SPEC

DC Microgrid Project in SNU

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Outline

1 Introduction

2 DC Microgrid Projects in SNU

3 Control of DC Microgrid

4 System Architecture

Microgrid

A group of interconnected loads and distributed energy resources (DER) with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid [and can] connect and disconnect from the grid to enable it to operate in both grid connected or island mode [DoE's definition]

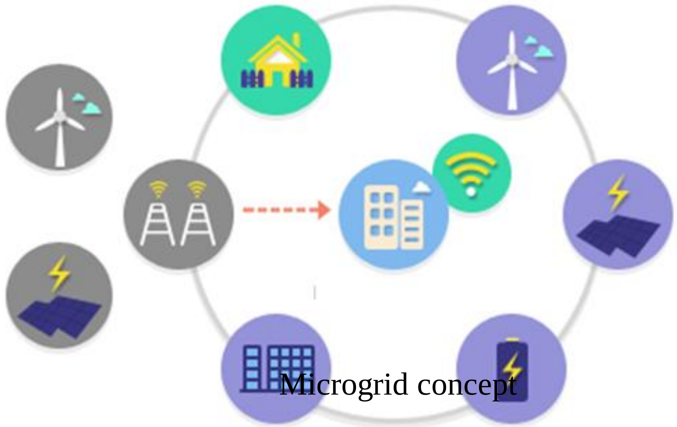
- Renewable energy sources (RES)
- Energy storage systems (ESS)
- Dispatchable DGs

Power electronics interface

- Fast and highly controllable

Operates in grid-connected or islanded

- Autonomous operation and energy security



Microgrid concept

Features

- Controllable Integration of sources and loads
- Efficient usage of DG sources
- Autonomous operation
- Environmentally friendly

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DC Distribution

DC distribution at low voltage level as an alternative of ac systems

Motivation

- Increase of dc loads: consumer electronics, digital, LED, inverter-based loads, EV
- Penetration of RES
- Needs for high power quality
- Development of power electronics and device technology

Advantages

- System efficiency
  High system efficiency due to reduced conversion stages for RESs and loads
- Power quality
  Elimination of ac issues: synchronization, reactive power, harmonic compensation
  Simplification of converter design
- Easy integration
  RES and ESS are more easily interconnected to the system

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Structure of DC Microgrids

Applications and ratings

- Residential / educational / industrial / commercial
- From few kWs to few hundreds of MWs

Sources

- Utility power
- RESs
- ESSs

Loads

- Classes of power quality (critical or ordinary load …)
- Types of loads (electric, motor, resistive …)

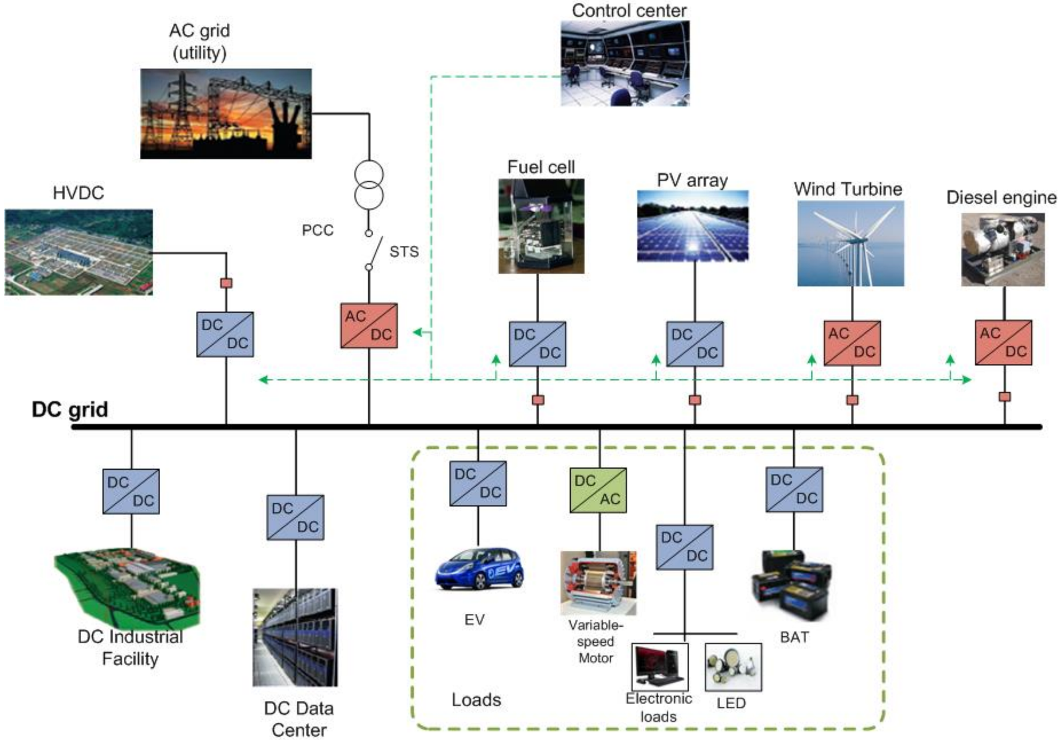

Diagram of DC Microgrid

2.1 Energy States of SNU

Energy Consumption in SNU Seoul Campus

- Gas: 5,750,056 m^3 – $4.3M/year
- Electricity: 131,180,340 kWh – $10M/year
- Water: 1,660,840 m^3 – $2M/year
- Oil for shuttles – $0.4M/year(26 buses)

$ 16.7M/year

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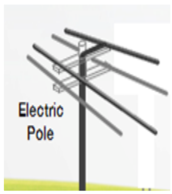
2.2 Green Zone Initiative of SNU



SNU NANO GRID

Green Campus
Energy Management System
[GCEMS]

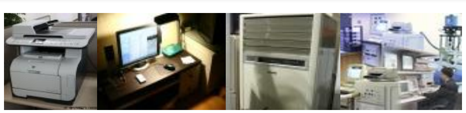
- Attaining Economic Feasibility
- Green- Building, Transportation, Energy

Green Building
[GBEMS] Energy Management System

eco-friendly Architecture
DC system, Green IT

Next gen. Building

Nano-Grid End-User Technology



Energy Saving Smart Appliance

Energy Saving Research Place

Green Energy

PV, Fuel Cell, Geothermal, Solar heating

Wind, Battery

Distributed Generation

Green Vehicle

Evs, E-motorcycle, E-bicycle

E-bus, monorail

Vehicle Sharing Service

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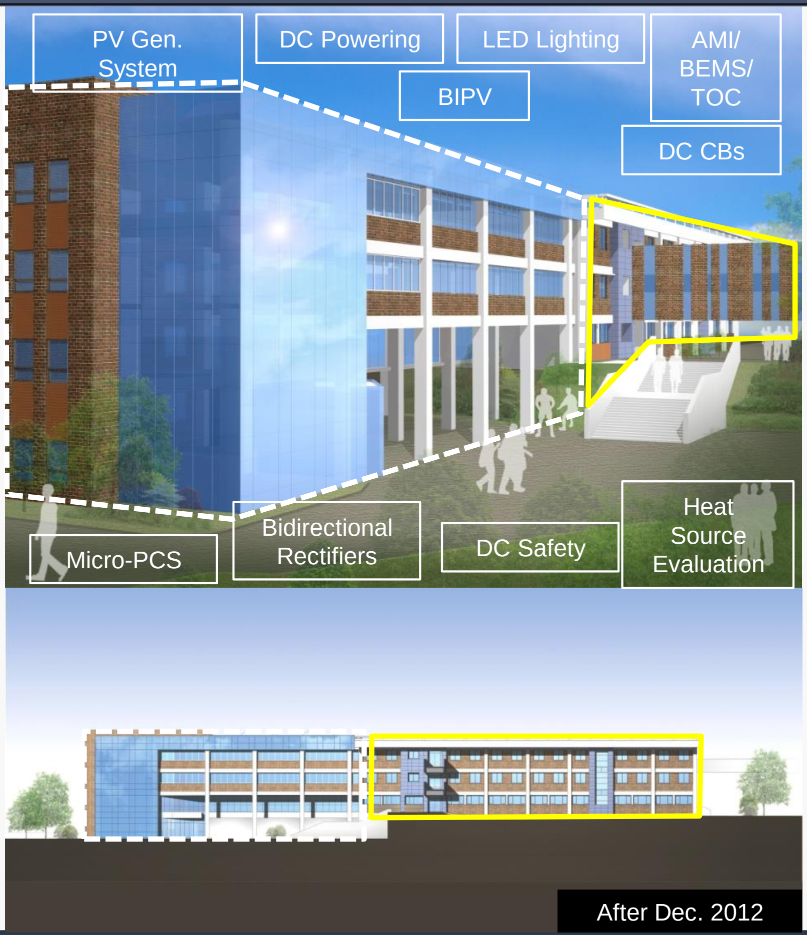
K-MEG Project for Green Zone Initiative

As-Is

To-Be

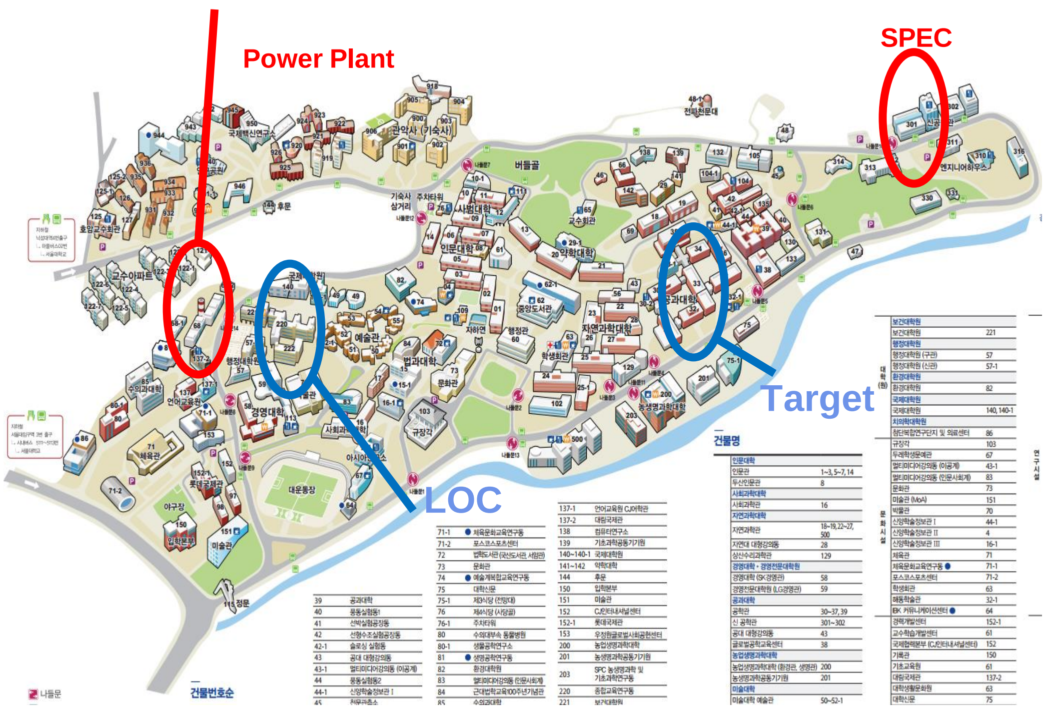


2 DC Microgrid Projects in SNU

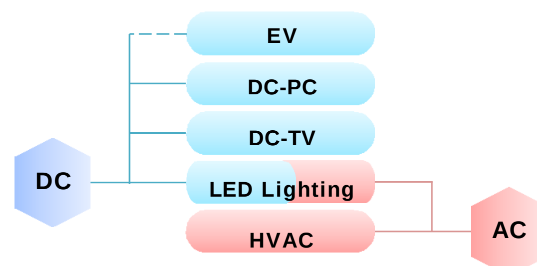
2.3 DC Microgrid in SNU

Korea Micro Energy Grid (K-MEG)

- 2011.7.1~2014.9.30(completed)
- 100kW DC System
  - Source: 36 kW RTPV + 20 kW BIPV
  - Storage: 80 kWh ESS
  - Load: 20kW Lightings, 12kW Office Appliances, 80kW Evs



- Location : 1, Gwanak-ro, Gwanak-gu, Seoul
  - SNU BLDG 33 (College of Engineering)
  - total floor area:2,280m2 (B1 – 3F)
  - Built in 1970
  - Remodeled in 2012
  - AC 400 kW, DC 100 kW Hybrid System



Korea Micro Energy Grid (K-MEG)

Final Goals

- Establishment of High-Efficiency DC Power System Structure
- Energy saving through DC technology
- Highly Stable and Safe DC system configuration
- Development of Key Components for DC system
- Energy Monitoring Database Establishment and Analysis and Evaluation

Optimal System Structure (Energy)

Stable & Safe DC Power Supply

DC Key Components Development

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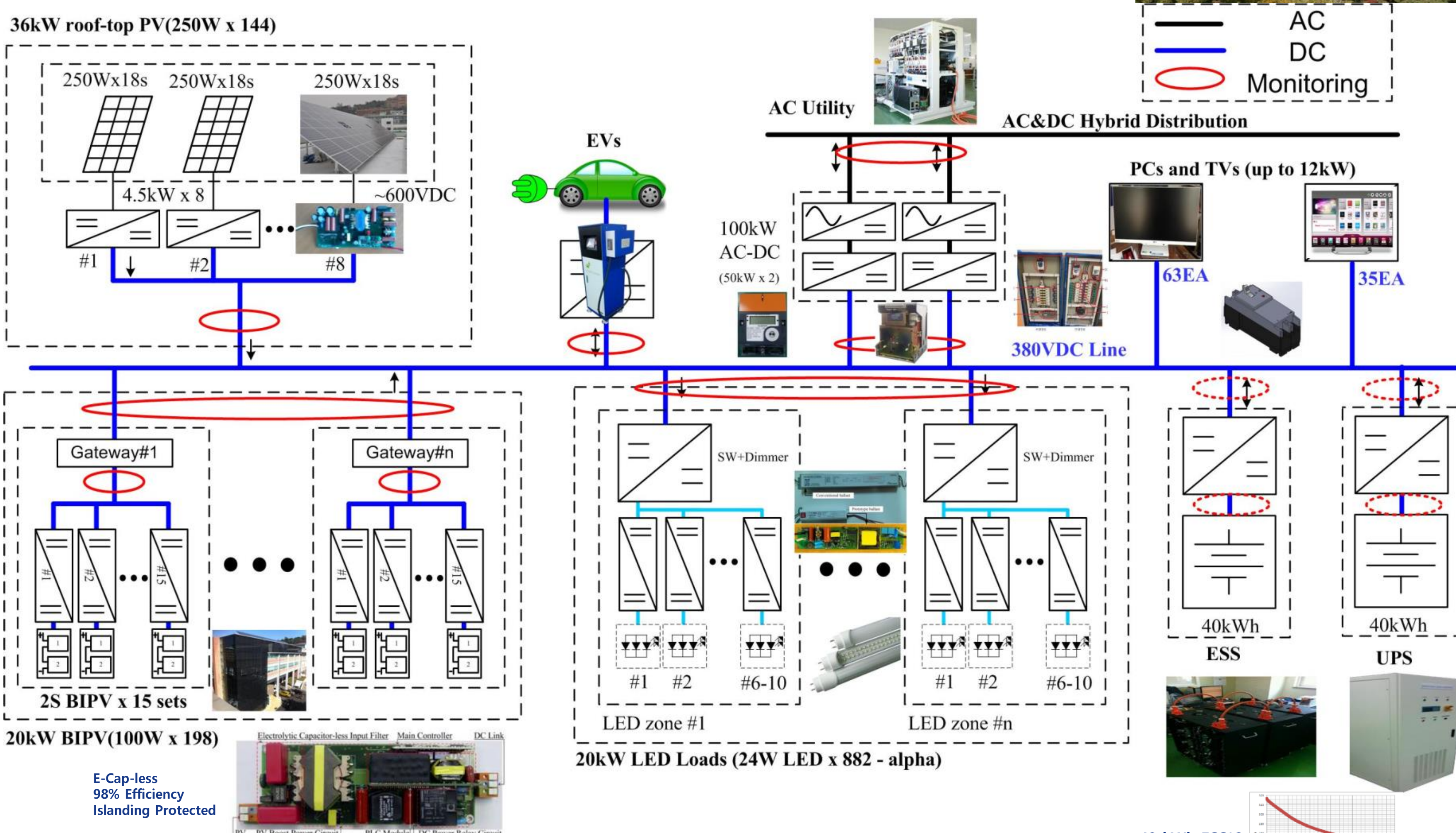
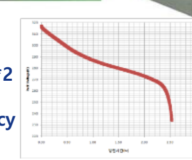
Korea Micro Energy Grid (K-MEG)- Overview



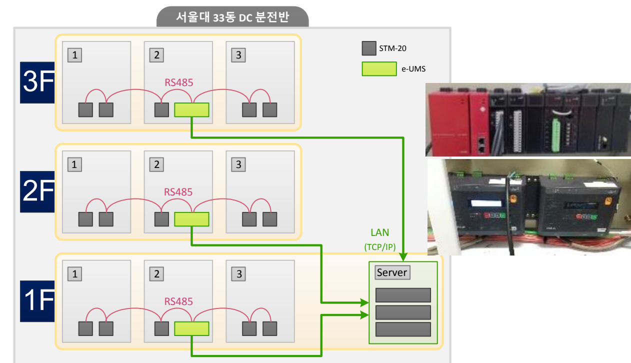
40 kWh ESS*2
80 kW rated
97% Efficiency



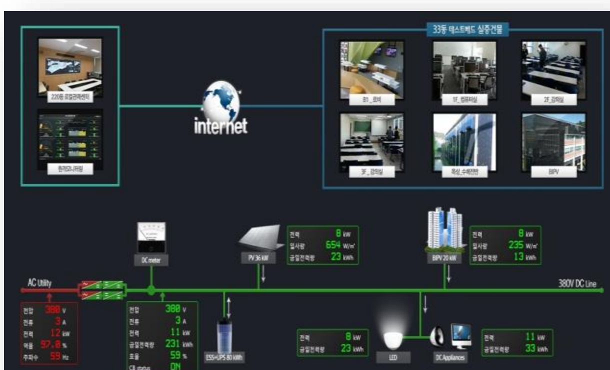
K-MEG - Local Operation Center

- Monitors more than 140 buildings energy states SNU including target building
- Real Time Web service and DB Reports available
- DGs Power Gen, Consumption Info available in detail

KMEG LOC @ Bldg. 220



LOC Configuration

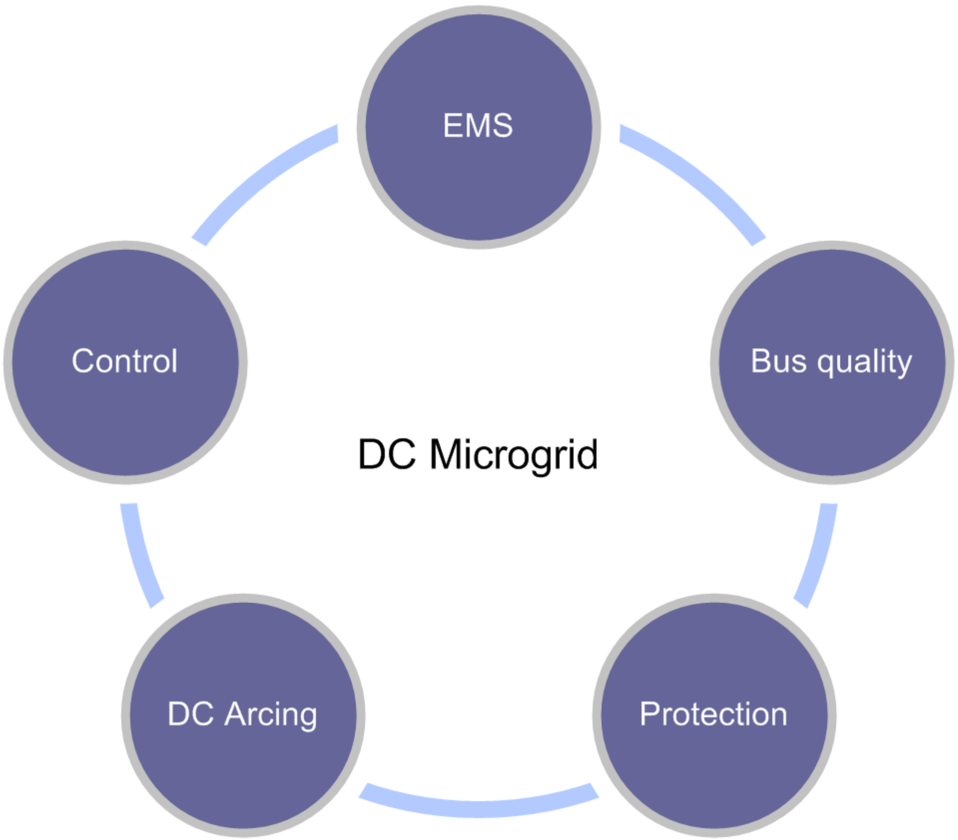


DC System Overview

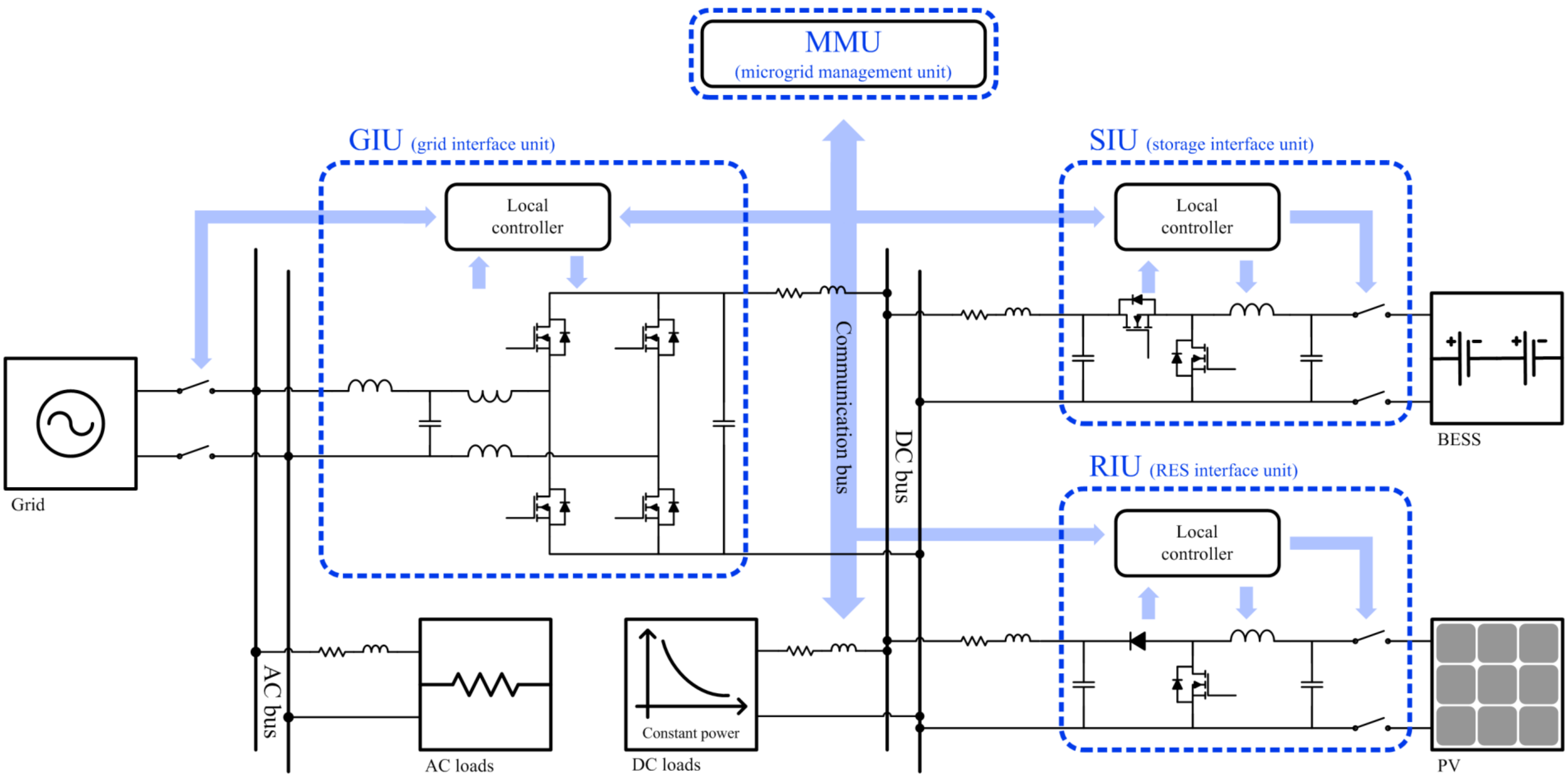
Energy Generation/Consumption Details

DC Microgrid Technology

- Interface Power Electronics and Control
- System Architecture
- EMS
- Bus Quality
- DC Protection



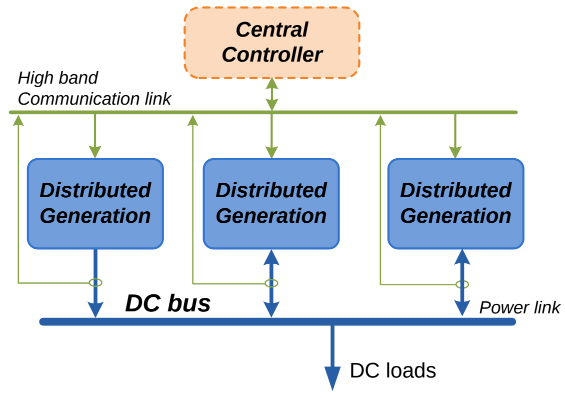
Overall Diagram



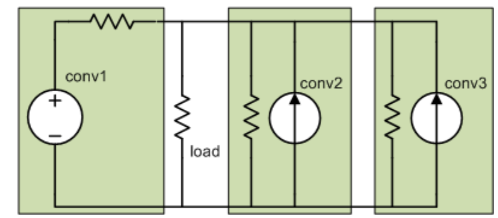
Control Philosophy

Centralized control

- Pros
  - Simple implementation
  - Improved regulation
- Cons
  - Communication burden
  - Single-point-of-failure



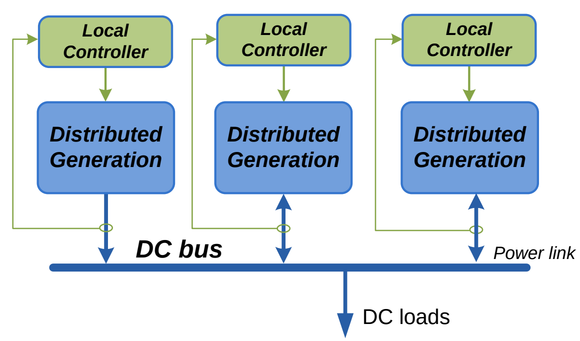
Centralized control structure



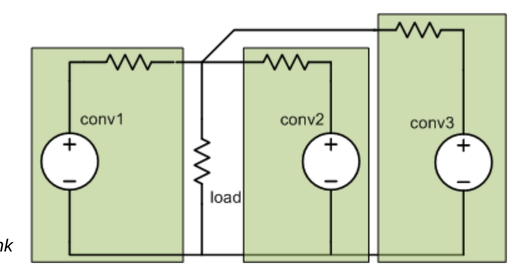
Equivalent circuit diagram

Decentralized control

- Pros
  - Autonomous operation
  - High reliability
  - High expandability
- Cons
  - Regulation trade-off
  - Low control flexibility



Decentralized control structure



Equivalent circuit diagram

Hierarchical (or Hybrid) Control*

Hierarchy

- Autonomous low-level controllers
- Communication with a central controller

Features

- High reliability using the droop method
- Flexibility of control
- Communication with system operators

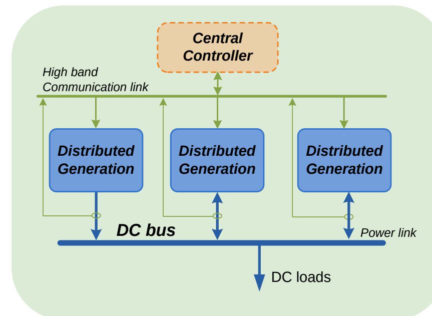
Literatures

- Most promising form of microgrid control
- Highlighted in research area

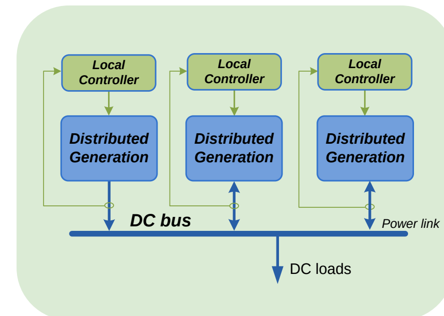
Issues

- DG source control schemes
- Degree of distribution
- Communications

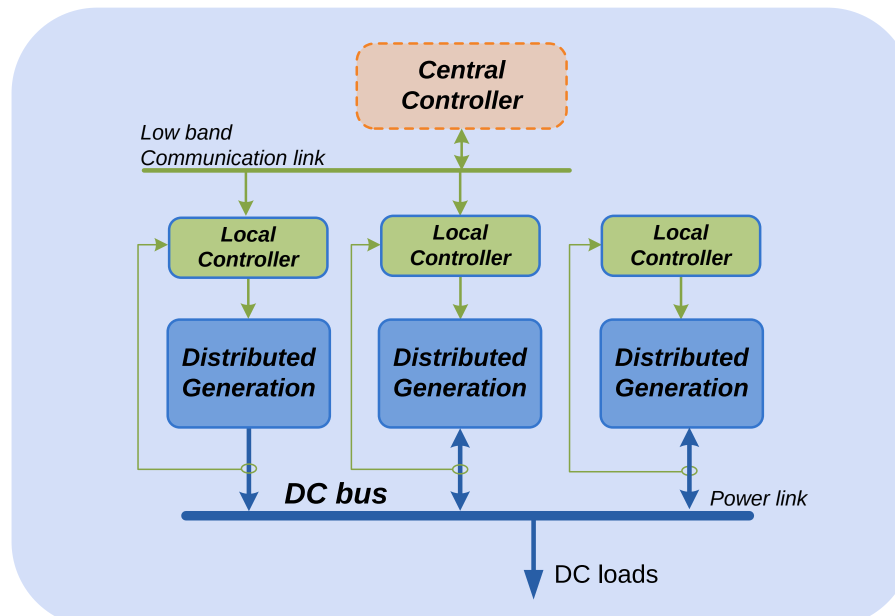
Central



Decentral



Hierarchical



* Guerrero, et al. "Hierarchical Control of Droop-Controlled AC and DC Microgrids—A General Approach Toward Standardization", IEEE Trans Ind. Eletron., Jan., 2011.

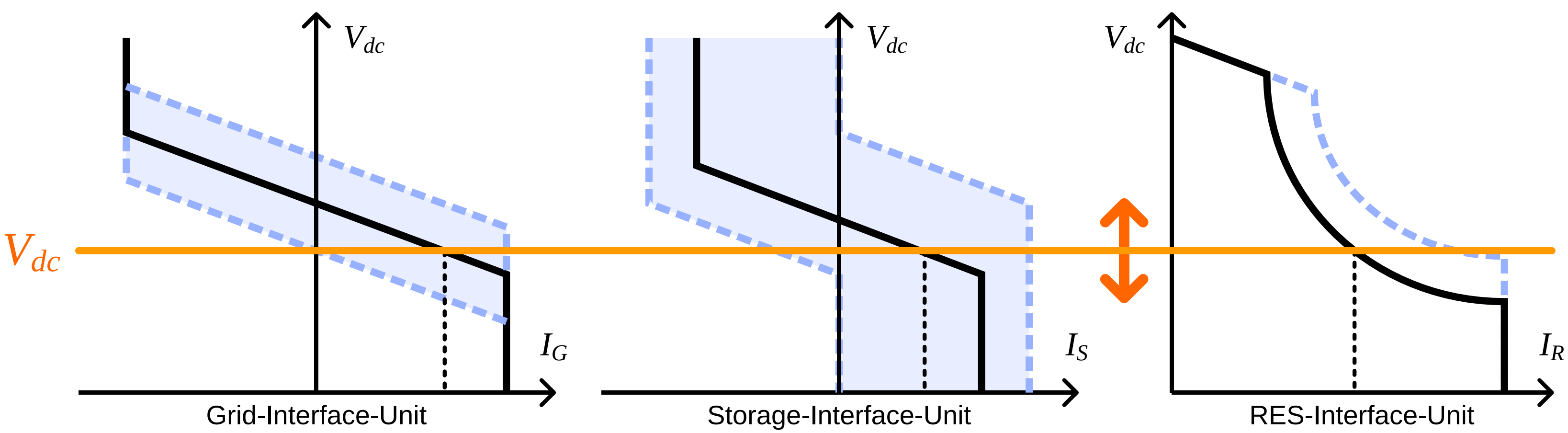
Control Strategy

Hierarchy of control

- IU: operating in the specific V-I curves $V^* = V_0 - R_d i_o$
- MMU: responsible for EMS

Table. Operating modes of converters

State	*Grid-interfaced conv.*	*State*	*Storage conv.*	*State*	*RES conv.*
1	Grid-connected: V_{dc}	1	Idle: V_{dc}	1	MPPT: P_{PV}
2	Stand-alone: V_{ac}	2	EMS: P_{ESS}	2	Off-MPPT: V_{dc}
3	Fail	3	Fail	3	Fail

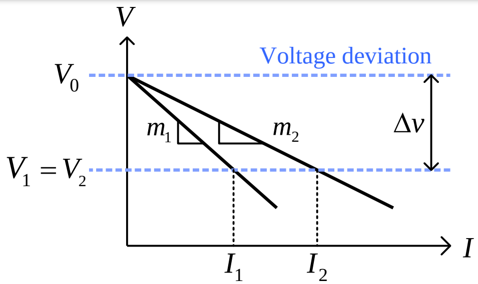


V-I curves of GIU, SIU, and RIU

Voltage Restoration in Droop Control

Droop Control

- Operating points on V-I curves
- Advantages: reliability, autonomy
- Voltage deviation as load increases



Voltage deviation

Conventional voltage restoration

- Droop equation modification

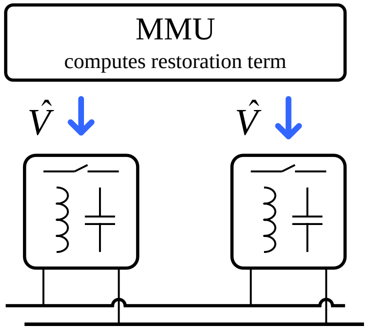
$$V_i^* = V_0 - m_i I_i + \hat{V}_i$$

Restoration term

- Conventionally in centralized manner
- Cons

  n-by-n communication burden

  Reliability issue



Conventional centralized voltage restoration

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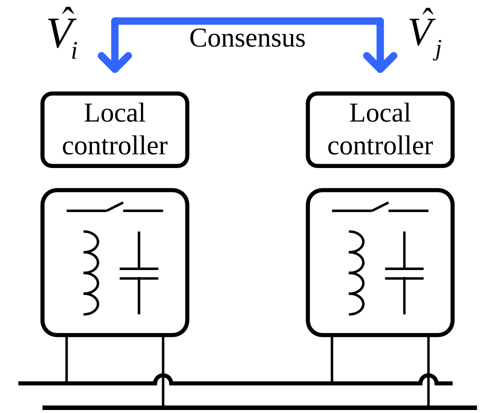
Proposed Voltage Restoration Scheme

Distributed voltage restoration scheme

- Load unbalance may occur without agreement



Distributed voltage restoration scheme using the consensus algorithm

Consensus algorithm

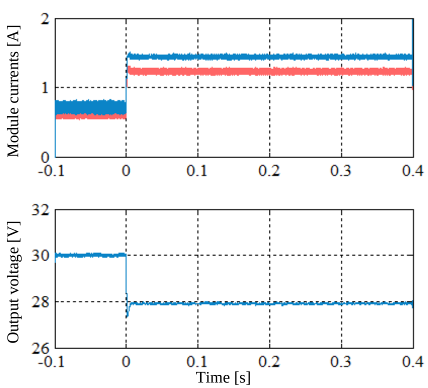
- Objective: agree on information between neighbors

$$\frac{d\hat{V}_i}{dt} = \hat{V}_j - \hat{V}_i$$

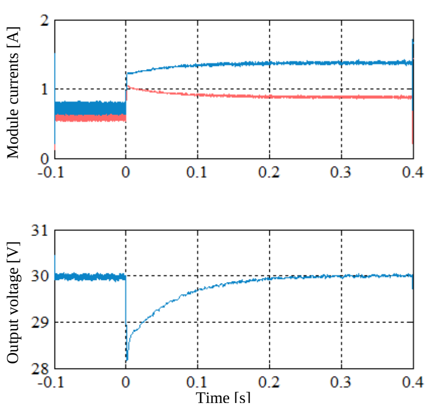
- Autonomous and reliable operation

Experimental results

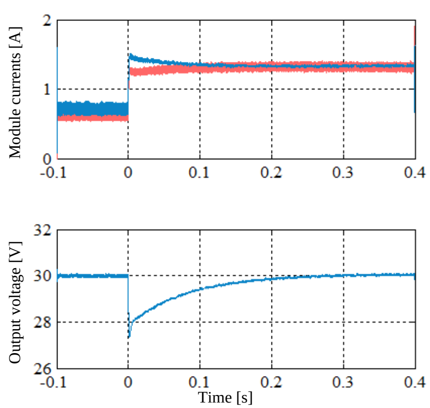
- Small-scale two-module experiment



w/o voltage restoration



Voltage restoration **w/o consensus term**



Voltage restoration **w/ consensus term**

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3.6 Multiple Energy Storage System

Motivation

Increased energy storage devices due to uncertainty problem in RES

Expansion of storage capability due to increased load or degradation of energy storage

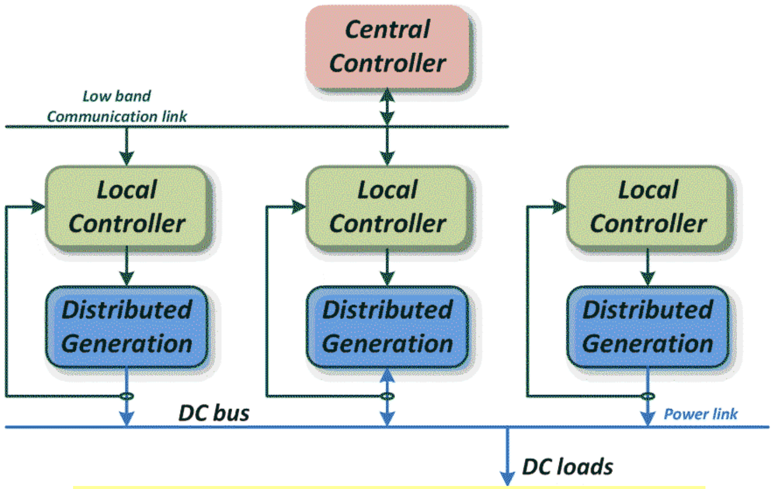
Multiple Energy Storage System (Multiple ESS)

Different capacity, different SOC

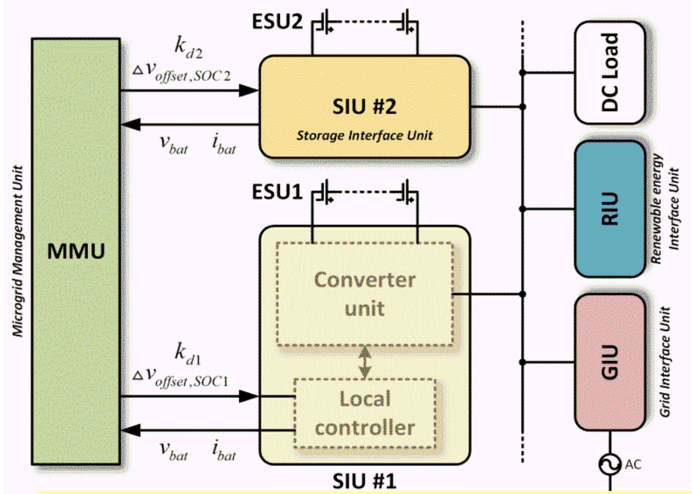
- Load sharing control : Balance the output power in each ESS
  - >> Higher SOC, Larger capacity → more power
  - >> Lower SOC, Smaller capacity → less power
- SOC Equalization: >> Better Reliability, Maximized Battery Lifetime

Proposed method

SOC and Capacity dependent adaptive droop control



Control Structure : Hierarchical control



Control Block Diagram of the proposed method

Ref: H. Kim, C. Y. Chun, G.-S. Seo, K. Lee, and B. H. Cho, Adaptive Droop Control Method for Multiple Energy Storage Systems in DC Distribution System, KIPE 2014.

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DC Microgrid with two energy storage units

Hierarchical control based on droop control

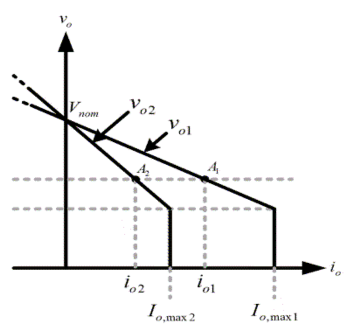
$$v_{ref,i} = V_{nom} - k_{d,i} i_{o,i} + \Delta v_{offset,SOC,i}$$

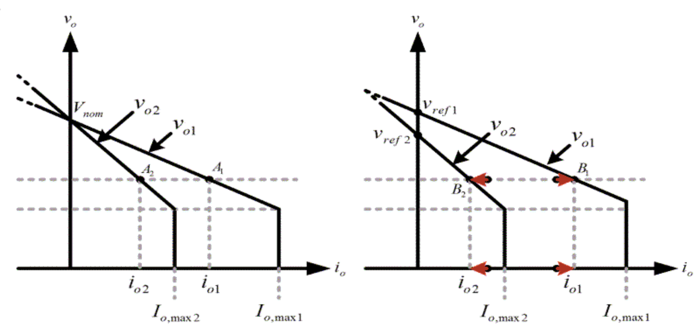
- Droop coefficients are changing according to the estimated capacity

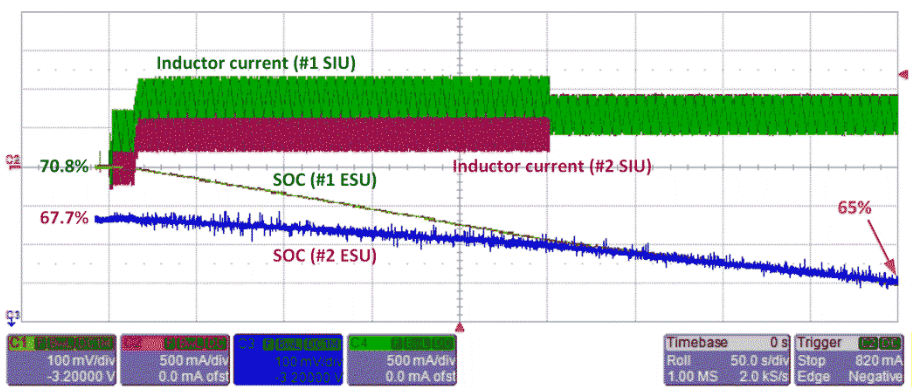
$$\Delta v_{offset,SOC,i} = (k_p + k_i / s)(SOC_i - SOC_j)$$

- Offset voltages are changing according to the estimated SOC

$$k_{d,i} = k_{d,0} \frac{C_{n,0}}{C_{n,i}}$$







Proportional load sharing control
Increased expected lifetime of the batteries

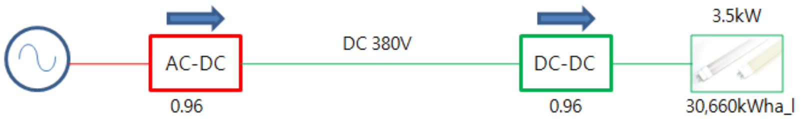
Experimental results

Ref: H. Kim, C. Y. Chun, G.-S. Seo, K. Lee, and B. H. Cho, Adaptive Droop Control Method for Multiple Energy Storage Systems in DC Distribution System, KIPE 2014.

In constructing Microgrids

Only load → Simple

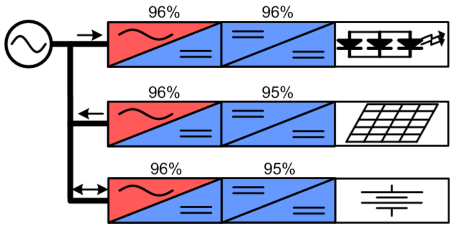
with AC



with DC

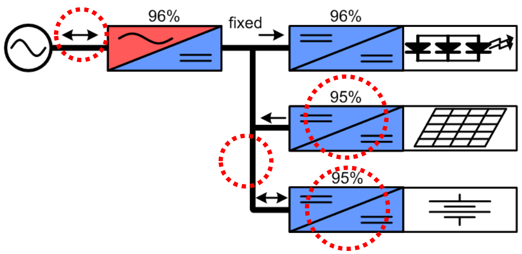
Renewable sources + Storage → give us more options

AC-RE1



with AC → no variations

DC-RE5



1. Bi or Uni Rec. ?
2. Variable or fixed DC line ?
3. Direct Storage or through charger?
4. Direct renewable?
5. Or other options?

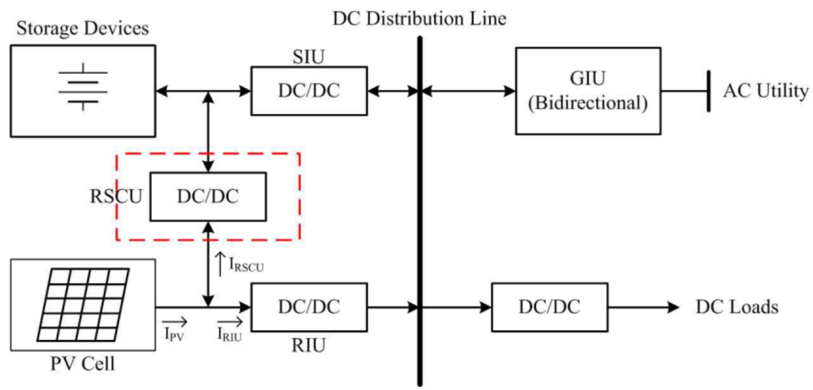
→ Application should be considered to achieve the main design goal, as the system architecture should affect the entire system performance

Renewable-Storage Connecting Unit(RSCU) in RES + ESS system

Concept

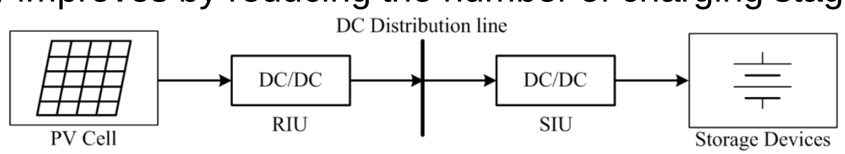
- Add a bidirectional bypass converter between storage devices and renewable energy source

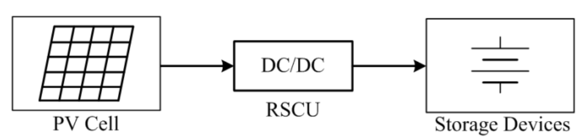
  >> Efficiency Improvement, Better Reliability (better fault response)



Characteristics

- Energy generated from PV cells charge directly to the storage deices using RSCU
- System efficiency improves by reducing the number of charging stages





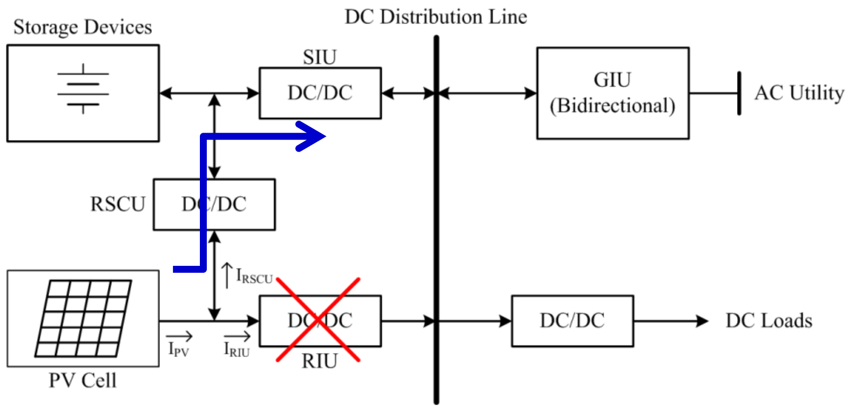
Ref: S.W. Lee, G. S. Seo, H. J. Kim, and B. H. Cho, A Structural Consideration of Storage Interface Unit(SIU) for DC Distributed Net Zero Energy Building, KIPE 2014,

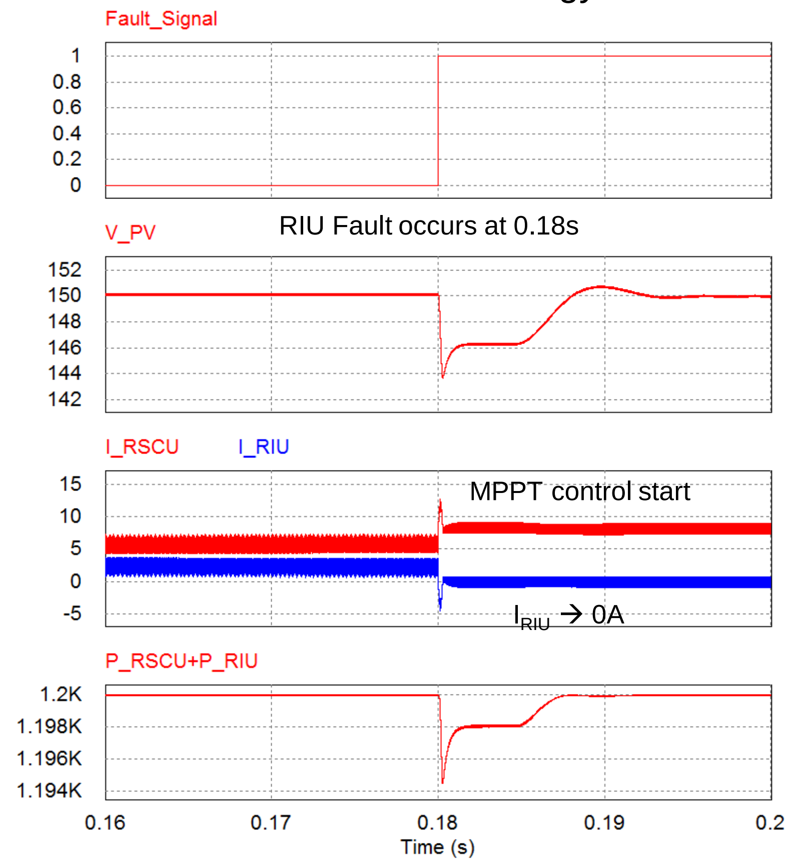
Renewable-Storage Connecting Unit(RSCU)

Fault Characteristics

- RSCU can transfers energy of PV cells and storage devices even SIU or RIU fault occurs

  If RIU fault occurs, RSCU operates as MPPT converter and transfers energy to the distribution line through SIU





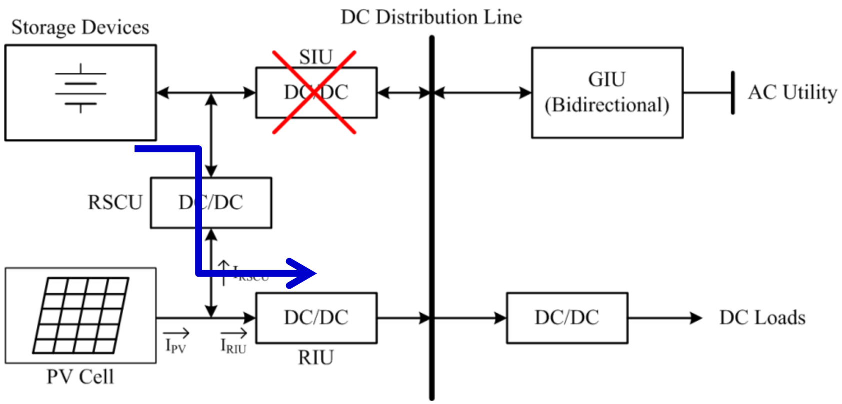
Ref: S.W. Lee, G. S. Seo, H. J. Kim, and B. H. Cho, A Structural Consideration of Storage Interface Unit(SIU) for DC Distributed Net Zero Energy Building, KIPE 2014,

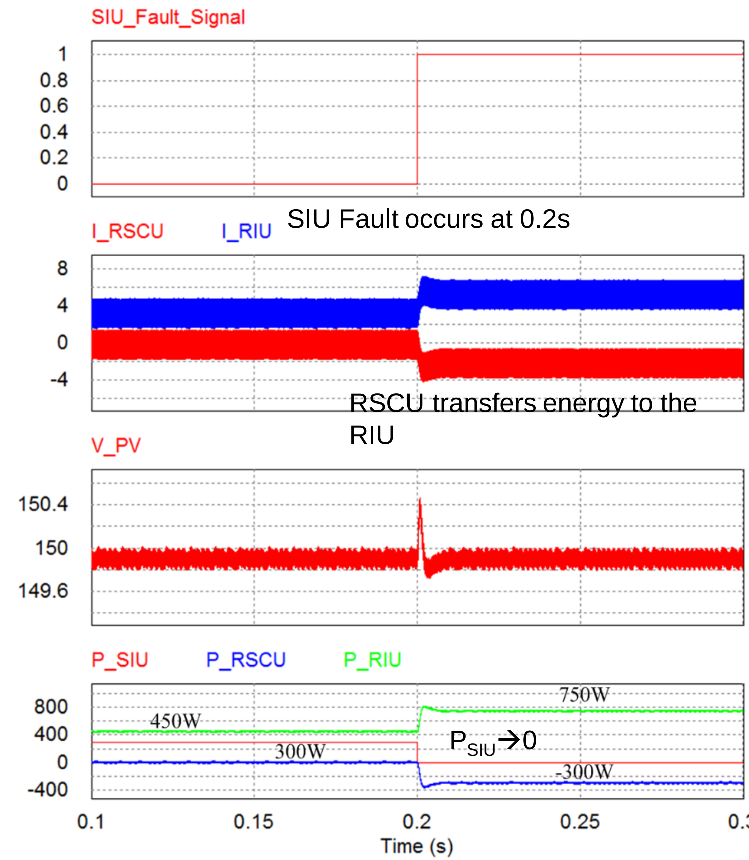
Renewable-Storage Connecting Unit(RSCU)

Fault Characteristics

- RSCU can transfers energy of PV cells and storage devices even SIU or RIU fault occurs

  If SIU fault occurs, RSCU operates as current source and transfers energy to the distribution line through RIU





Ref: S.W. Lee, G. S. Seo, H. J. Kim, and B. H. Cho, A Structural Consideration of Storage Interface Unit(SIU) for DC Distributed Net Zero Energy Building, KIPE 2014,

Grid-to-Grid Interconnection: Modular Approach

Motivation : Inherent limitations of single DC Microgrid

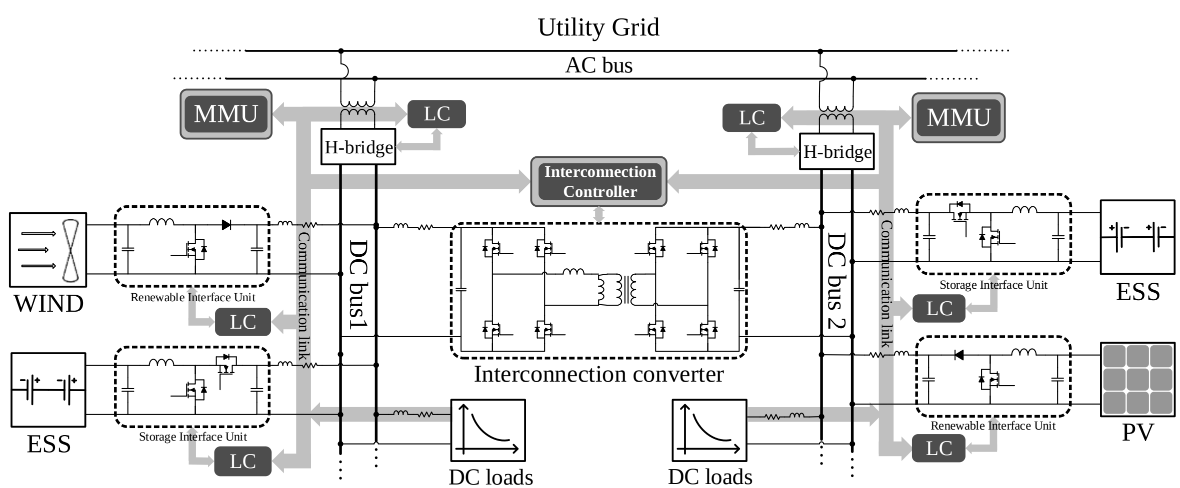
- Output variation of RES
- Charging/Discharging limits of ESS
- Unfavorable actions for overload condition : Load shedding and adding extra DGs

Interconnection interface

- Bi-directional DC-DC converter : Dual Active Bridge(DAB)
- Galvanic isolation to keep each system's safety and local control scheme

Features

- Direct support available
- Efficient system operation
- Reduce the limitations
- High reliability



Configuration of interconnected DC microgrids

Implemented schemes

Power scheduling

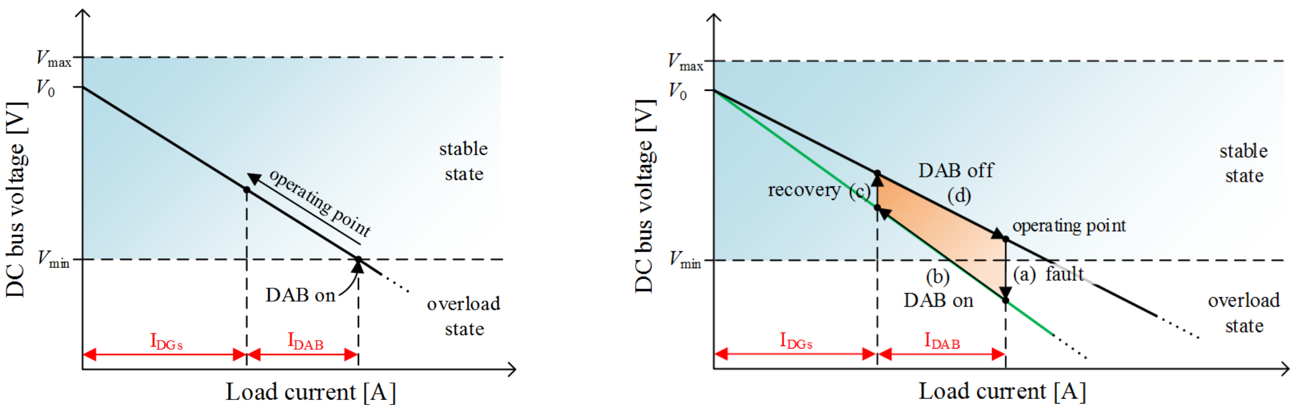
- Power scheduling of DGs and loads based on DC bus voltage
- DC bus voltage represents power condition in DC Microgrid
- Inverse-proportional relation between DC bus voltage and loads

Operation schemes of Interconnection converter

- Direct power conversion

  Prevent surplus power of one microgrid from transmitting to the other via utility grid
- Voltage restoration

  Keep DC bus from voltage collapse for cases of several overload conditions



Voltage restoration process for general overload condition and fault situation of DG

Ref: M. H. Lee, H. J. Kim, W. I. Choi, and B. H. Cho, Operational Schemes of Interconnected DC Microgrids using a Bi-directional Converter, KIPE 2014.

Lab. Set-up Test

Direct power conversion

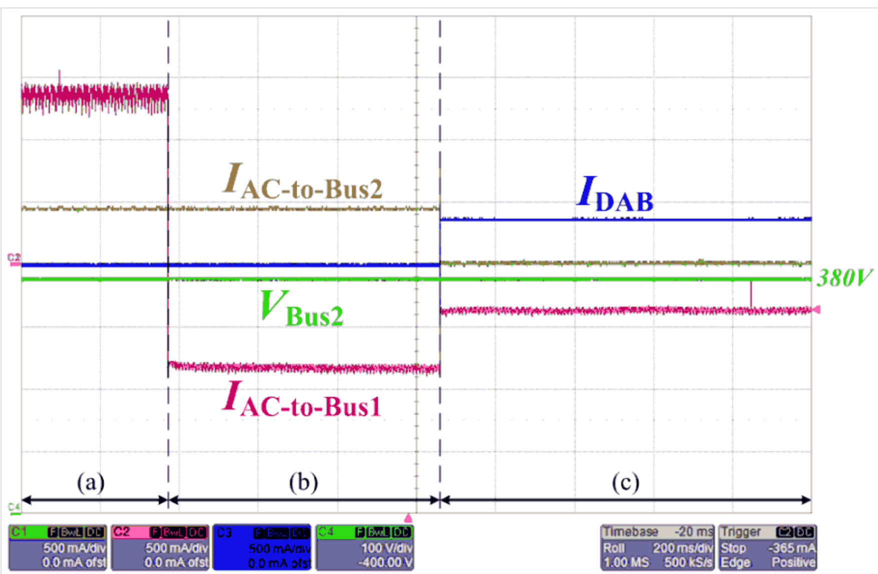
- Lower circulations via utility grid

Voltage restoration

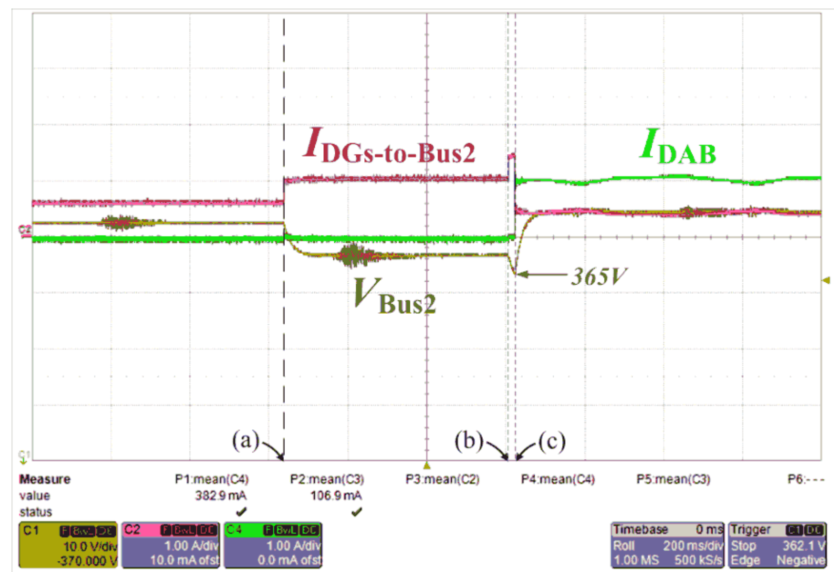
- without load shed or extra DGs

Table of experimental specifications

Power	Case A [power transfer]		Case B [power shortage]	
	microgrid 1	microgrid 2	microgrid 1	microgrid 2
Sources	500 W (DG)	0 W	400 W (AC)	450 W
Loads	200 W	200 W	0 W	250 → 650 W
DAB	200 W (microgrid 1 → 2)		400 W (microgrid 1 → 2)	



Experimental waveform : Direct power conversion



Experimental waveform : Voltage restoration

Ref: M. H. Lee, H. J. Kim, W. I. Choi, and B. H. Cho, Operational Schemes of Interconnected DC Microgrids using a Bi-directional Converter, KIPE 2014.

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Thank you!