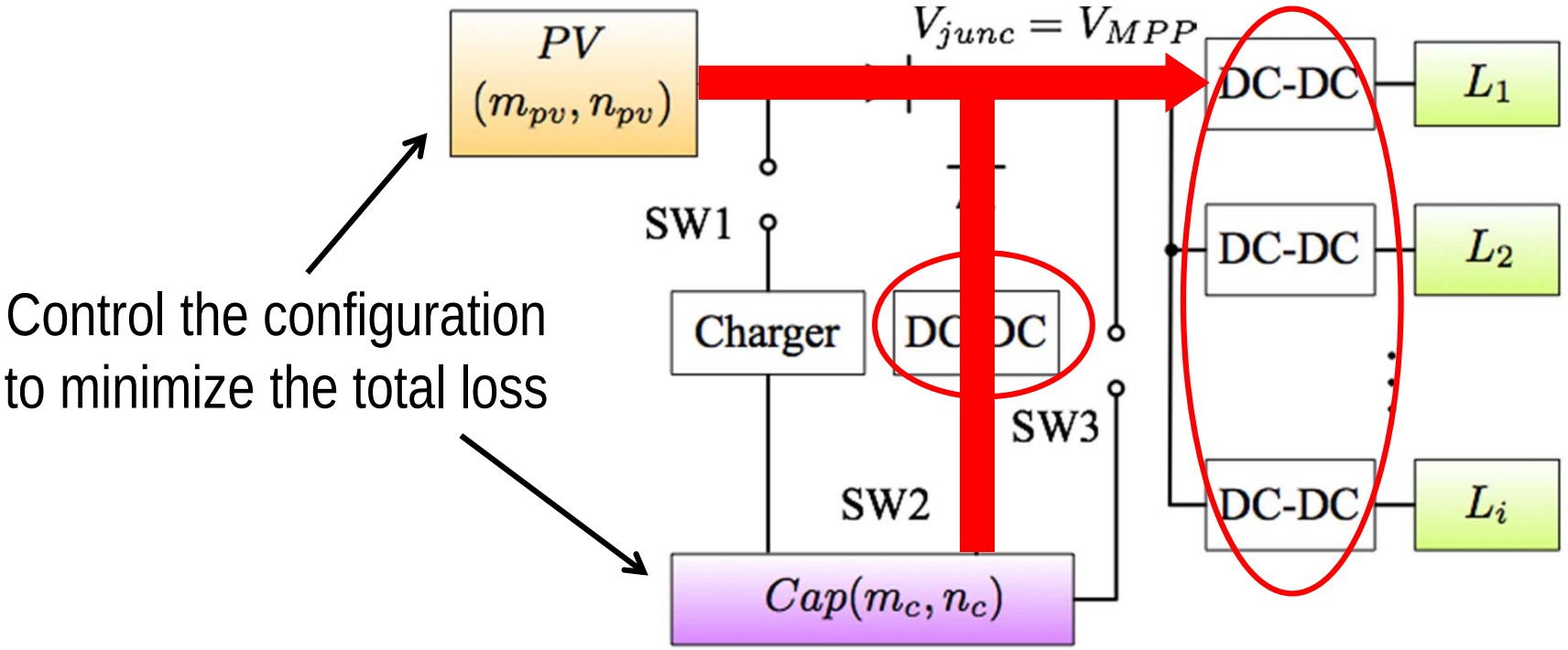
- Enough sunlight to operate the loads





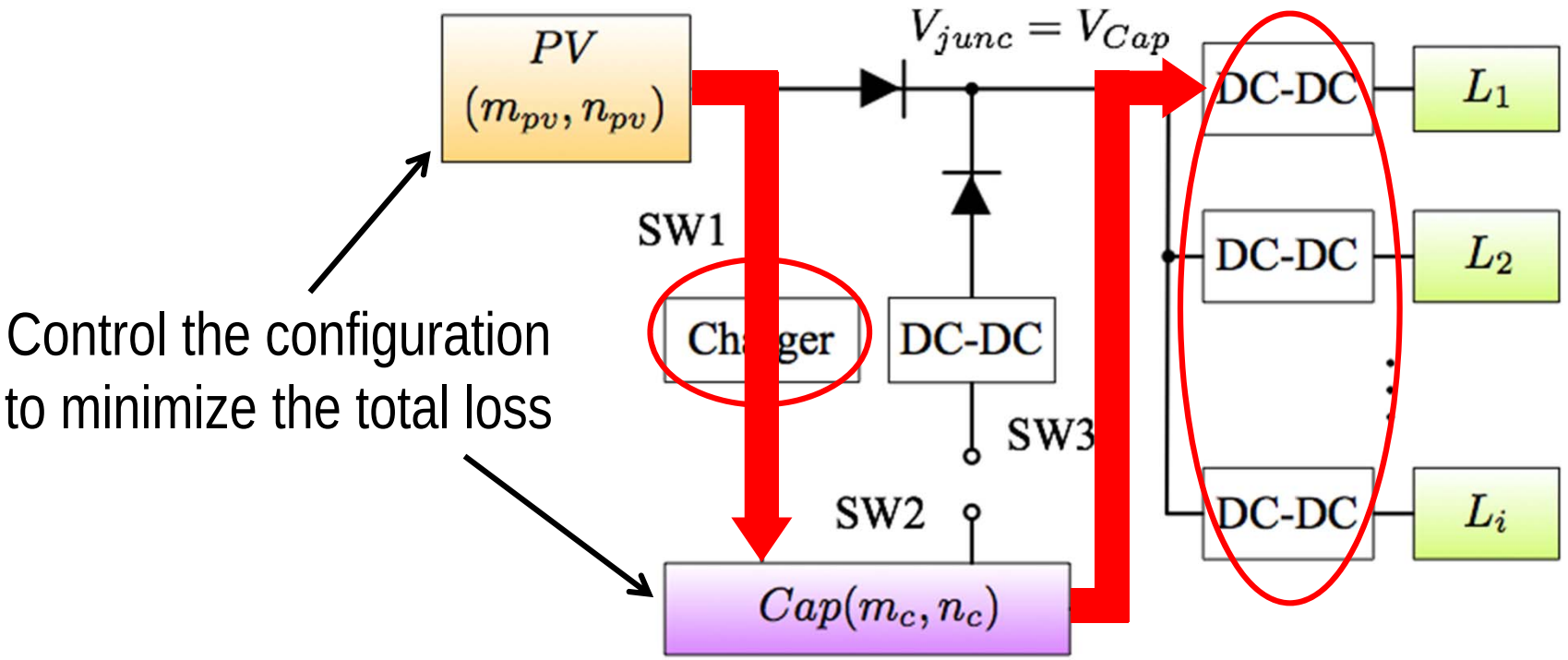
Hybrid Mode

- Not enough sunlight to operate the loads



Bad Harvest Mode

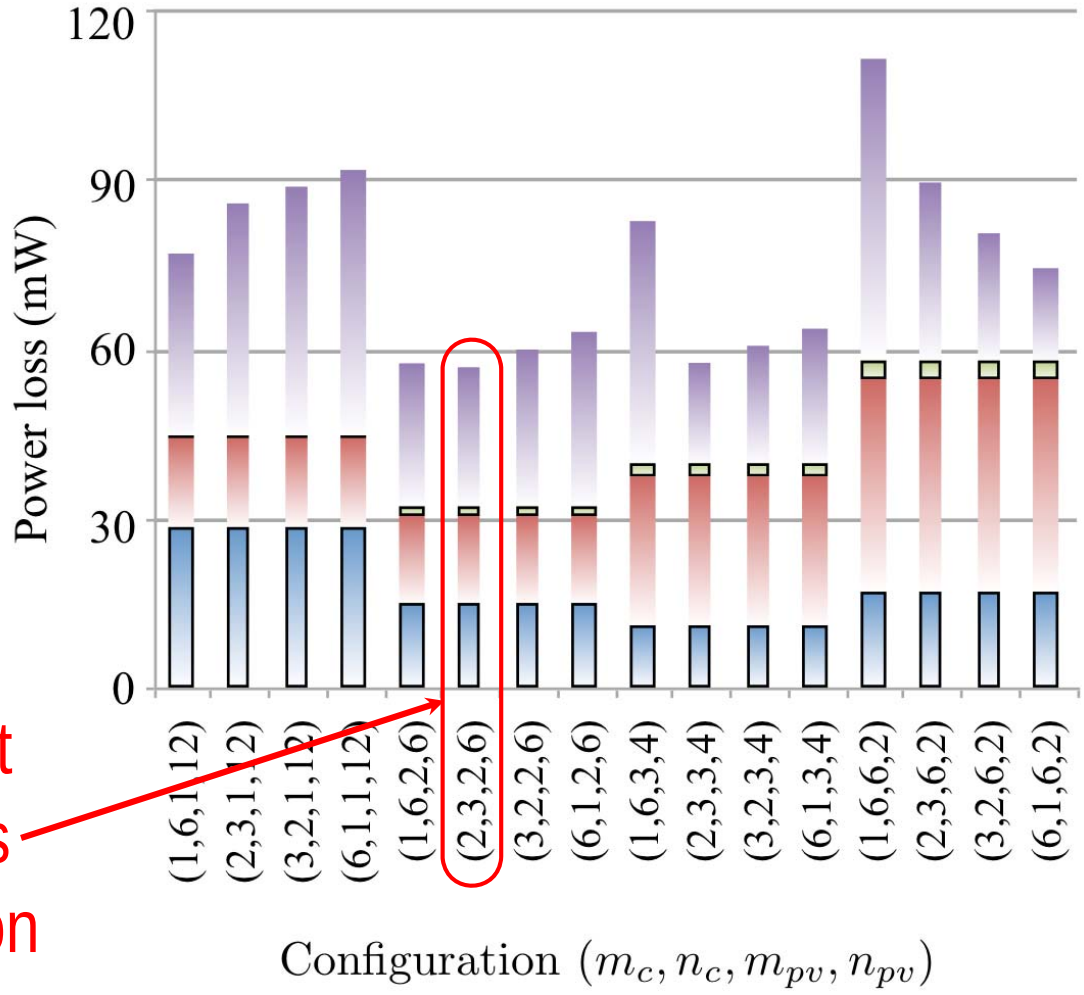
- The power loss in the Conv_cap is more than the amount of generated power from the PV array



One Case Result for the Array Configuration

- Power loss in converters for different configurations

- CPU, modem, and camera consume 100mA, 30mA, and 1mA respectively
- Sunlight intensity and state of charge in super-cap are 100% and 20% respectively



The lowest power loss configuration

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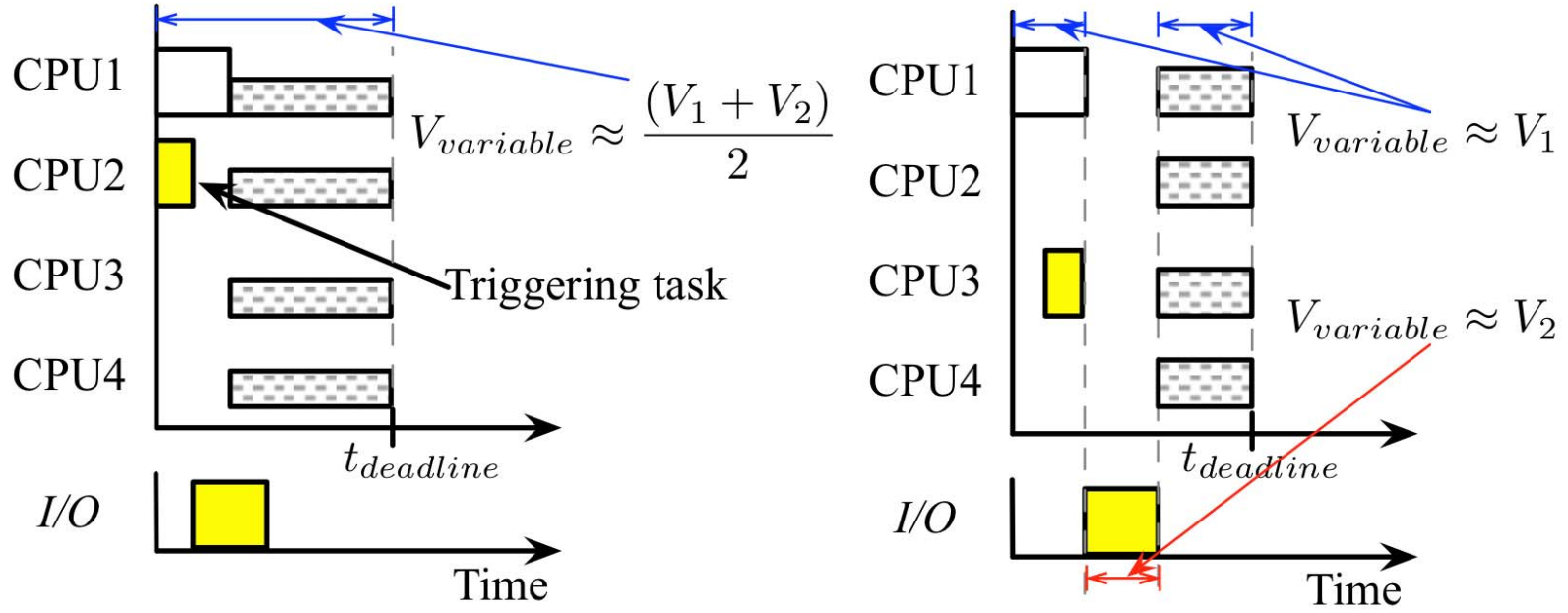
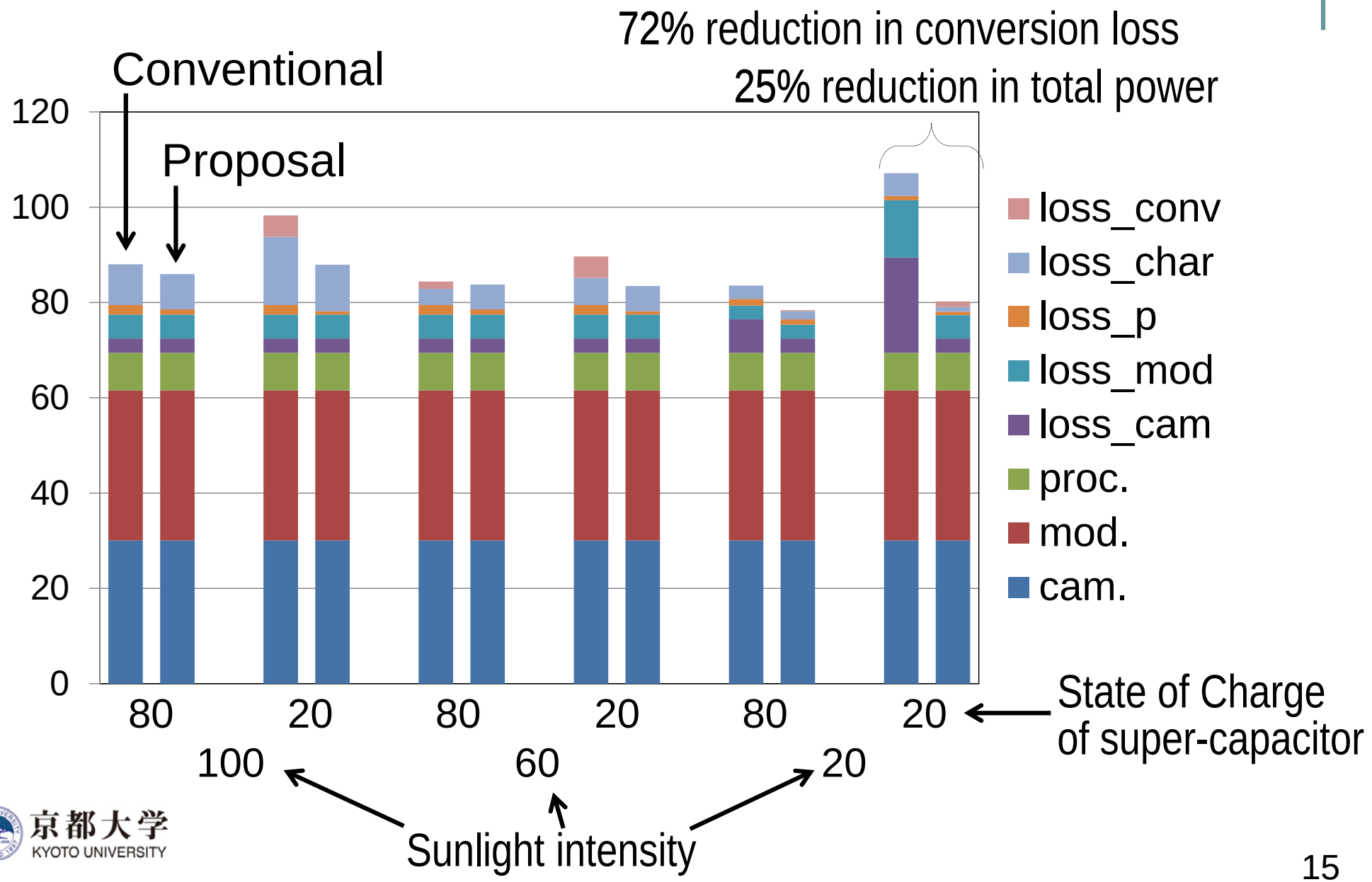
Scheduling

- I/O aware task scheduling
  - Minimize the overlap among CPU tasks and I/O tasks
  - Make the chance of power reduction larger



K. Lee, T. Ishihara, "I/O Aware Task Scheduling for Energy Harvesting Embedded Systems with PV and Capacitor Arrays," in Proc. of IEEE Symposium on Embedded Systems for Real-Time Multimedia (ESTIMedia 2012), pp. 48-55, October, 2012

Experimental Results



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Conclusion

- Dynamic selection of three power path configurations
  - Energy efficiency in each harvesting condition can be maximized
- Simultaneous array configuration and task scheduling
  - Multiple supply voltage loads are considered
  - Power loss in DC-DC converters can be reduced by 72%

- Contribution
  - System cost efficiency and quality of services can be improved
  - without oversizing a PV array or an energy storage