A DC Microgrid with Batteries Directly Connected Bus-line

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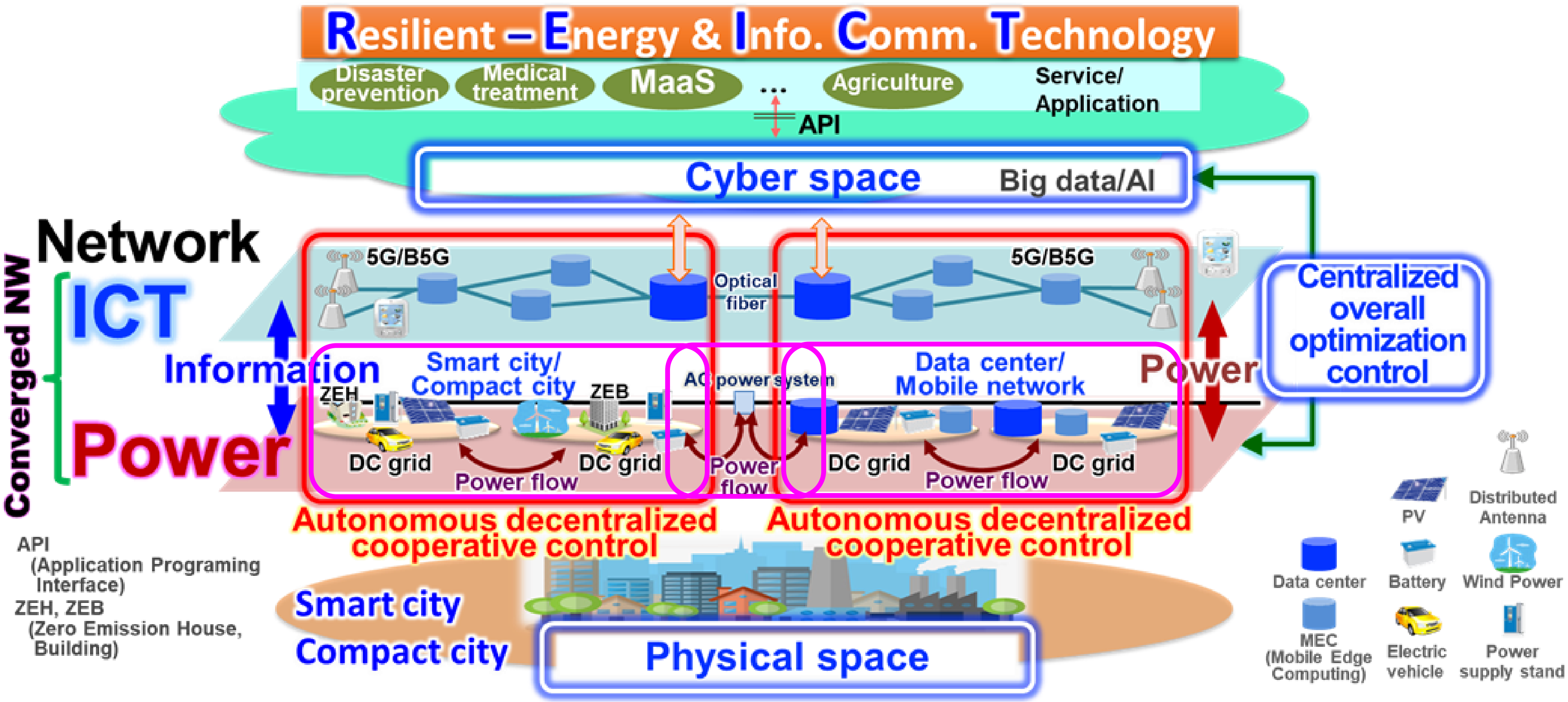
Overview of JST OPERA Project

Resilient electric power and ICT (R-EICT) converged network infrastructure technologies based on overall optimization of autonomous decentralized cooperative control of DC microgrids

Project leader: Prof. Taiich Otsuji

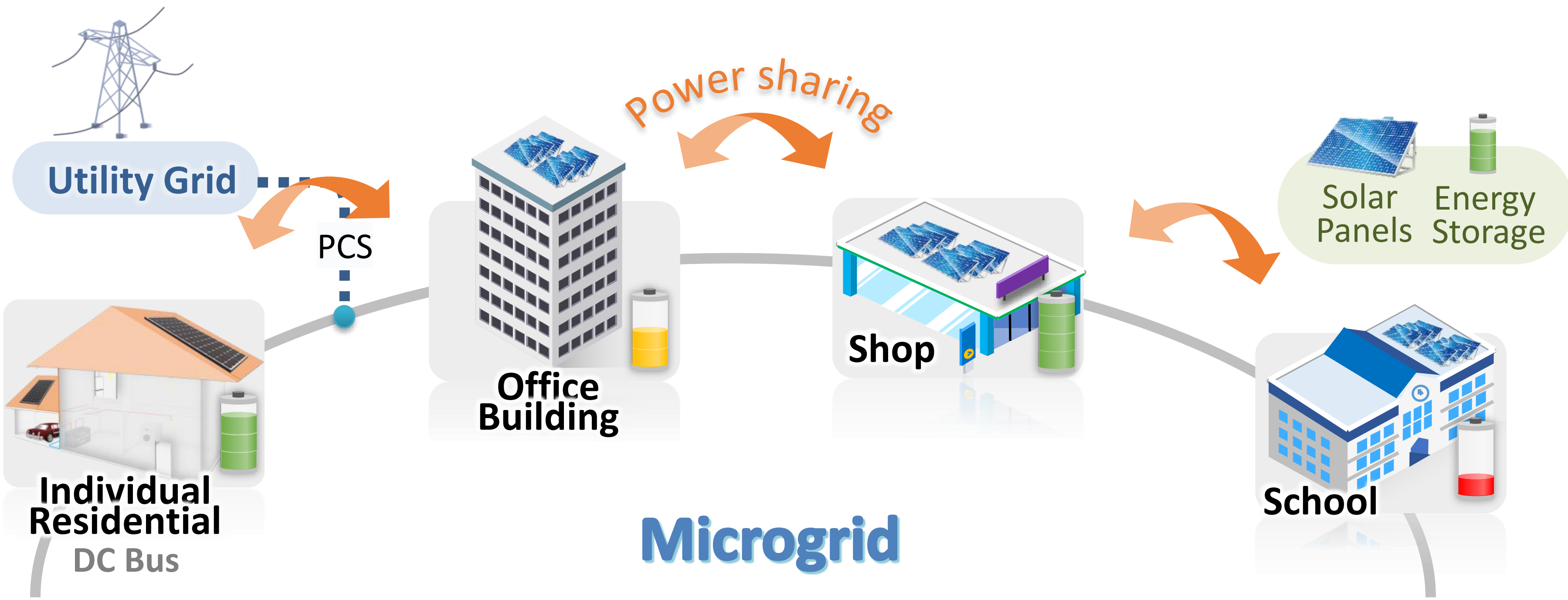


- Optimal operation of DC Microgrid
- Power exchange operation between DC Microgrids
- Job scheduling of renewal energy driven distributed micro dater center

DC microgrid

Distributed power sources such as renewable energy and storage batteries

Local production and consumption of electricity



PCS: Power conditioning subsystem

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Control method of DC microgrids

1. Centralized Control

A central controller monitors overall grid status (bus-line voltage, state of charge (SoC) of each storage battery, PV power generation, load power consumption, etc.) through communication links, and controls each device. The central controller performs control to stabilize the grid and optimizes the entire grid so that the SoC of each storage battery is equal.

2. Decentralized Control

Each device distributed on the bus-line does not have a central control device and operates based on its own judgment based on the voltage at the connection point with the bus-line.

- Distributed Autonomous Cooperative Control (DACC)

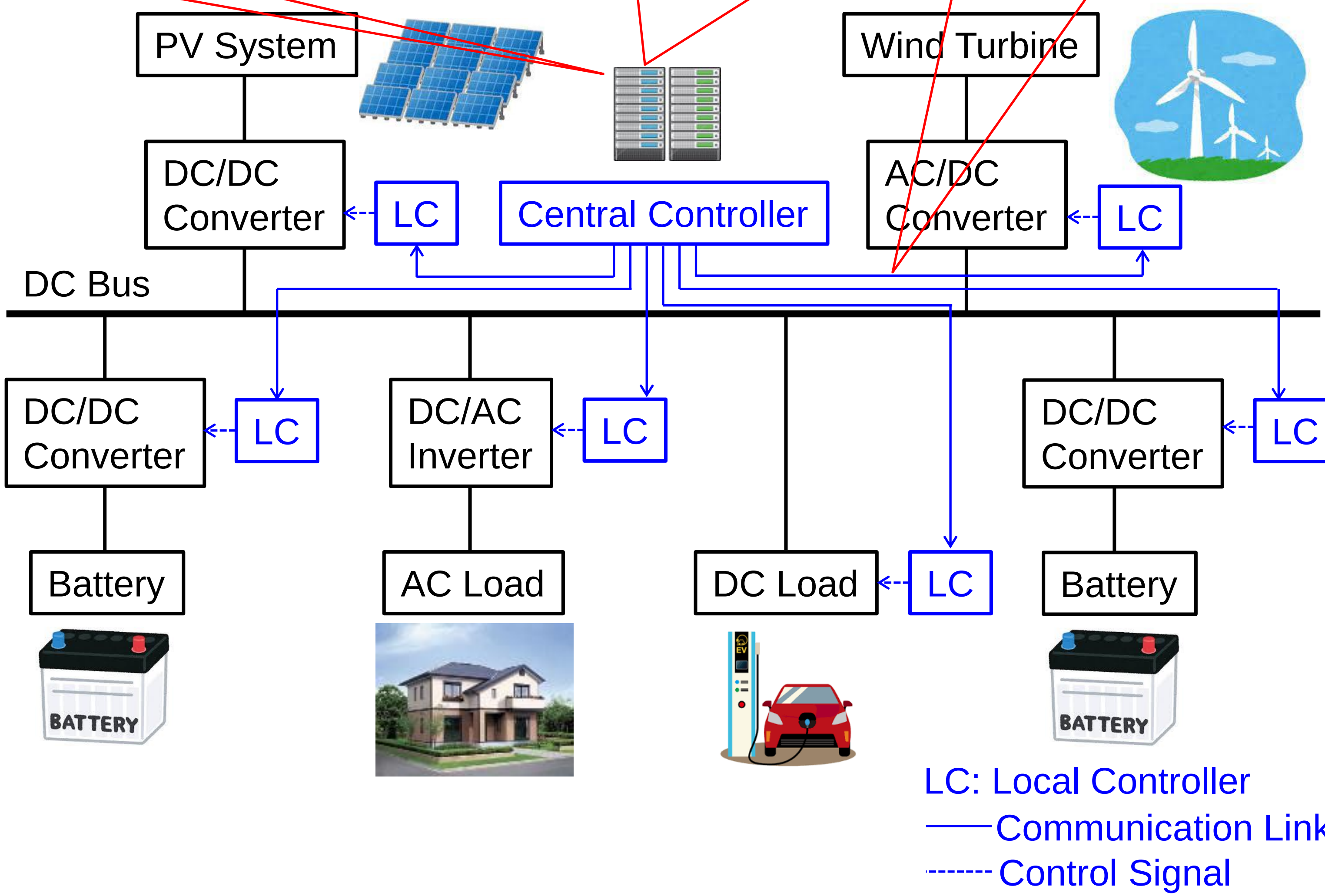
Neighboring devices communicate with each other and work autonomously while cooperating with each other.

Centralized Control method

Stable and optimization of entire grid can be achieved with high accuracy

Disadvantage

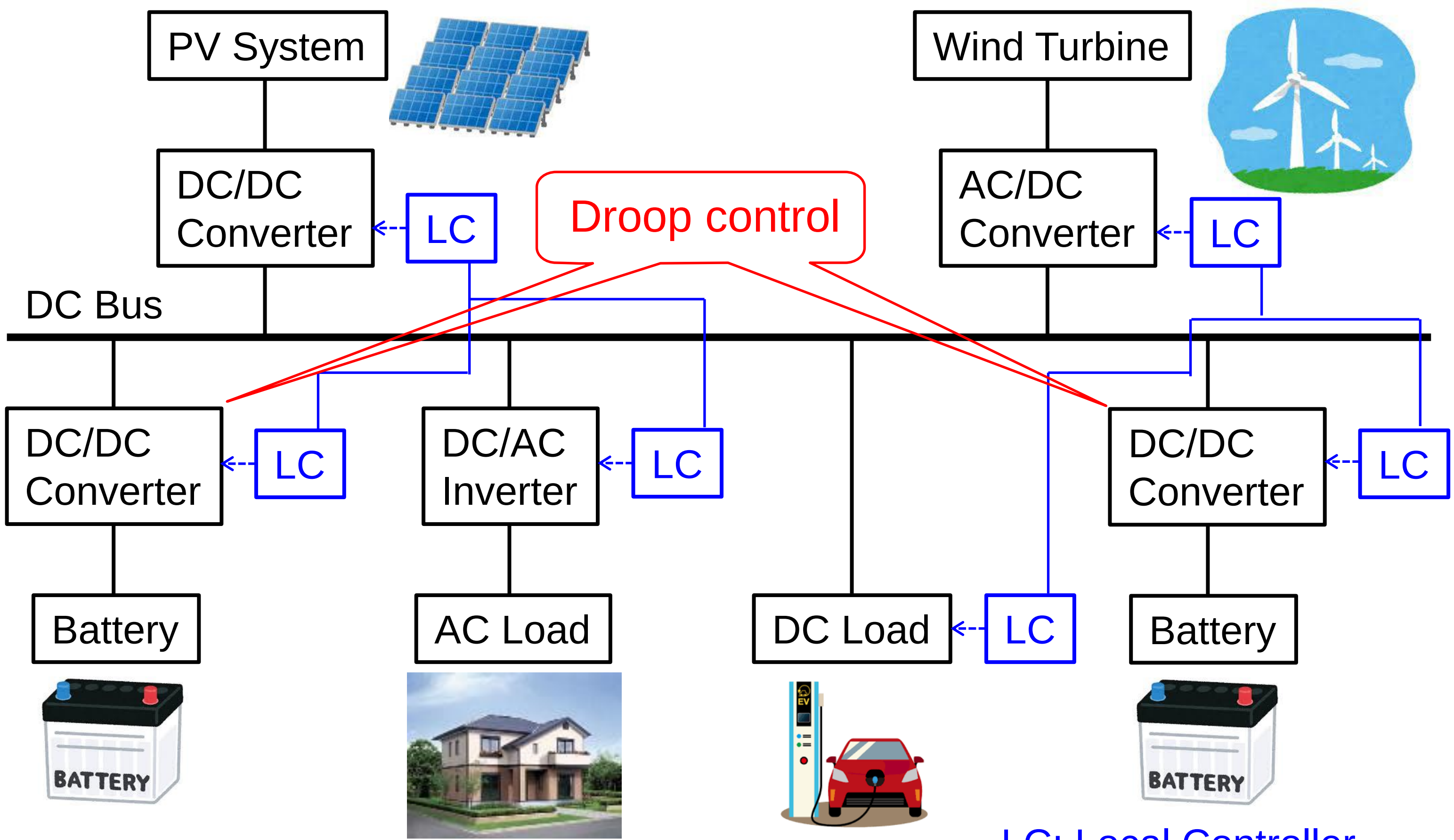
- Complex algorithms to control many devices
- The control program needs to be changed as the grid scale changes
- If the communication link breaks, the connected device becomes uncontrollable



Distributed Autonomous Cooperative Control method

Nearby LCs exchange information through communication links although there is no central controller

Some mechanism is needed to make devices work together



LC: Local Controller

—— Communication Link

------- Control Signal

Challenges of the DACC

How can we achieve cooperative operation between devices?

Conventional DACC method

- Devices communicate and negotiate with each other
- Droop Control of DC/DC converters

⇩ Our method

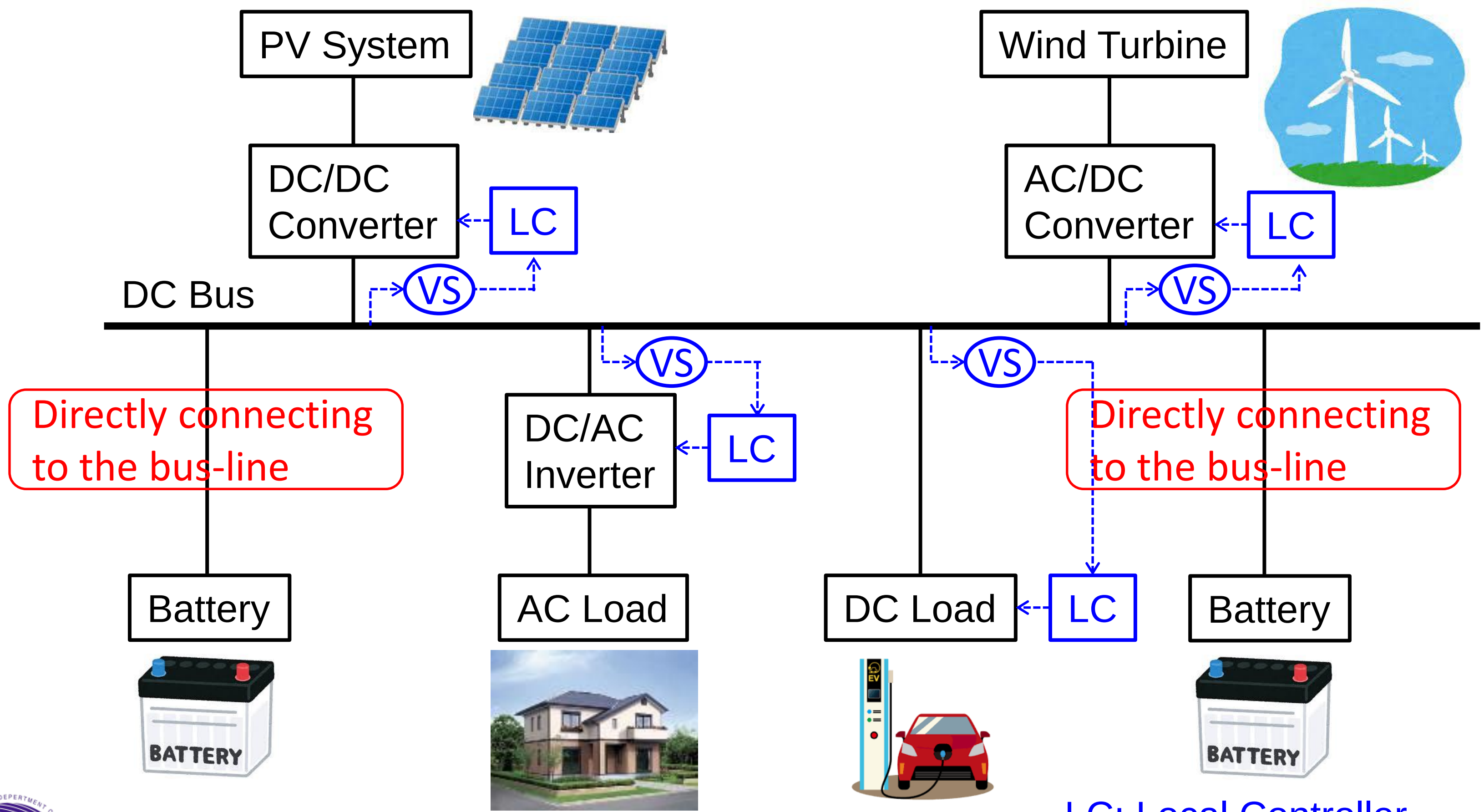
- Directory connecting batteries to the bus-line
- Passive control with droop characteristics of batteries
- To apply electrical inertia to the bus-line

Passive DACC method

Passive DACC method

Our method

Connecting storage batteries whose terminal voltage is equal to the bus-line voltage directly to the bus-line



LC: Local Controller
VS: Voltage Sensor
------- Control Line

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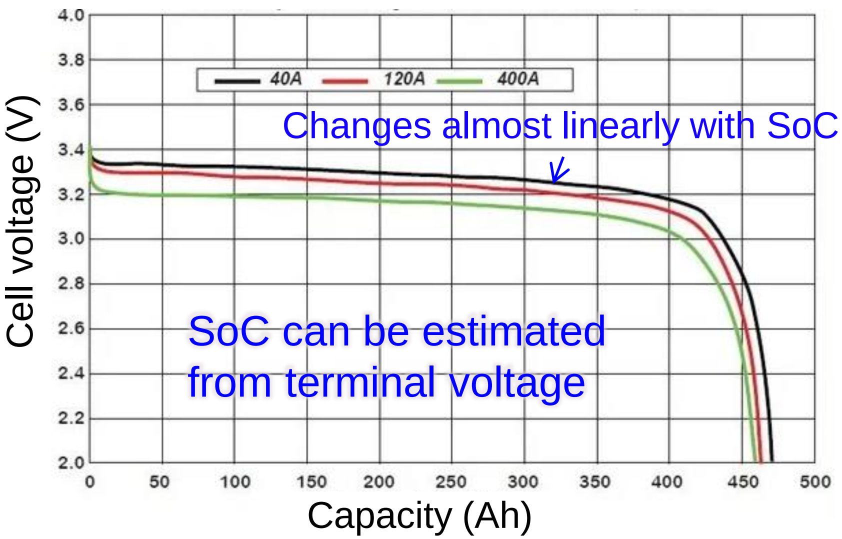
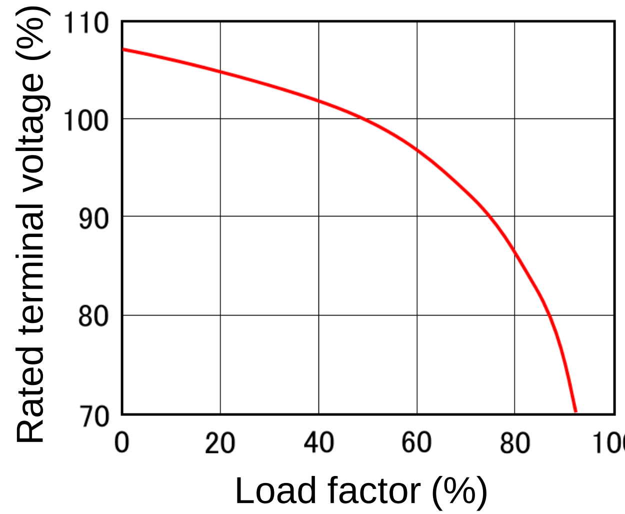
Passive DACC using battery characteristics

Utilizes the characteristics of lithium-ion batteries



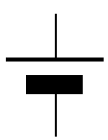
Discharge curve of $LiFePO_4$ battery



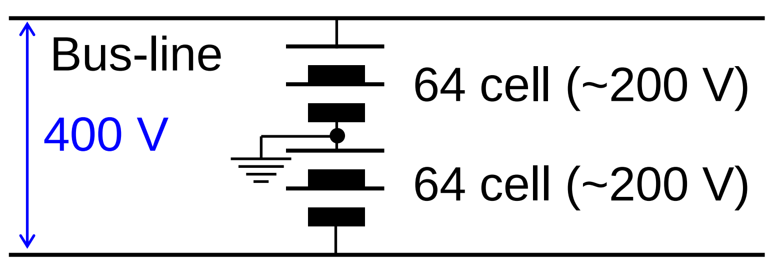
Droop characteristics of batteries

Make the terminal voltage equal to the bus-line voltage
by connecting an appropriate number of cells in series

Cell voltage of $LiFePO_4$ battery



~3.2 V



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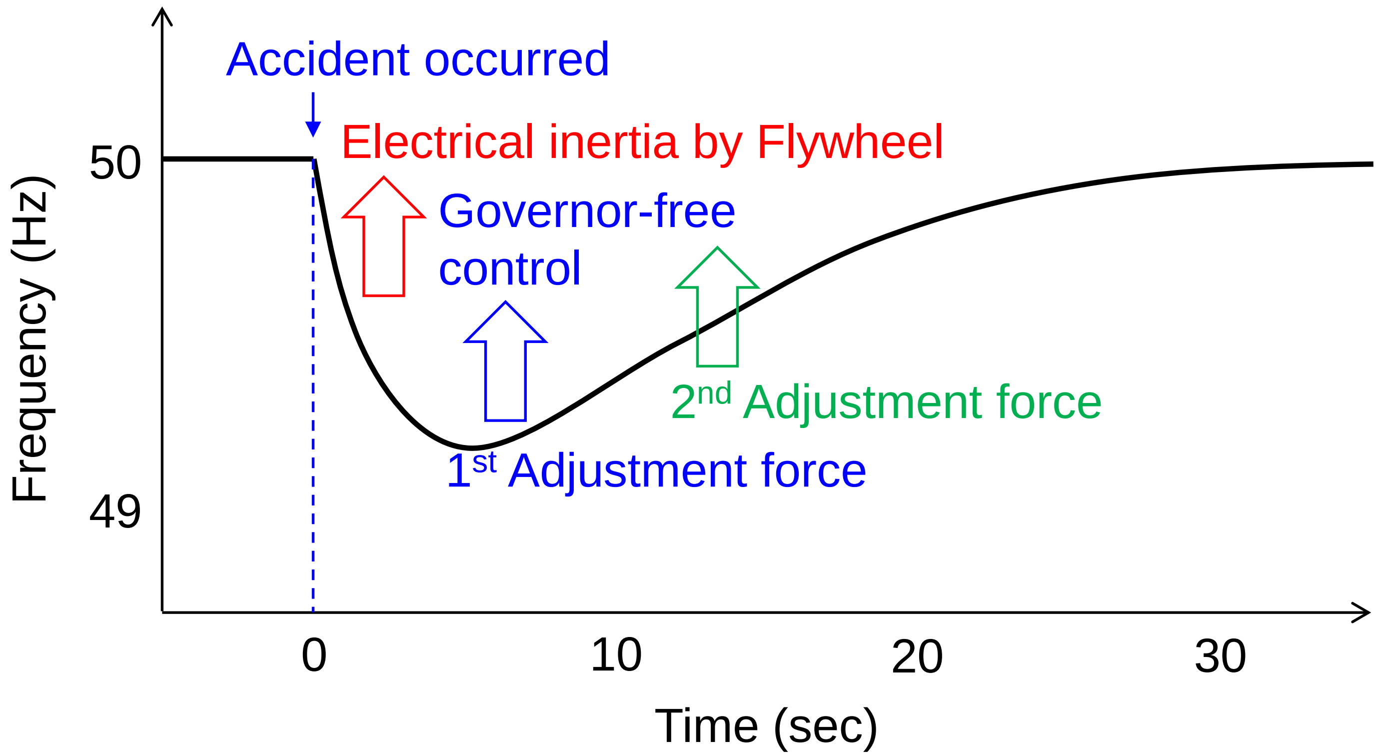
What is electrical inertia?

Electrical inertia is the ability of a bus-line to maintain a constant voltage or frequency in response to power load fluctuations

Electrical inertia in existing AC power grid

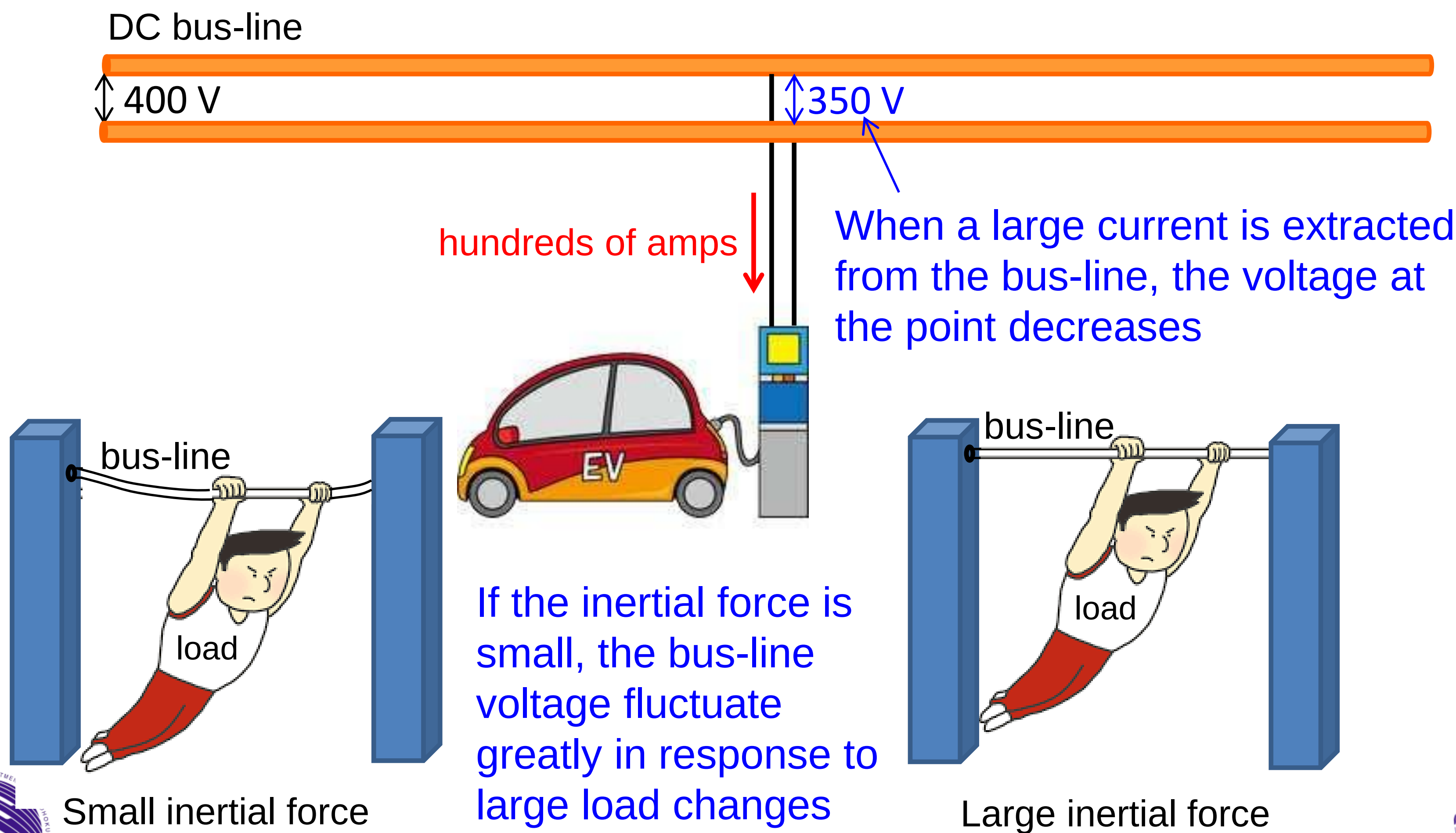
Electrical inertia is a short-term adjustment force



Frequency change when failure occurs

Electrical inertia in DC grid

Electrical inertia in DC grid is the ability to maintain a constant bus-line voltage in response to power load fluctuations.



Passive DACC using battery characteristics

Our original method

Storage batteries, such as Li-ion batteries, which have a region where the terminal voltage changes linearly with respect to the SoC and have appropriate Droop characteristics, are distributed and loaded directly onto the bus-line

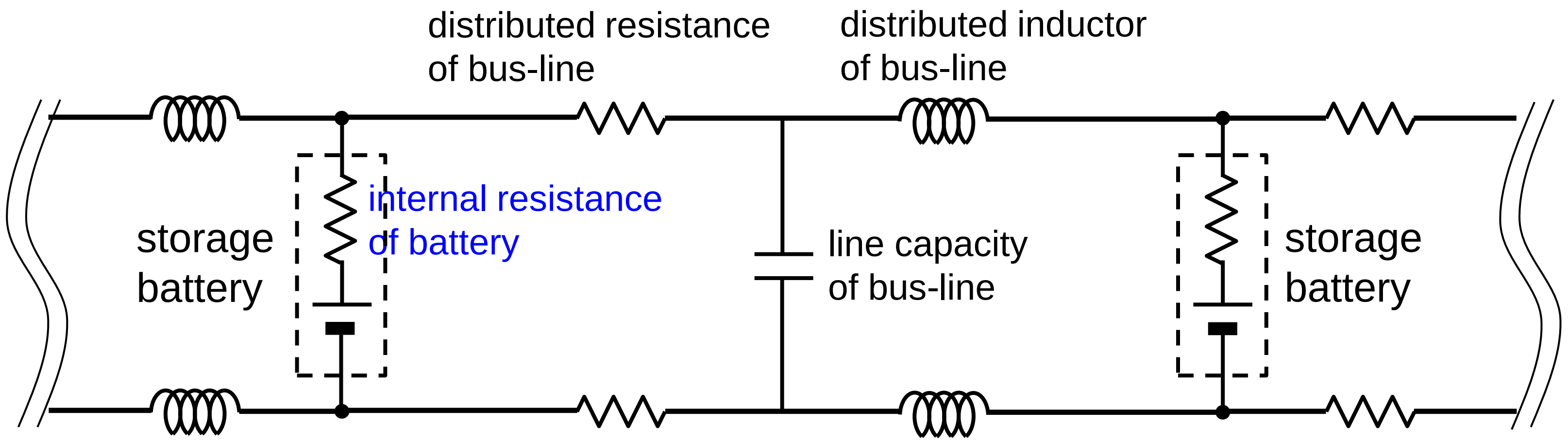
Contributes to cooperative and stable operation

Contributes to electrical inertia

Features

- Simple configuration (No communication links required)
- Easy to control (Bus-line voltage reflects the SoC of the battery)
- Scalable (Can treat even if the grid scale expands/shrinks)
- Resilience (Even if some parts are damaged, the remaining parts will still function)

Electrical equivalent circuit of battery loaded bus-line



Local bus-line voltage = Terminal voltage of battery connected: (ex. 400 V)

Internal resistance of battery: small (large) → electrical inertia: large (small)

Storage capacity of battery: small (large) → Power supply duration: long (short)

↑

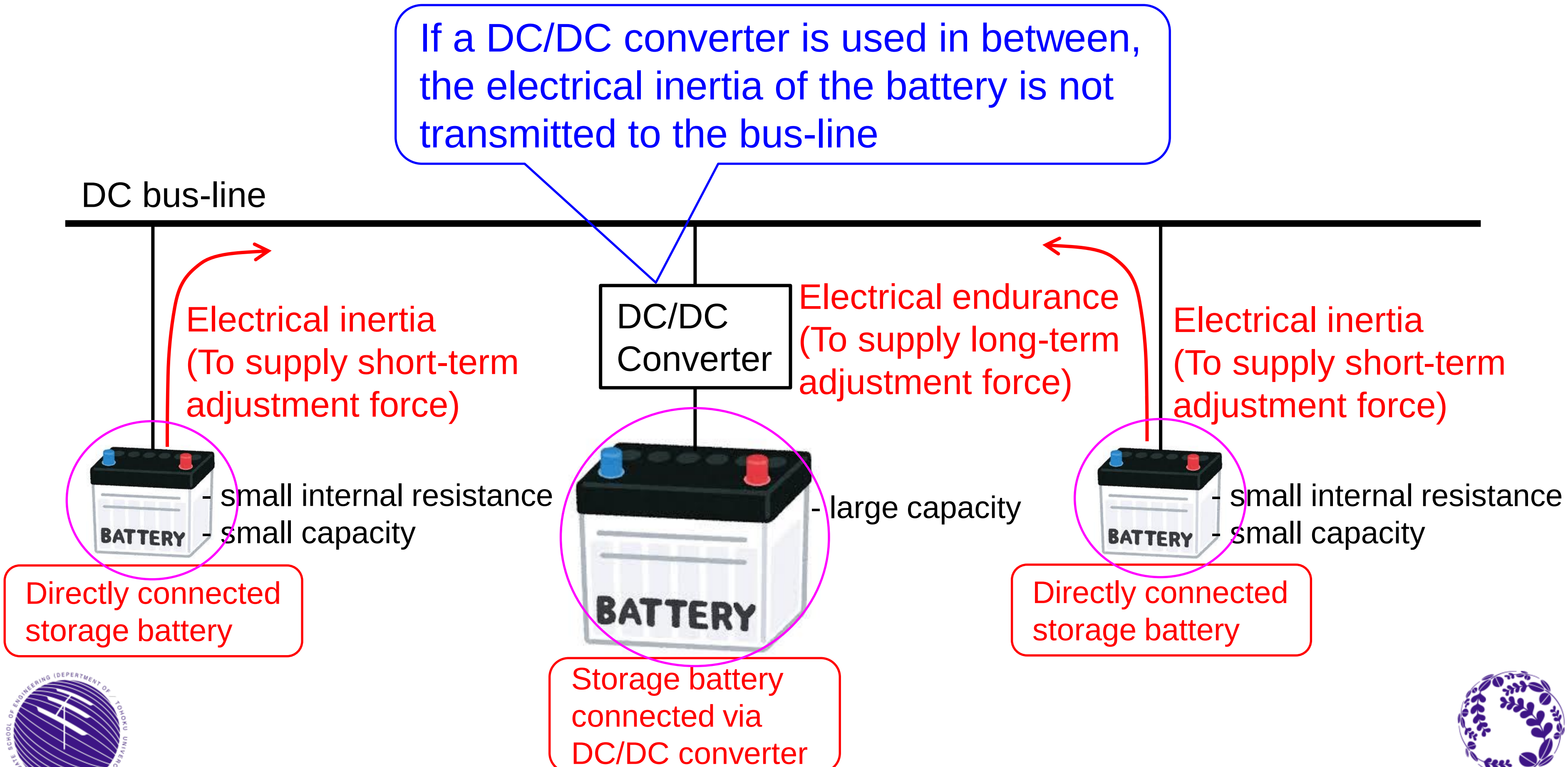
Not directly related to electrical inertia

To obtain large electrical inertia, distributed loading of batteries with low internal resistance is effective

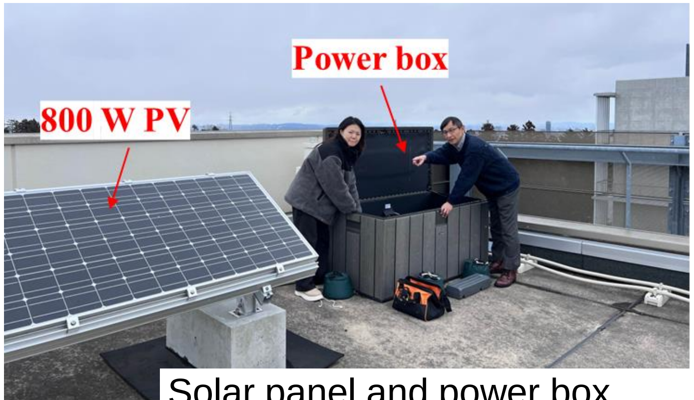
Composite storage battery system

Composite storage battery system combining

- Directly connected batteries: short-term adjustment force (Electrical inertia)
- Large capacity battery connected via DC/DC converter: long-term adjustment force

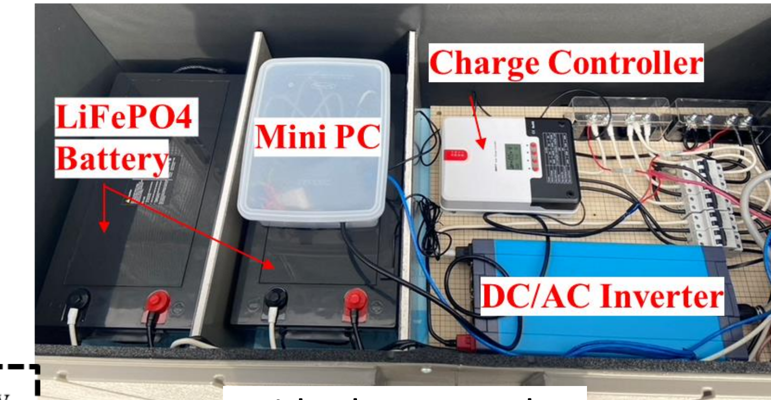


Constructed a battery-directly connected DC microgrid

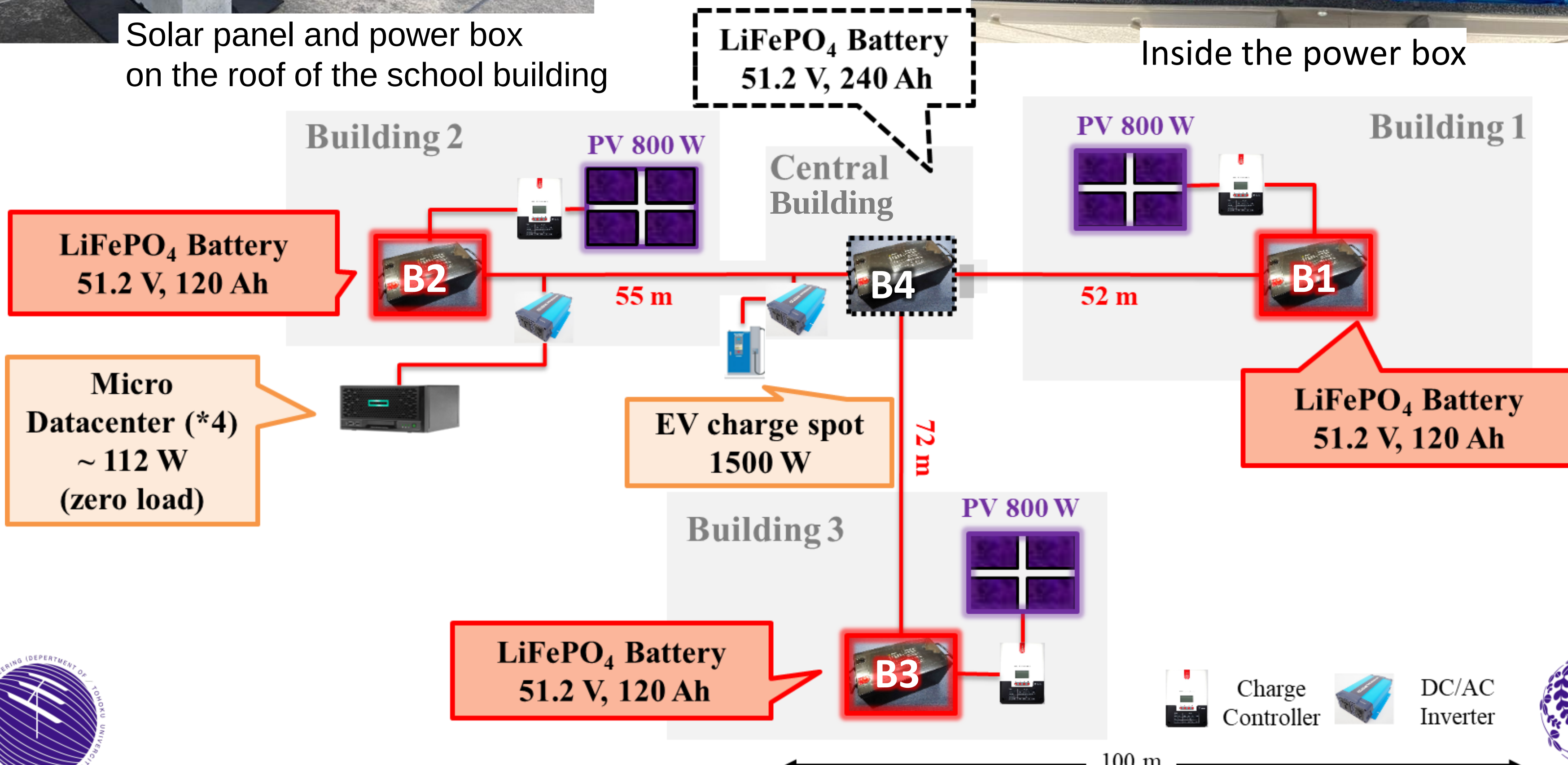


Solar panel and power box
on the roof of the school building

Off-grid without grid connection



Inside the power box



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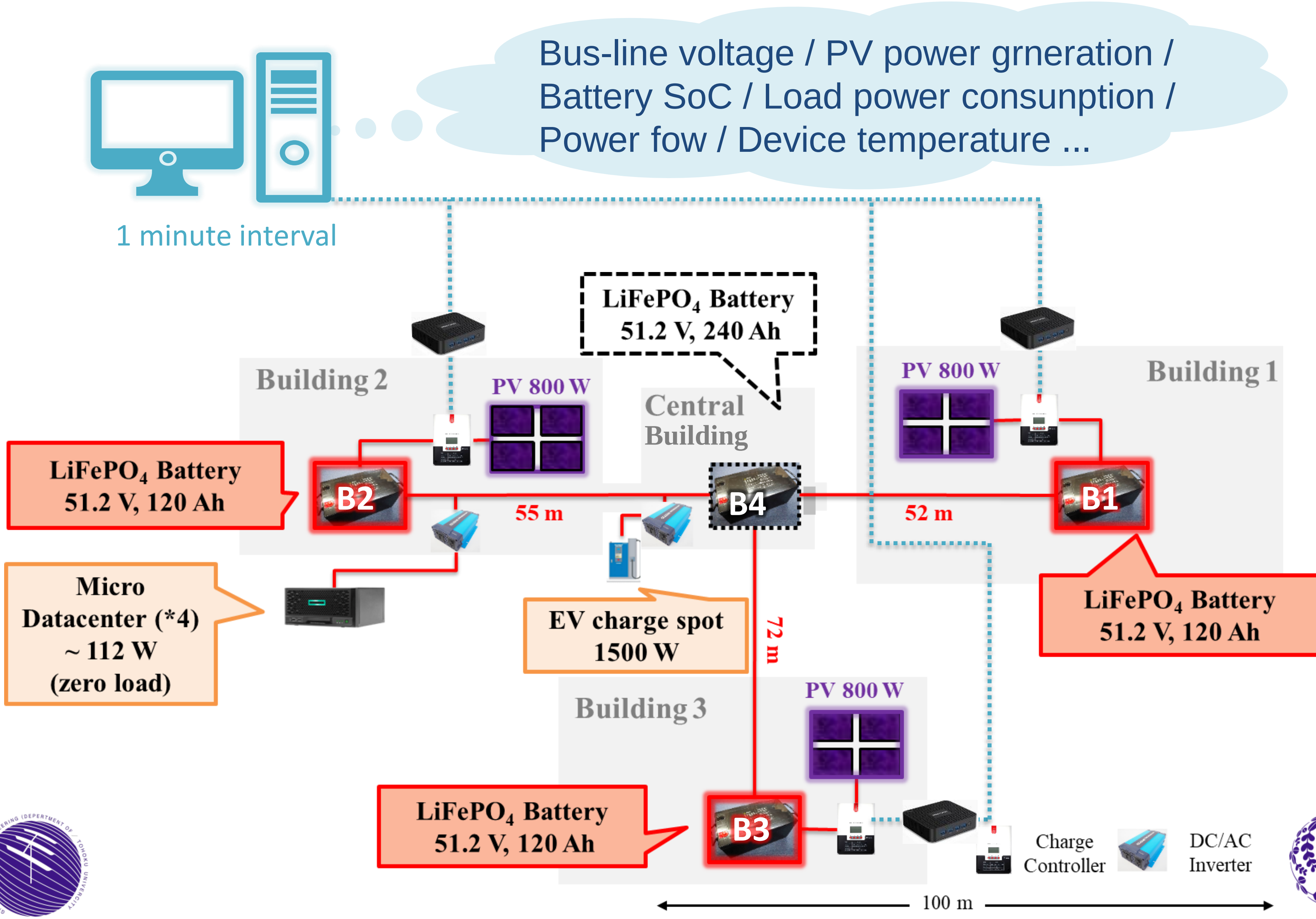
Parameters to monitor the grid status



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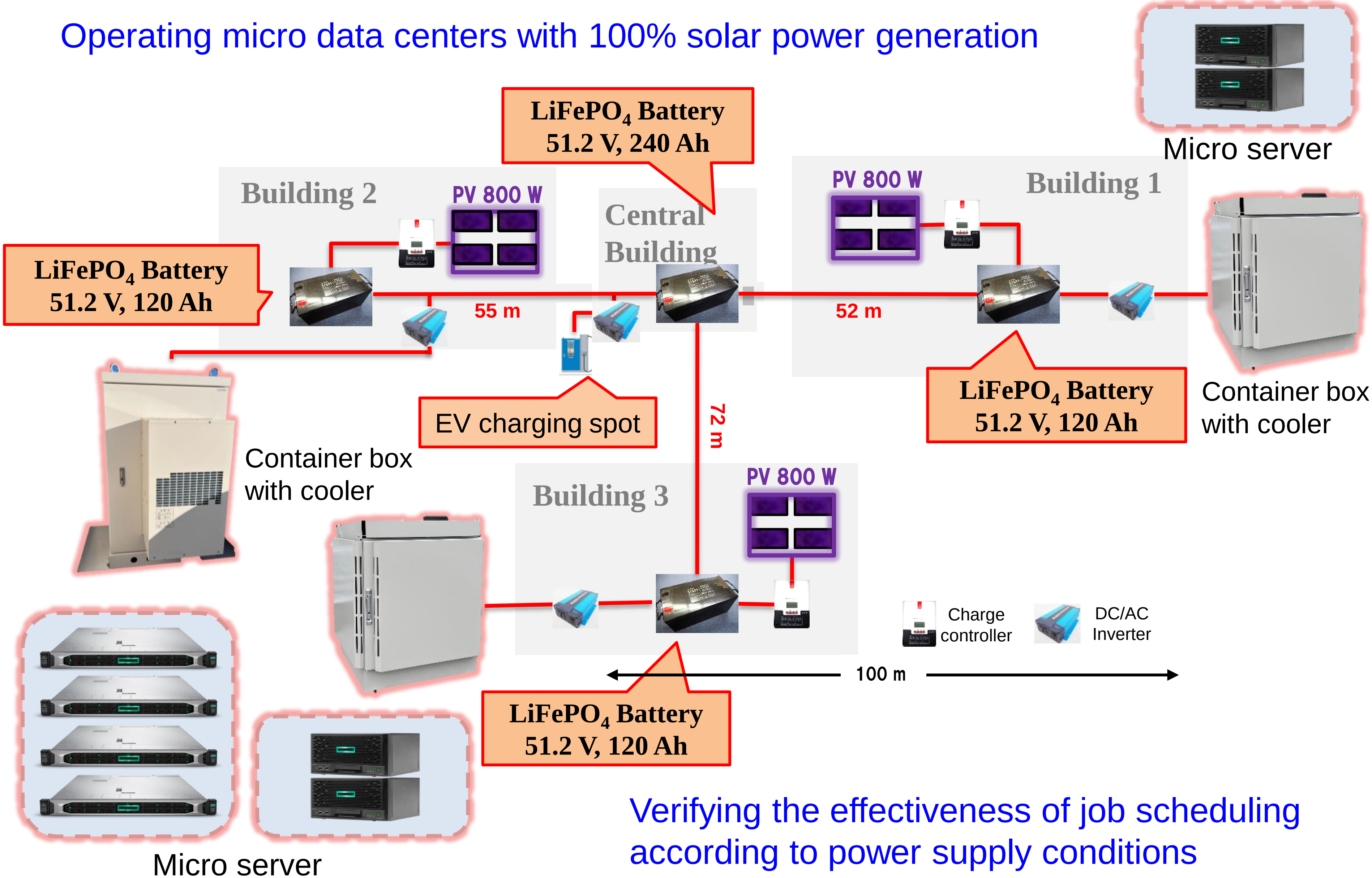
Micro data center as a primary power load

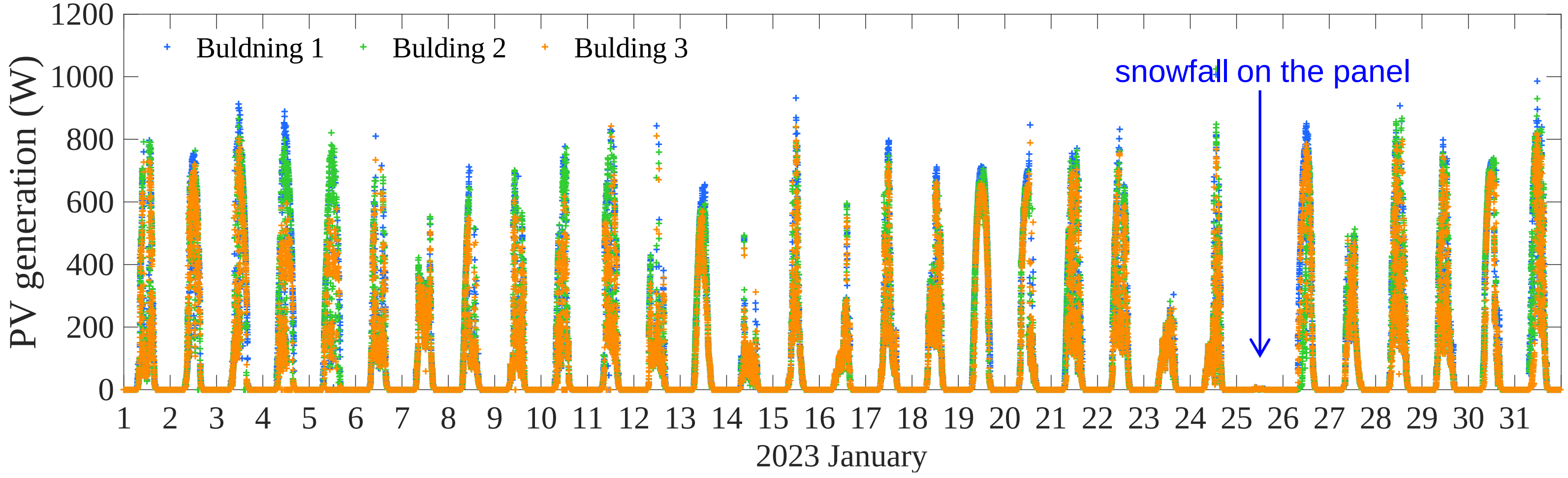
Operating micro data centers with 100% solar power generation



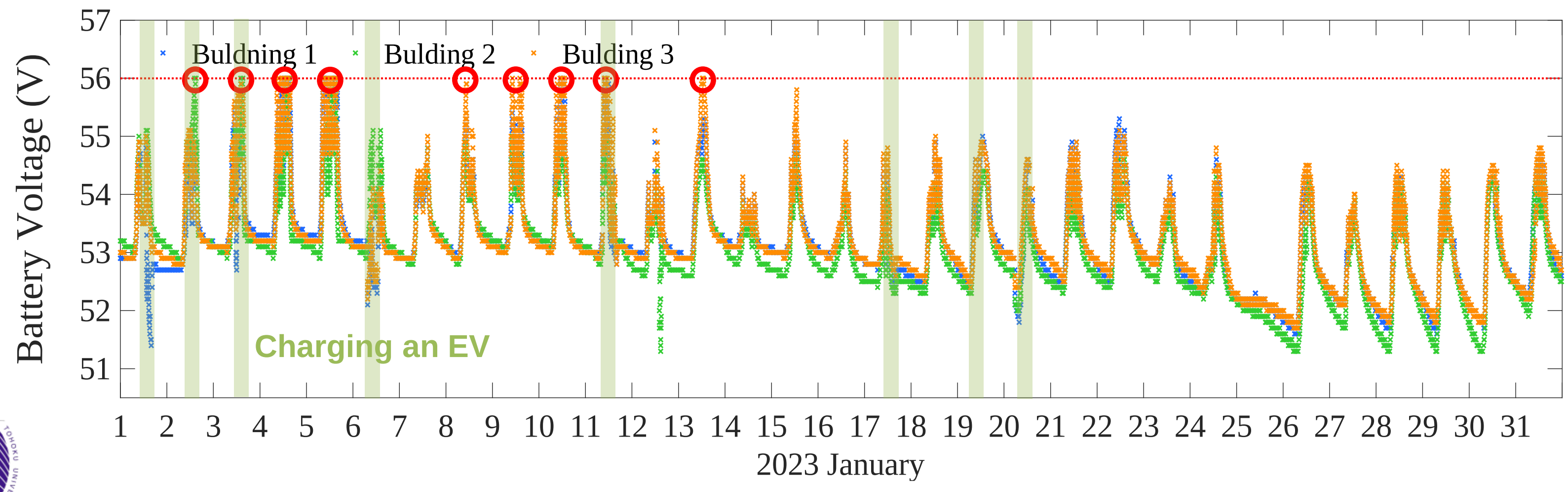
Verifying the effectiveness of job scheduling according to power supply conditions

System operation for one month in January 2023

PV generated power in January this year



Changes in battery terminal voltage



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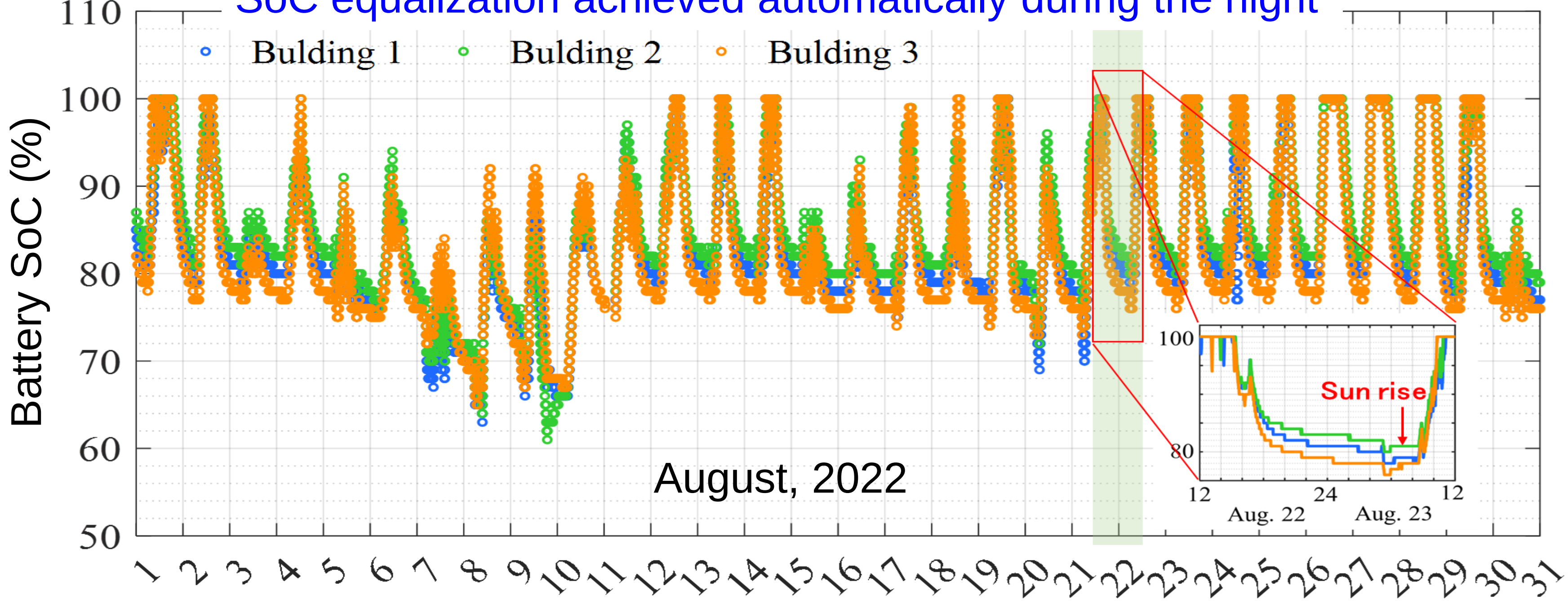
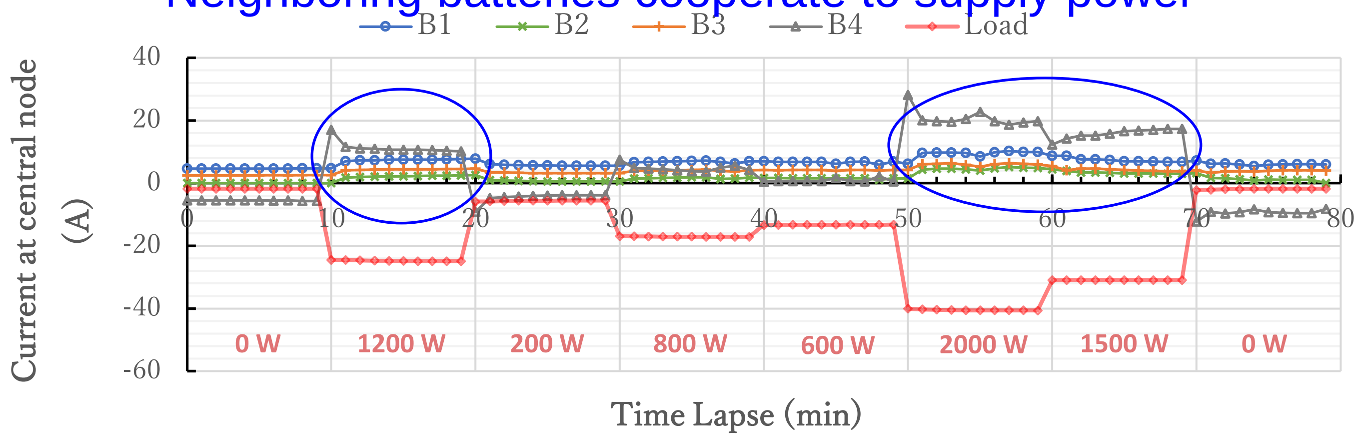
SoC equalization and cooperative power supply

SoC equalization achieved automatically during the night



Neighboring batteries cooperate to supply power



NE-008
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Power flow when power load is connected to bus-line at Building 4

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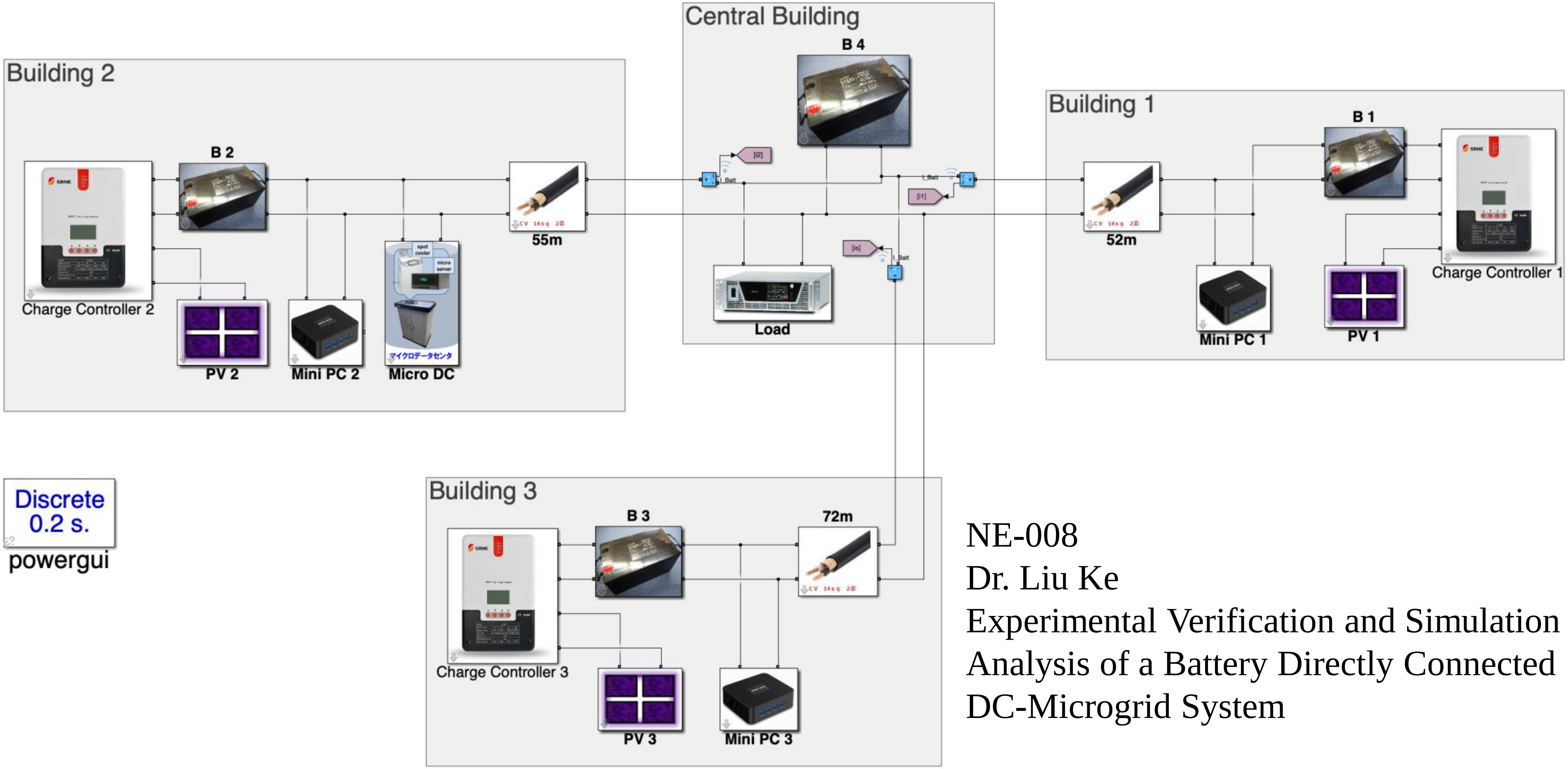
Building a simulator to analyze grid behavior

Constructed a grid simulator that runs on MATLAB/Simulink



NE-008
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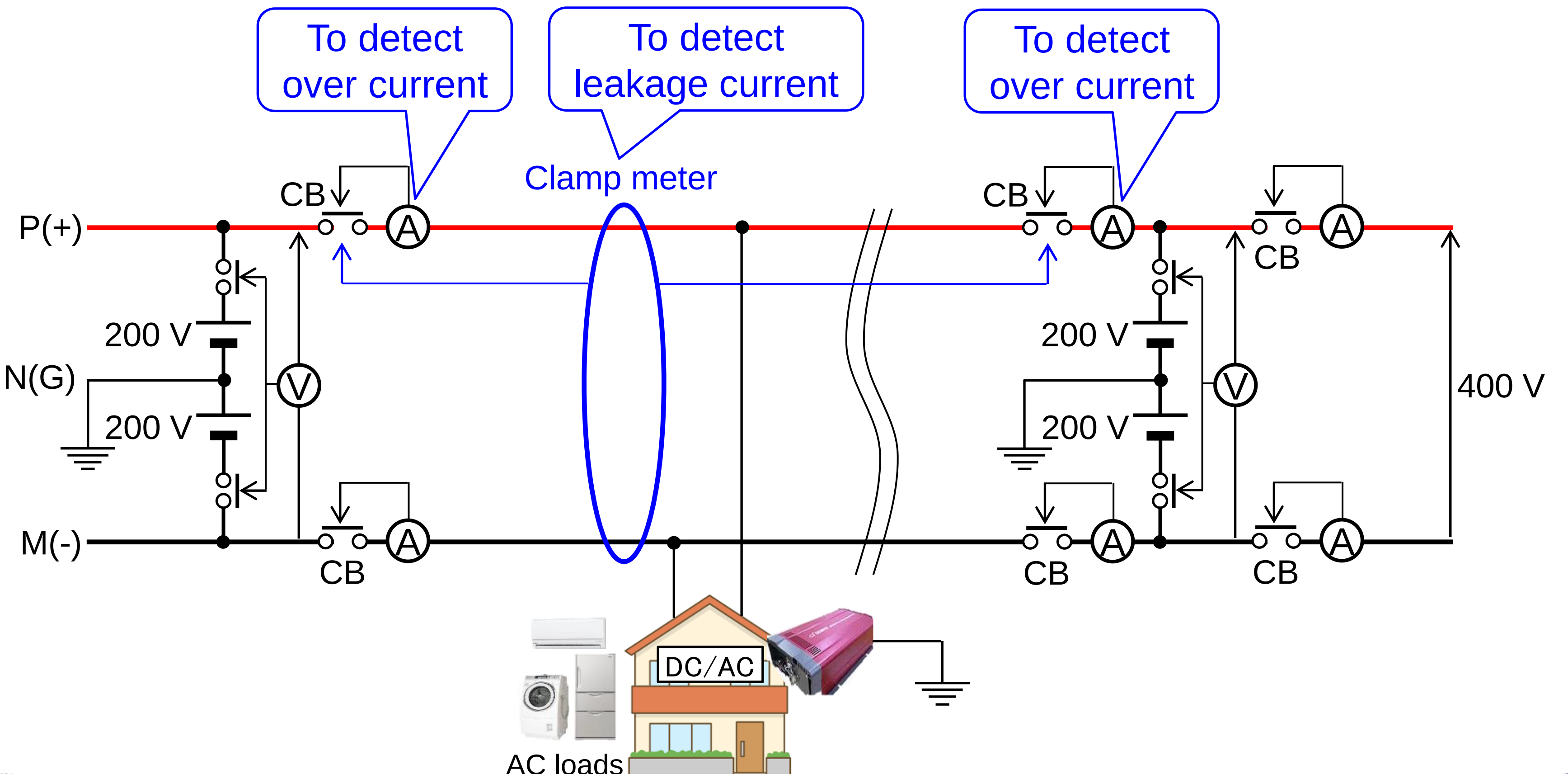
Experimental Verification and Simulation Analysis of a Battery Directly Connected DC-Microgrid System

Safety measures of the grid

If the bus-line has electrical inertia, a mechanism is needed to detect leakage current or over current due to short circuit, and cut off the power supply



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Summary

- ✓ We proposed a DC microgrid in which storage batteries are distributed and directly connected to the bus-line, and demonstrated the operation.
- ✓ Adding electrical inertia to the bus-line simplifies grid control and analysis
- ✓ We introduced a composite storage battery system combining directly connected batteries and large capacity battery via DC/DC converter
- ✓ Safety measures of the grid is inevitable when electrical inertia is given to the bus-line

Acknowledgment

This study was supported by JST OPERA Prog. "Creation of R-EIC (Resilient-Energy-Information-Communication) Converged Network Infrastructure based on Overall Optimization of Autonomous Distributed Decentralized Cooperative DC Microgrids" (JPMJOP1852).

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